Forecasting the Effectiveness of Well Performance Improvement Techniques

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Abstract. The article discusses the Pearson criterion method to determine the effectiveness of the chemical methods of the bottomhole formation zone treatment, the well zone and further improvement of the corresponding methods. Despite the rather high efficiency of the physicochemical methods used to increase oil recovery in the Shirotniy Ob area, ongoing geological and technical measures do not always ensure the optimal volumes of additional oil production achievement. Because of the bottom-hole formation zone treatments, an increase in the wells production rate was obtained. However, there are wells in which, after applying the enhanced oil recovery (EOR) techniques, the well production rates not only did not increase, but, moreover, their decrease and increase in water cut were noted. The increase in well flow rates after treatments varies widely; the effect duration is also different. The study of the effectiveness of the bottomhole formation treatment jobs organization modeling calls for a fundamentally new formulation and new methodological solutions. It should be carried out taking into account the economic feasibility of various forms and methods of work organizing, providing for maintenance based on analysis and geological field material processing by means of mathematical methods and computer technology. In this regard, the a systematic approach methodology application for analyzing and regulating the effectiveness of physicochemical methods of oil recovery enhancing at a late stage of oil field development is an urgent task and involves the creation of models that can significantly increase the of reliability of the justification and work organization for the use of progressive wells formation treatment techniques.

1. Introduction
The trends of the last ten years are to apply various methods of formation treatment to increase production efficiency. For this purpose, chemical methods are widely used. In this regard, a systematic approach methodology for analyzing and regulating the effectiveness of physicochemical methods for oil recovery improving at a late stage of oil field development is an urgent task and involves the creation of methods that can significantly increase the reliability degree of the justification and planning procedures for organizing work on wells with progressive formation impact technologies application.

When solving the tasks, probabilistic-statistical methods, reliability and mass service theories with the widespread use of computer technology were used. The tasks were solved basing on the actual data processing obtained from the unique Priobskoye oil field, which is part of the large Khulymsko-
Priobskoye oil and gas accumulation zone, stretching from north to south in the form of a wide strip in the central part of the West Siberian Plain [4].

The geological structure features are so that the oil-saturated thickness of the field has a reservoir-garden character and is represented by the main productive horizon of the AS-12-3 layer of the Cherkashinsk suite, the thickness of which increases (up to 16–18 m) to the arch part of the field and decreases (up to 4–5 m) in its wing zone.

2. Research methods

The researchers used a comparative assessment of the effectiveness of physicochemical methods for the bottom-hole formation zone treatment using the Chi-square criterion.

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Determining the effectiveness of chemical methods of the bottom-hole formation zone treatment refers to optimization problems. The solution to such problems comes down to finding the best or otherwise optimal result that would be most acceptable from the standpoint of technological and economic requirements. Mathematical optimization is understood as the choice of the best element, taking into account some specific criterion from a set of available alternatives, carried out by comparing the percent of “successful jobs” on the proposed technology, with the percentage of “successful treatments” performed by another method. Moreover, the percentage of success is understood as the ratio of the successful operations number to the total number of treatments performed in percent.

To separate the treatments results into successful and unsuccessful, a set of parameters was initially considered that characterize the change in the well flow rate after physicochemical treatment. The following parameters were selected: well productivity coefficient, oil production rate and production water cut. The result of the EOR techniques application should be classified as successful if the following conditions are simultaneously met:

[1] 1. The well productivity coefficient increases, which corresponds to the inequality

$$\frac{K_{\text{prod}a}}{K_{\text{prod}b}} > 1$$  \hspace{1cm} (1)

where $K_{\text{prod}a}$ and $K_{\text{prod}b}$ are well productivity coefficients after and before the EOR application accordingly.

[2] Oil flow rate increases, which corresponds to the inequality compliance

$$\frac{q_{o,a}}{q_{o,b}} > 1$$  \hspace{1cm} (2)

where $q_{o,a}$, $q_{o,b}$ are oil production rates after and before the EOR application accordingly.

[3] The well water cut is reduced or remains at the same level, which corresponds to the inequality

$$\frac{B_{w,a}}{B_{w,b}} \leq 1$$  \hspace{1cm} (3)

where $B_{w,a}$, $B_{w,b}$ are the water content of the products after and before the EOR application.

Later it became clear that the first of the selected criteria ($K_{\text{prod}}$) is almost impossible to use. This is because the determination of the productivity coefficient is very seldom carried out (for the analyzed wells, the productivity coefficient assessment before and after treatment is as a rule performed in single instances), and this excludes the possibility of using this criterion for statistical processing of the results. It was also not possible to determine the parameter by calculation with sufficient reliability due to the absence of dynamic and static levels value, bottomhole and reservoir pressures.
measurements in the analyzed wells at the given point of time, that is, at the time of the bottomhole formation zone treatment period or at least in the next 3 months before and 3 months after it.

Therefore, the criterion under consideration was deliberately excluded. As for the second criterion, the question is legitimate: how much should the flow rate ratio exceed unity? Taking into account the objectives of the research, an excess value of 1.05 was chosen.

Thus, processing is considered successful if the result meets the condition

\[
\frac{q_{o,b}}{q_{o,do}} \geq 1.05
\]

where \(q_{o,a}\), \(q_{o,b}\) are average daily oil production rates on average for 3 months respectively after and before the bottomhole formation zone treatment.

A five percent increase in oil production after the bottomhole formation zone treatment is, of course, not an indicator of the high method efficiency. However, it indicates the fundamental possibility of obtaining positive results when using the analyzed bottomhole formation zone treatment technique in the given geological and physical conditions characterizing such wells.

The change in the water cut ratio before and after the bottomhole formation zone treatment, selected as the third criterion, is ideal. In practice, the result of the bottomhole formation zone treatment, especially in flooded wells, is the intensification of fluid production, and not selectively – the oil. The water cut can both decrease and increase. At the same time, a change in the absolute water cut value does not play such a significant role, that is, an estimate of the change in oil production under conditions of one or another water cut value in a well’s production at the bottomhole formation zone treatment period is a more significant parameter. Thus, the main indicator characterizing the achievement of the bottomhole formation zone treatment goal is the increase in oil production. Therefore, when assessing the bottomhole formation zone treatment effectiveness, the criterion for dividing the treatments results into successful and unsuccessful is the change in the oil flow rate. However, such an assessment does not take into account the number of carried out treatments and often turns out to be uneven and erroneous, because volumes of the performed treatments may vary by an order of magnitude [1-15].

3. Discussion

Such an approach to comparative effectiveness assessing can lead to the risk of mistaking the “ineffective” method for the “effective” and vice versa. Therefore, a comparison of success rates can lead to erroneous conclusions and the rejection of previously used materials and proven techniques. In this regard, for an objective comparison of a wide range of different bottomhole formation zone treatment techniques, a methodology for the comparative effectiveness evaluation based on criterion \(X^2\) was worked out.

For example, we examine an object or phenomenon that has parameters describing it, the values of which we can set. Such parameters are understood as input data \((x_1, x_2, \ldots, x_n)\). They are subject to certain restrictions:

\[
G_i(x_1, x_2, \ldots, x_n) \geq 0
\]

\[
G_m(x_1, x_2, \ldots, x_n) \geq 0
\]

Based on the meaning of solving optimization problems, we need to find such values \(x_{1*}, x_{2*}, \ldots, x_{n*}\), for which there will be no restrictions violation and for which the function \(F(x_1^*, x_2^*, \ldots, x_n^*)\) takes the largest or the smallest value, we denote it by \(F^*\). The function is called the optimization criterion, or the objective function, the input parameters \((x_1, x_2, \ldots, x_n)\) are the optimization parameters. The values \(x_{1*}, x_{2*}, \ldots, x_{n*}\), for which the function \(F(x_1^*, x_2^*, \ldots, x_n^*)\) takes the optimal value \(F^*\), are the optimal values of the input parameters.
The solution to our problem is reduced to the analysis of the bottomhole formation zone treatment effectiveness using the Pearson criterion. This method is based on comparing the number of “successful” jobs and the number of “unsuccessful” jobs using a particular technology.

Let there be data on the 2 different formation stimulating techniques application, one of which is the main one, and the other is competing. For ease of perception, let the data be in table 1. Method 1 is the main, and Method 2 is competing. The number of successfully performed operations using method 1 is denoted by $A$, unsuccessful – by $B$; the number of successful operations using the second method we denote by $C$, the unsuccessful ones – by $D$. The total amount ($N$) of the operations performed by the two methods is equal to the total sum of successful and unsuccessful experiments carried out by methods 1 and 2.

\[
\begin{array}{c|c|c}
\text{methods 1} & \text{Successful} & \text{Unsuccessful} \\ \hline
A & B & A+B \\ \hline
\text{methods 2} & C & D & C+D \\ \hline
\text{Sums} & A+C & B+D & A+B+C+D=N \\
\end{array}
\]

We need to determine the most effective technique. To perform this, we hypothesize that the competing method 2 is more successful than the main method 1.

The algorithm for solving the problem of effectiveness evaluating using the Pearson criterion

1. We accept hypotheses: $H_0$ is the null hypothesis, which shows the equivalence of methods in terms of effectiveness. $H_1$ is an alternative hypothesis that shows the effectiveness of method 2 compared to method 1.

2. We find the expected frequencies for each cell of the table according to the formulas:

\[
f_a = \frac{(A + B) \cdot (A + C)}{N} \\
\]

\[
f_a = \frac{(A + B) \cdot (B + D)}{N} \\
\]

\[
f_a = \frac{(A + C) \cdot (C + D)}{N} \\
\]

\[
f_a = \frac{(C + D) \cdot (B + D)}{N}
\]

(6) \quad (7) \quad (8) \quad (9)

To exclude the possibility of error, it is necessary to summarize the expected frequencies, and the amount should be equal to $N$.

3. We find the absolute difference between the observed and the expected frequencies according to the formula:

\[
|f_o - f_a|
\]

(10)

4. From every absolute difference value we subtract the correction for continuity equal to 0.5, and we square the result:

\[
\left(|f_o - f_a| - 0.5\right)^2
\]

(11)

5. Each value obtained in paragraph 5 is divided by the corresponding $f_a$ value. Then summarize and get:
\[ \chi^2 = \sum_{i=1}^{r} \sum_{c=1}^{c} \frac{(f_{0i} - f_{ai})^2}{f_{ai}} \]  

(12)

where \( r \) is the number of columns in the table; \( c \) is the number of rows in the table.

6. We find the number of degrees of freedom by the formula:

\[ df = (r - c) \cdot (c - 1) \]

(13)

Initially, we set the significance level \( \alpha = 0.05 \). From the Pearson table we find the critical value \( \chi^2 \) for a given significance level and the number of degrees of freedom.

7. We compare the calculated \( \chi^2_{\text{observed}} \) value and the table \( \chi^2_{\text{table}} \) value.

If \( \chi^2_{\text{observed}} \geq \chi^2_{\text{table}} \), then the hypothesis \( H_1 \) is accepted, and the hypothesis \( H_0 \) is rejected, which indicates the existence of a difference, i.e. in terms of the operations success, method 2 is superior to method 1.

If \( \chi^2_{\text{observed}} < \chi^2_{\text{table}} \), then the hypothesis \( H_1 \) is rejected, the hypothesis \( H_0 \) is accepted, which indicates the absence of a difference in the efficiency between the methods, i.e. methods are equivalent to each other.

4. Conclusions

Based on the analysis of the calculation results of the Shirotny Priobye oil field:

1. Analyzing the results (with a probability of 95% and the number of degrees of freedom \( df = 1 \)) from the Danilovskaya Formation, the following conclusions can be drawn:

   – The Don-52 technique is more effective in comparison with the hydrochloric acid treatment, as \( X^2 = 6.93 > X^2_{\text{table}} = 3.84 \).

   – The HF+HCL technique is more effective in comparison with HF+HCL+IVV-l, as \( X^2 = 4.38 > X^2_{\text{table}} = 3.84 \).

   – The Don-52 technique is more effective in comparison with HF+HCL+IVV-l, as \( X^2 = 12.10 > X^2_{\text{table}} = 3.84 \).

   – The hydraulic fracturing technique is more effective in comparison with Don-52, as \( X^2 = 11.52 > X^2_{\text{table}} = 3.84 \).

   – The hydraulic fracturing technique is more effective in comparison with HF+HCL, as \( X^2 = 4.787 > X^2_{\text{table}} = 3.84 \).

2. When conducting an analysis with a probability of 90%, the following conclusions will be added to the previous ones:

   – The HCL+IVV-l technique is more effective in comparison with HF+HCL+HBB-l, as \( X^2 = 3.31 > X^2_{\text{table}} = 7 \).

   – The Don-52 technique is more effective in comparison with HCL+IVV-l, as \( X^2 = 3.74 > X^2_{\text{table}} = 2.7 \).

   – The hydraulic fracturing technique is more effective in comparison with HCL+IVV-l, as \( X^2 = 3.60 > X^2_{\text{table}} = 2.7 \).

   In this case, the generalized result of the effectiveness of the methods with a probability of 90% is as follows: the most effective method is hydraulic fracturing technique.

5. References

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