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ON THE QUESTION OF THE EFFICIENCY ANALYSIS OF THE BOTTOM-HOLE AREA STIMULATION METHOD

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ABSTRACT

This article considers the efficiency of a bottom-hole area stimulation method - a polymer acid treatment. The production data for the wells of 21 deposits in the west of Bashkortostan are analyzed, where the polymer acid treatments were carried out. Regression equations for dependent variables are obtained. The article presents comparative forecast data and the real ones and determines the error rate of the equations obtained. The efficiency of the considered method of bottomhole area treatment with another method is compared. According to the obtained error rate the accuracy of the forecast of the regression equations is estimated.

Keywords: polymer acid treatment, bottomhole well zone, normal distribution, regression equation, statistical analysis, constraint equation, Box-Cox transformation, determination coefficients.

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1. INTRODUCTION

The bottomhole well zone is the area characterized by the fastest flow of all processes in it. A sole node of current lines is formed during extraction, with further disparity during pumping the fluid. Here, the energy losses, the filtering resistances, and the velocity of fluid transfer have minimal values. The state of the bottomhole well zone is one of the most important criteria for the efficiency of deposit exploitation, production rates and injection capacity of wells [1].

One of the main directions in the development of the deposit is an increase in the permeability of the bottomhole well zone.

The most significant factor for reducing the permeability of adjacent to the wellbore layers is their watering due to water breakthrough in cracks with high permeability [2, 3].

Watering of layers leads to significant reduction of oil production, high expenditures for lifting, transportation, preparing and re-injecting water into reservoirs, operating new deposits [4].

Therefore, the prevention of layers' watering was and is one of the most urgent problems in the oil and gas industry.

To increase oil production various methods are applied, as well as their combinations [5].

The greatest efficiency in limiting water supply is shown by the hydrolyzed polyacrylonitrile treatment [6].

HPAN (hydrolyzed polyacrylonitrile) is a reagent that is produced in an aqueous condensate in the static polymerization of acrylonitrile, followed by a hydrolysis process with caustic soda.

HPAN is widely used as the main component - the insulating reagent. Its insulating properties can be revealed without the use of special curing or precipitating substances [7].

The technology for injecting HPAN is relatively simple.

The interval of water breakthrough is isolated by the initial injection of the electrolyte, which is the mineralized water or a solution of calcium chloride of a certain concentration. After injection of the coagulant, HPAN is injected into the layer. Then the hydrochloric acid is injected. In the layer, the permeable channels of the watered part of the layer are saturated with a coagulant [8].

Due to the affect of electrolytes of formation water, containing minerals, on HPAN a blocking mass is formed.

Due to the hydrochloric acid, which dissolves the rock skeleton, new conducting channels are formed in the oil-saturated stratum of the formation.

Availability and low cost of technology led to an increase of its application.

For the analysis 21 deposits in the west of Bashkortostan were used, in the wells of which, hydrolyzed polyacrylonitrile treatments were carried out.

The resulted parameters are: Qo incr – increase of oil flow rate, t; Tdr – duration of effect, month; qo after/qo before – the ratio of the oil production rate after the treatment to the oil production rate before treatment; Wbefore/Wafter – the ratio of the watercut value before processing to the water cut after treatment; Hп – perforation interval, m; Top – operating time, day; Pform – formation pressure at the moment of treatment, MPa; Pinj – injection pressure, MPa; V – the volume of injected HPAN, m3; qo after – oil output after treatment, t/day; Wafter – watercut after treatment, %; qo before – the debit of oil before processing, t/day; Wbefore – watercut before processing, %.

2. CALCULATION METHOD

Average values of oil flow rates and water cuts of wells were calculated before and after the treatment. The results are shown in Figure 1 and Figure 2.

On average the oil production rate increased by more than two tons per day. Thus, we see that the use of HPAN acid treatment allows a significant increase in oil production, and proves the effectiveness of its use.

Dependence of the flow rate after treatment from oil production before treatment, and the dependence of watercut after treatment from watercut before treatment allow establishing the regression equations. These equations were later obtained by the authors with the program Statistica 6.0.

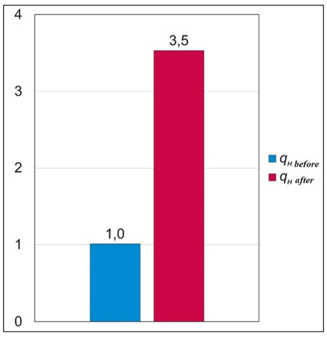

Figure 1 Average values of oil production rates before and after hydrolyzed polyacrylonitrile treatment

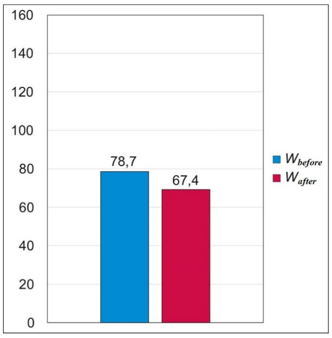

Figure 2 Average values of watercut before and after hydrolyzed polyacrylonitrile treatment

2.1. Check of the sample for normal distribution

Before carrying out any of the operations available in the above-mentioned program - either regression or variance analysis - it is necessary to check the sample for the normal distribution [9].

For the application of parametric methods of statistical analysis, it is necessary to subject the sample to the law of normal distribution - the Gaussian distribution.

The curve, in this case, is bell-shaped.

The module Descriptive Statistics in the program Statistica provides a graphical way to check the normality of the sample distribution. The module allows building a histogram and visually estimating if the values are distributed normally [10].

Let us consider one parameter from the whole set of parameters under investigation - the dependent variable Qo incr.

The graph, constructed from the initial data for this variable, is shown in Fig. 3.

As can be seen, the distribution of this variable is not normal, since a significant number of values are outside the bell-shaped curve, which is highlighted in red in the figure.

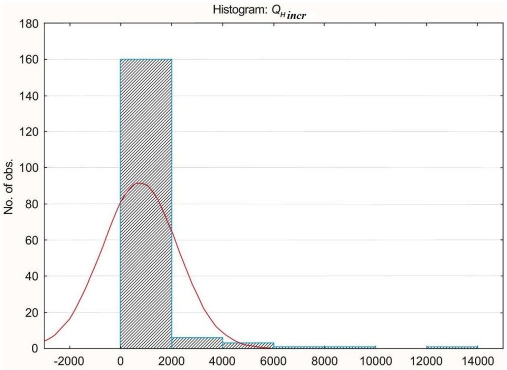

Figure 3 Distribution histogram for $Q_{o\ incr}$ from source data

2.2. Box-Cox Transformation

These data, as they are, are not applicable for further analysis. The series is to be transformed.

Statistics offers several ways to bring data to a normal distribution [11]. The most famous of the transformation methods is the Box-Cox transformation [12].

The parameter of this transformation is λ. The transformation is determined by the following formula:

$$h_i(Y_i,\lambda)=\frac{Y_i^{\lambda}-1}{\lambda}. \qquad 1$$

If $\lambda \to 0, \quad \frac{Y_i^{\lambda}-1}{\lambda} \to \ln Y_i, \quad h(Y,0)=\ln Y.$

The parameter λ is chosen by the user [13]. The change in this parameter leads to an increase or a decrease in the log likelihood. Consequently, the correctly chosen parameter will allow obtaining the maximum value of the logarithm, and thus most fully approximate the transformed sample to the normally distributed series [14].

The quantile of the normal distribution function correlates with the transformed series, previously sorted [15]. In this case, finding the largest value of the correlation coefficient will, in turn, gives the most suitable parameter for the transformation λ [16].

This method allows working only with non-negative quantities. In order to take into account negative values, as well as values equal to zero, the modified equation [17] is used:

$$Y_i^{\lambda}=(Y_i+\alpha)^{\lambda}-1. \qquad 2$$

If $\lambda \to 0, \ Y_i^{\lambda} \to \log(Y_i+\alpha).$

The value α is a constant, to the amount of which all values shift. The following condition [4] is necessary:

$$(Y_i + \alpha) > 0, \quad i = 1,\ldots, n.$$

In the process of transformation, we used the parameter λ equals to 0.0335.

As a result of the transformation, a normal histogram of the distribution of the values of the series was obtained. The graph is shown in Fig. 4.

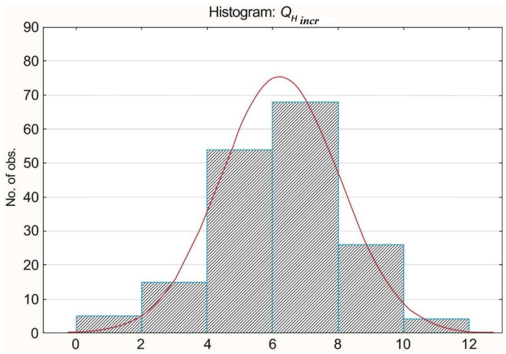

Figure 4 Distribution histogram for $Q_{o\ incr}$ according to the data transformed using the Box-Cox transformation

Also, the subordination to the normal distribution law of the series obtained as a result of the transformation is confirmed by the graph in Fig. 5.

The distribution is considered normal when the points on the graph are located directly on the line (highlighted in red), and as close to the line as possible [18].

According to this graph, we can conclude that the series obtained during the transformation has a normal distribution, and can be used in further statistical analyzes.

During the Box-Cox transformation, normal distributions were also achieved for the remaining parameters used in the analysis.

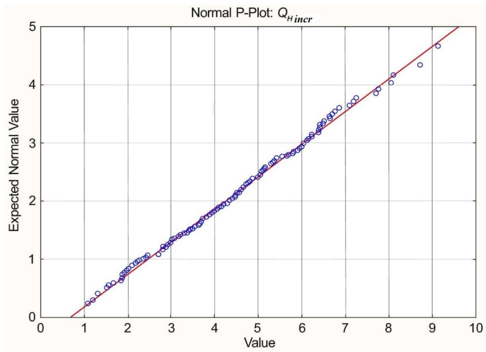

Figure 5 Normal probabilistic graph of residues

2.3. Regression analysis

After completing the necessary transformation and obtaining normally distributed data, we can proceed to the next stage of statistical analysis - regression analysis [19].

Each of the phenomena is influenced by a whole range of reasons.

But, as known, not every reason affects the phenomenon under consideration. Therefore, a careful selection of the parameters most influencing the given phenomenon is necessary [20].

The following parameters are used as the studied dependent variables: $Q_{o\ incr}$, T_{dr},

$q_{o\ after}/q_{o\ before}$, W_{before}/W_{after}.

The dependence of each of the dependent variables from the explanatory parameters, chosen in advance as the most significant ones, are studied. These parameters include: Hп, Top, Pform, Pinj, V, qo before, Wbefore.

The problem of finding the relationship between the above-mentioned parameters allows us to solve a multiple (multifactor) regression analysis [21].

The relation between the parameters is linear [22]. Consequently, the equation will have the form:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_m x_m, \qquad (3)$$

where y, x – the characteristics under analysis;

b0 – the free term of the regression equation;

bm – the regression coefficient.

Regarding the value of the regression coefficients, one can assess the contribution of the independent variable to the formation of the regression equation for the dependent variable. The more the coefficient differs from zero, the stronger the relationship between the analyzed parameters is.

2.3.1. Equations obtained from the regression analysis

First of all, let us find the equations connecting the oil output and water cut after polymer-acid treatment with the output and watercut before the polymer-acid treatment.

In this particular case, *y* is the oil output and watercut before hydrolyzed polyacrylonitrile treatment, and *x* is the output and water cut after hydrolyzed polyacrylonitrile treatment.

The regression equation, considering the rounding of values, is written as follows:

$$q_{o\ after} = 0.153 + 0.01184 q_{o\ before}, R^2 = 0.875 \qquad (4)$$

$$W_{after} = -1.739 + 0.139 W_{before}\ R^2 = 0.958 \qquad (5)$$

The obtained equations allow predicting the output and water cut of oil after hydrolyzed polyacrylonitrile treatment.

The coefficients of determination R2 explain the variance of the dependent variables, which is, in turn, explained by the obtained regression equations. The greater the value of the coefficient, the greater the variation ratio due to the parameters that were included in the analysis [23].

The model is considered suitable for practical use when coefficients of determination in regression equations have values exceeding 50%.

The coefficients obtained for the regression equations (4), (5) satisfy this condition. It allows us to make a conclusion about the adequacy and significance of the regression equations obtained.

After the calculations made with the substitution of data on the oil production rate before the polymer acid treatment in the regression equation (4) obtained, which expresses the relationship between the rates after and before treatment, a number of wells were identified with the discrepancy between the forecast (qforecast, t/day) and the received oil production exceeds 1 t/day.

The discrepancies between the production rates for 15 wells are shown in Fig. 6.

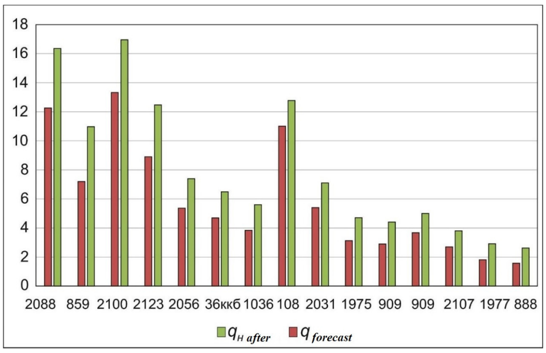

Figure 6 Histogram showing the discrepancy between the debits after and before treatment

It can be assumed that the discrepancy between the flow rates is due to the influence of the filter-capacitance and physicochemical properties of the layers that are not quite correctly determined, which could entail an influence on the technological factor (pressure and injection volume of the polymer) [24].

However, the regression model obtained must be taken into account. Namely, the coefficient of determination must be estimated. It is 0.875, and a part of the values equal to 0.125, is not included in the coefficient.

Accordingly, a variant that is more possible is the impact of a value not equal to 0.125. In other words, the value of 0.125 values is the magnitude of the unexplained variance of the dependent variable.

Therefore, this is the reason for the discrepancy between the flow rates of more than 1 t/day. It does not prove the ineffectiveness of the event, since, as was shown above, the oil flow rates after the event significantly increased, which proves the adequacy of the use of hydrolyzed polyacrylonitrile treatment.

Then the regression models for the dependent variables, which were listed above, were compiled. The equations obtained are presented below.

$$Q_{o\,incr} = 98.097 - 0.1539H_n - 12.177q_{before} - 0.2233W_{before} + 1.167T_{op} - 0.00998P_{form} + 0.388P_{inj} + 3.263V \quad R^2 = 0.897 \qquad 6$$

$$T_{dr} = -7.931 - 0.155H_n - 0.213q_{before} - 0.054W_{before} - 0.284T_{op} + 0.2051P_{form} + 0.0112P_{inj} + 0.0293V \quad R^2 = 0.607 \qquad 7$$

$$W_{before}/W_{after} = -1.0233 + 0.021H_n - 0.1q_{before} + 0.03705W_{before} - 0.03T_{op} - 0.01036P_{form} - 0.027P_{inj} - 0.051V \quad R^2 = 0.9 \qquad 8$$

$$q_{after}/q_{before} = 0.060082 + 0.0021H_n - 0.00261q_{before} - 0.0101W_{before} + 0.02003T_{op} - 0.00214P_{form} + 0.02012P_{inj} + 0.00212V \quad R^2 = 0.76 \qquad 9$$

In this case, the determination coefficients have significant values. It proves the adequacy of the equations obtained in the course of the analysis.

Comparison of the prediction data with the real ones resulted in the following error values: Qo incr – 12.8 %, Tdr – 16,7 %, Wbefore/Wafter – 6,9 %, qo after/qo before – 15.8. The values of the errors obtained are in the range of 6-20%, which corresponds to a good forecast accuracy.

A comparison of the results of treatments based on hydrolyzed polyacrylonitrile with hydrochloric acid treatments showed that the average efficiency when using hydrochloric acid treatment is lower than when using hydrolyzed polyacrylonitrile treatment. The difference between the efficiency of using hydrolyzed polyacrylonitrile treatment from using hydrochloric acid treatment is about 18%.

The existing characteristics of the wells allow obtaining high results from carrying out treatments based on HPAN. In case of using these formulas, the percentage of unprofitable works is reduced by 27%.

Selection of wells for treatments should be done taking into account the above-mentioned recommendations (equations) (6)-(9), which will reduce the likelihood of selection of wells, processing on which will lead to an unprofitable result. It follows from the studies in [8] that the use of hydrolyzed polyacrylonitrile treatment will allow reducing the percentage of unsuccessful wells by 22%.

3. RESULTS AND DISCUSSION

Analysis of equations is based on the fact that:

- the higher the value of the coefficient before a particular variable entering into the regression equation, the more the analyzed variable depends on the contribution of the given quantity;
- the signs before the coefficients of the parameters of the equation indicate the nature of their influence on the parameter under analysis: a positive sign means that as the parameter increases, the effective parameter increases correspondingly, and a negative sign indicates the opposite accordingly - a decrease in the value of the dependent variable [25].
- Thus, it can be concluded that all independent parameters were included in the regression equation, but have different degrees and patterns of influence on the analyzed dependent variables:
- The efficiency of the application of the polymer acid treatment can be estimated from the equation compiled for Qo incr. The largest positive effect on this parameter is provided by the injected polymer capacity, the largest negative effect is the output rate before treatment;
- The time of the treatment effect depends directly on the layer pressure, with its increase the time increases;
- The growth rate of oil flow is positively affected by the perforated thickness, the operating time of the well before the impact, the pressure and volume of the injected polymer.

4. CONCLUSION

The most important area of the field development is the bottomhole well zone. One of the main problems in this zone is the reduction of its permeability. The reason for the permeability decrease in this area is the watering of the layers because of the breakthrough of water along the cracks with high permeability. Therefore, the main task was and is to increase the permeability of this zone.

Analysis of the data on wells of 21 deposits in the west of Bashkortostan makes it possible to verify the significant efficiency of the use of polymer acid treatment (18% higher than the efficiency from hydrochloric acid treatment), in which HPAN was used as a polymer. Preference is given to this component due to the relatively simple injection technology, cheapness, and availability.

The criteria for selection of the wells for treatment provide the greatest effect to be achieved.

The statistical analysis resulted in regression equations with coefficients of determination, the values of which range from 60.7 to 95.8%.

In accordance with the deterministic coefficients obtained, the regression models are adequate, and the degree of error determined by comparing the predicted and actual data is of good forecast accuracy. It makes the equations applicable in practice.

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