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Informational Method of Selecting Operating Wells for Stimulation

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Информационный способ выбора действующих скважин для проведения на них геолого-технологических мероприятий

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Due to the natural decline in hydrocarbon production, oil producing enterprises have to carry out well stimulation methods (WSM) aimed at increasing well productivity. At the same time, despite the use of various, including progressive, geological and technical technologies, the problem of the effectiveness of industrial application of methods remains. A significant part of the implemented volume of WSM does not produce positive results in increasing the main technological and economic indicator of well operation - productivity coefficient, which is often associated with incorrect selection of wells for carrying out the designed well stimulation technology. According to the current standards in Russia, when choosing a technology for drilling into productive formations, as well as when choosing wells for WSM, it is recommended to comply with the requirements of the relevant guidance documents. The main control indicator in these documents is the coefficient of potential (i.e. natural) productivity loss of a well (K), with positive values of which decisions are made on the implementation of WSM in wells. However, due to changes in the physical properties of the reservoir continuum of wells and the hydrodynamic interaction between them, problems arise with the reliability of determining the initial parameters for calculating K, which casts doubt on the need for its participation in the process of assessing the actual state of the bottomhole formation zone (BFZ).
To increase the reliability of assessing the BFZ current state degree, this work substantiates and proposes a more reliable criterion for assessing the potential productive capabilities of production wells before conducting WSM - a complex parameter Z, which has a high correlation with the actual productivity coefficient in the corresponding wells. A practical test of the introduced criterion effectiveness was demonstrated at oil wells in the Perm region. At the same time, proposed method of analyzing the collected factual information obtained during the sequential implementation of hydrodynamic well testing and WSM in the fields made it possible to increase the wells selection reliability for the priority implementation of planned measures to influence the reservoir zone. The methodological approach presented in the work to the wells selection for WSM can ensure the expected positive effect on oil production.

Ключевые слова:
скважина, пласт, призабойная зона пласта, геолого-технологические мероприятия, обработка призабойной зоны, коэффициент продуктивности, коэффициент потери потенциальной продуктивности скважиной, гидродинамические исследования скважин, скин-фактор, кривая восстановления давления, комплексная переменная *Z*, удельная поверхность дренажной системы скважины, пластово-дренажный фильтр, радиус и пропускная способность фильтра, динамика продуктивности, эффективность.

В связи с естественным снижением добычи углеводородного сырья нефтедобывающим предприятиям приходится проводить геолого-технические мероприятия (ГТМ), направленные на повышение продуктивности скважин. При этом, несмотря на использование разнообразных, включая прогрессивные, технологий ГТМ, проблема эффективности промышленного применения методов остается. Значительная часть реализуемого объема ГТМ не дает положительных результатов по повышению основного технолого-экономического показателя эксплуатации скважин – их коэффициента продуктивности, что зачастую связано с неправильным подбором скважин для проведения запроектированной технологии ГТМ. Согласно действующим в России стандартам, при выборе технологии вскрытия добывающими скважинами продуктивных пластов, как и при выборе скважин для проведения ГТМ, рекомендуется выполнять требования соответствующих руководящих документов. В качестве основного контрольного показателя в этих документах выступает коэффициент потери скважиной потенциальной (т.е. естественной) продуктивности (*К*), при положительных значениях которого принимаются решения по реализации ГТМ в скважинах. Однако по причине изменения физических свойств пластового континуума скважин и гидродинамического взаимодействия между ними возникают проблемы с достоверностью определения исходных параметров для вычисления *К*, что подвергает сомнению необходимость его участия в процессе оценки действительного состояния призабойной зоны пласта (ПЗП).
Для повышения достоверности результатов оценки степени текущего состояния ПЗП в настоящей работе обоснован и предложен более надежный критерий оценки потенциальных продуктивных возможностей эксплуатационных скважин перед проведением ГТМ – комплексный параметр *Z*, который имеет высокую корреляцию с фактическим коэффициентом продуктивности в соответствующих скважинах. Практическое испытание эффективности введенного критерия продемонстрировано на нефтедобывающих скважинах Пермского региона. При этом использование предложенного метода анализа собранной фактической информации, полученной при последовательном проведении гидродинамических исследований скважин (ГДИС) и ГТМ на промыслах, позволило повысить надежность выбора скважин для первоочередной постановки на них запланированных мероприятий по воздействию на ПЗП. Представленный в работе методический подход к выбору скважин для воздействия на их ПЗП может обеспечить получение ожидаемого положительного эффекта по добыче нефти.

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Introduction

At present, when the majority of oil producing enterprises in the regions that have been supplying hydrocarbons to the market for a long time are at the stage of declining production, well stimulation methods (WSM) of impact on oil-bearing formations which increase well productivity are of fundamental importance for curbing this process. There have been invented and implemented [1–7] many different technologies of WSM, including injection into wells of various reservoir-destroying reagents and mixtures, with different methods of subsequent extraction of reaction products, but the problem of efficiency of industrial application of these methods remains unsolved. So far, a significant part of the realized volume of WSM does not give positive results in increasing the main technological and economic indicator of well operation, their productivity coefficients. In such cases, to assess the degree of success of the measures taken in the production practice, it is used a short-term increase in the current flow rate of wells, obtained by intensification of their operation modes after well stimulation [8–13]. The reason for this situation is insufficient attention of the customer companies' service personnel to the process of selecting specific wells intended for each planned WSM.

Today, according to the standards in force in Russia, when selecting the technology of penetration of productive formations by producing wells, as well as when selecting wells for hydraulic fracturing, it is recommended to fulfill the requirements of the relevant ruling documents RD, including RD 39-0147001-742-92 [14], earlier (RD 39-0147009-509-85).

In order to make a certain decision on realization of WSM these RD introduced a control indicator (K) – the coefficient of well potential loss (i.e., natural) productivity as a result of previously performed technological operations:

$$K = (1 - \text{OP}). \quad (1)$$

Let's consider the physical essence of this parameter.

Here OP is the coefficient of hydrodynamic (HD) perfection of the well, which is equal to the ratio of coefficients of its actual and potential productivity (ηf / ηp), which are calculated according to the results of hydrodynamic well testing (HDWT), performed before WSM [15–33].

The first coefficient is calculated according to the indicator diagram – ID ($\eta\phi = Q/\Delta P_o$), taken during the operation of the well, the second one is calculated according to the pressure recovery curve (PRC) ($\eta p = 1/2\alpha A$), recorded after its shutdown. In the first expression ($\eta f = Q/\Delta P_o$), the numerator and denominator are the steady-state well flow rate and reservoir underbalance ($\Delta P_o = Pr - \text{P}bh$), where Pr and Pbh are the measured reservoir and bottomhole pressures. In the second expression ($\eta n = 1/2\alpha A$), where the coefficient $\alpha = \text{tg}\varphi$, φ is the slope angle of the control rectilinear section of the PRC graph plotted in transformed coordinates ($\Delta P\tau/Q$; $\ln\tau$). In the numerator of the transformed coordinates is the incremental pressure at the bottom of the well during the time τ of its holding on the PRC: ($\Delta P\tau = [P\tau - (P_o + B)] / Q$), $A = \ln R/r$, where R and r are conditional, i.e., in reality do not exist, radii of the feed zone and the open wellbore, taken for calculations peremptorily.

Positive decision on application of WSM is made in the case of OP < 1, i.e. at positive values of K, and negative – in the case of OP > 1, i.e. at negative K values.

If registration of the indicator diagram at the well is not provided, the actual productivity factor, according to the second variant of the RD, is calculated by the formula $\boldsymbol{\eta}\text{f} = \boldsymbol{\eta}\text{n}\cdot$ OP. In this case, OP = A/(A + S) with ηn and S (skin factor) determined according to PRC [34–45].

In spite of oil producing enterprises' regular fulfillment of the requirements corresponding to RD, the efficiency of the implemented WSM to increase productivity coefficients turns out to be negative in many wells. This forces the relevant technological services of the enterprises to use other "veiled" methods of its positive assessment. To find out the reasons for this situation we'll analyze in more depth the information used in calculating the K index.

It is known that the most reliable source of data on the values of ηn and S are the reconstructed plots of PRC, containing only one control (rectilinear) section, which is usually registered at the initial period of well operation.

In the future, due to the inevitable change of physical properties, formation continuum of wells, and also as a result of hydrodynamic interaction between them, which is especially characteristic of old, including Perm, oil-producing regions, the shape of PRC degrades, forming a number of rectilinear areas on the graph. There are appeared the problems with the location of the control area, which leads to anthropogenic errors in S and φ [46-48]. This should also include the use of obviously imaginary values of the radii of the feeding zone and open borehole R and r in the calculations. The resulting random variation in the values of S, φ, R and r leads to random significant errors in calculations of ηn and K coefficients, which increase the probability of obtaining incorrect values of the latter [49] and further erroneous selection of wells for realization of a particular technology of WSM. As a result, wells with deteriorated results of newly acquired productivity quite often appear after geological treatment.

Besides, the coefficient K contains an imaginary unit – (i) ($i^2 = -1$) [51], since at $\eta\phi = \eta\pi$, $K = 1 + (-1)$, here – OP $= i^2$, then $K = i^4 + i^2 = i^2(i^2 + 1) = i^2(1 - \text{OP}) =$ $= i^2 \cdot 0 = 0$. Therefore, K, as the imaginary number, has a low degree of confidence. Perhaps it is for these reasons, according to field experience, that the values of well productivity coefficients ηf calculated according to the second option of RD differ significantly from the productivity coefficients obtained according to the first option of RD.

All of the above casts doubt on the ability of K to be an unambiguous criterion for evaluating the results of comparing the changing physical properties of actually existing natural objects. There are also doubts about the expediency of using K to assess the state of the bottomhole formation zone (BFZ) before WSM, as well as a factor reflecting the dynamics of the productivity of production wells and, moreover, a possible toolkit for synchronizing different well intervention technologies with the specific reservoir conditions of each well, where a positive effect on the dynamics of ηp is expected to be obtained.

The listed properties of K indicate the need for the technological services of oil-producing enterprises to acquire a more reliable criterion for assessing the potential productive capabilities of production wells before conducting well interventions. The solution of this issue will require the complete exclusion of purely imaginary variables from the calculations.

One Way to Improve the Reliability of Assessing the Extent of BFZ Condition

• In order to increase the reliability of assessing the state of the bottom-hole formation zone, let us turn to the materials presented in the paper "The information approach to improving the efficiency of methods for influencing the bottom-hole formation zone in operating wells" [50], where the coefficients A and K, which are not materializable in their essence, are not used to assess the state of BFZ. Instead, according to the results of hydrodynamic well testing the real physical properties of the BFZ are determined:

• specific surface area of the drainage system of the well;

• radius of the reservoir drainage filter (RDF));

• throughput capacity of the reservoir drainage filter (RDF).

These physical parameters of the reservoir continuum form the structure of the oil flow on the way from the remote zone of the reservoir (RZR) to the wells and ensure the mode of filling their wells with products. The above properties make it possible to use the following complex variable instead of a purely imaginary K criterion to assess the state of the wells before WSM:

$$Z = C(x) + iD(x), \qquad (2)$$

where (x) – argument proportional to the value of the hydraulic conductivity of the RZR; C – real number; D – imaginary number, resulting from regular combinations of the values of the four physical properties of the reservoir continuum of each well.

Industrial Variant of using the Complex Parameter Z

As an example for possible industrial application of Z we will analyze the results of calculation of this indicator based on the materials of the corresponding processing of information obtained from 45 HDWTs carried out at 15 oil fields in the Perm region.

Since the values of the indicator Z, calculated for all PRC, being complex numbers, also have a part of disadvantages in terms of reliability, we adapt the obtained values with real numbers in order to increase it in the results of subsequent calculations.

Fig. 1 shows a plot of such an operation, where a fairly good degree of correlation between the selected parameters ηf and Z is recorded. A similar graph constructed using the parameter K instead of Z turned out to be unrepresentative, with a cloud of points scattered along the +/- axis, and therefore is not presented in the form of a figure.

After calculating Z for any investigated well in the Perm region, Fig. 1 is used to determine K_p – its average stochastic productivity coefficient, let us call it local-potential. Comparative analysis of the elements of this sample showed the presence of two characteristic groups of objects in its composition; group No. 1 contains wells with locally potential productivity coefficient greater than the actual one (K_p > ηf) (Fig. 2, *a*), group No. 2 – vice versa (K_p < ηf) (Fig. 2, *b*).

Sufficiently high correlation coefficients of these graphs indicate the presence of a regular relationship of represented parameters which does not exclude the possibility of using proposed control criterion Z for reliable separation of reservoir continuums of wells

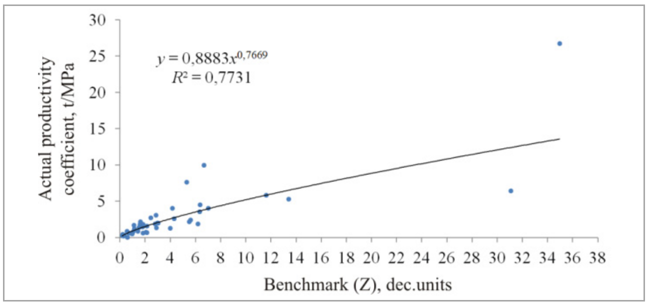

Fig. 1. Graph of the dependence of the actual coefficient of well productivity on the control indicator Z

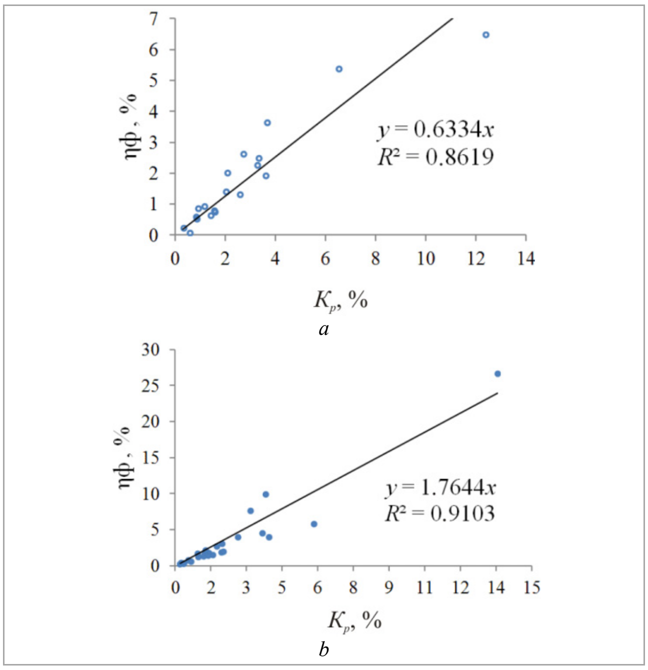

Fig. 2. Graph of dependency of ηф on K_p; *a* – K_p > ηф (group of wells № 1); *b* – K_p < ηф (group of wells № 2)

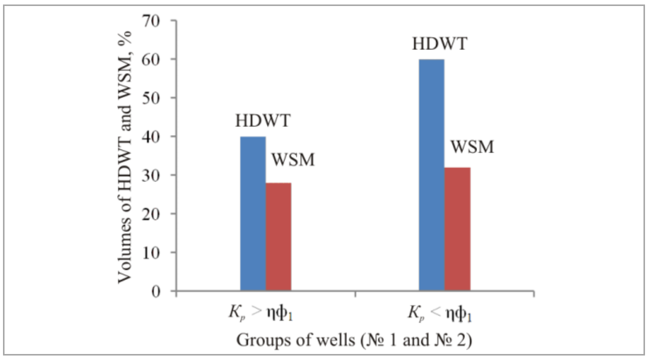

Fig. 3. Graph of the ratio between the volume of HDWT and WSM in groups of wells with K_p > $ηф_1$ и K_p < $ηф_1$

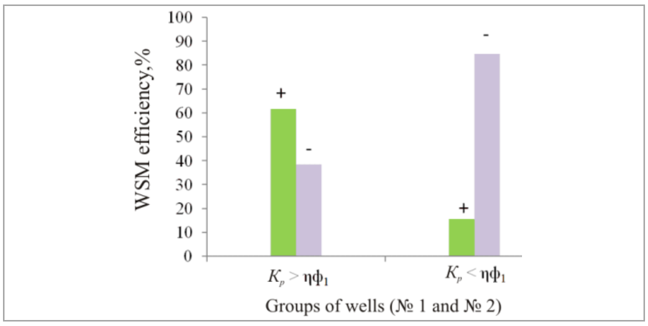

Fig. 4. Graph of the results of the implementation of the standard BZT (WSM) technologies in groups of wells

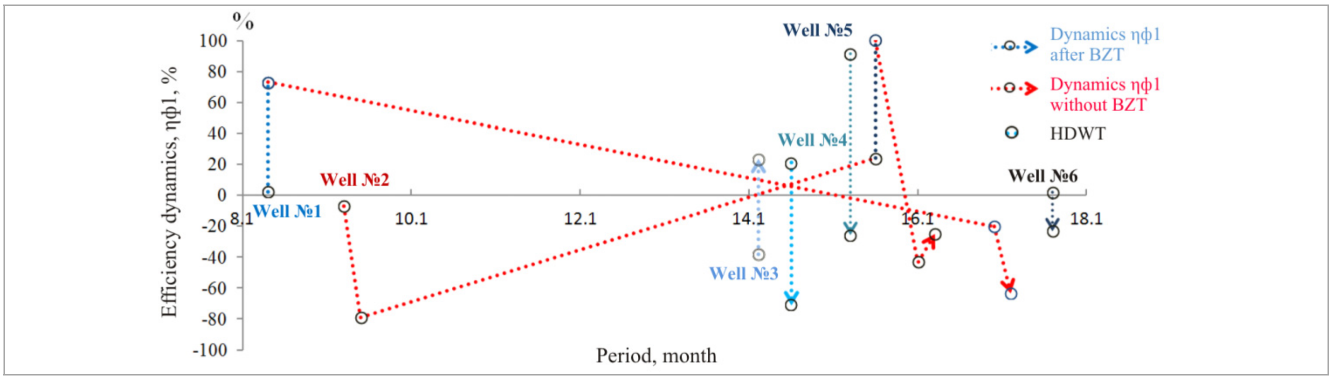

Fig. 5. Dynamics of ηф1 from predicted to the actual value

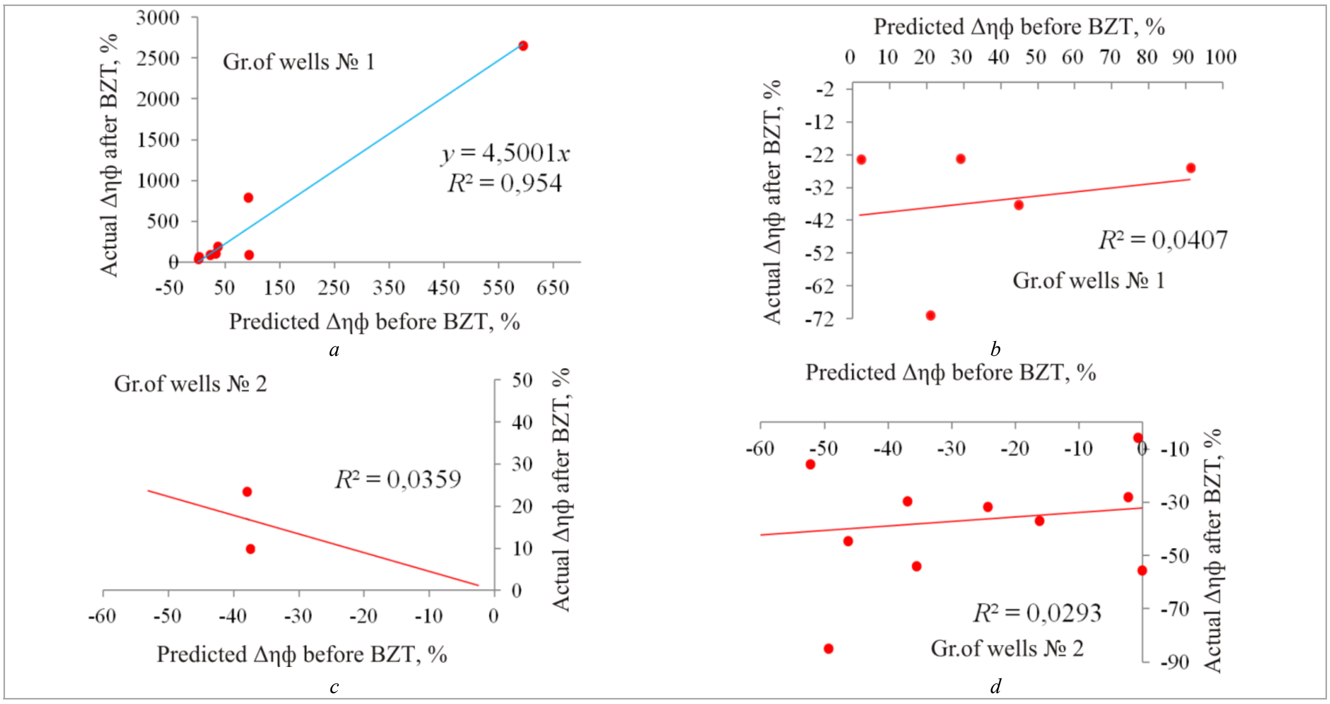

Fig. 6. Graphs of dependence of actual productivity increments η*f*2 – η*f*1 of wells after BZT from the predicted K_p – η*f*1 determined with the help of *Z* before BZT, %

by an unknown qualitative feature, presumably affecting the results of WSM. Possible natural signs of such separation may be geological features, i.e. distribution of the studied wells in different groups of fields having close to each other mineralogical, structural or other petrophysical properties of formation continuums, as well as physical properties of oil. Such separation may also be related to the use of different but similar technologies of WSM in the same geological conditions.

To check the degree of possible influence of these assumptions on the results of geological and engineering operations it was used the information on the results of bottom-hole zone treatment (BZT) technologies developed by one of the companies servicing wells throughout the Perm region. These are mainly various types of simple acid treatments of wellbore bottomhole zone (BHZ). The result of dividing the whole sample of these wells by the types of well interventions for group № 1 – 10/7 and № 2 – 15/8 (in %) is shown in Fig. 3. 3. In one part of the studied wells BZT was carried out more than once, in another part it was not carried at all.

Official information on the effectiveness of the implemented interventions was not available, so their actual outcome was determined by comparing the parameters (ηf1 and ηf2) obtained by the ID as a result of HDWT conducted by a subcontracted firm before and after the interventions. The data set derived from the PRC was not used for this purpose.

A first indication of the quality of the typical BZT technology can be obtained by dividing both groups of wells with BZT according to the effectiveness of their treatments into effective ηf2 > ηf1 (+) and ineffective ηf2 < ηf1 (-), in % ratio, Fig. 5.

It turned out that more effective, gaving a real increase in the coefficients of productivity, regardless of the signs of *K* and *S*, are the technologies of BZT, used to affect the bottom-hole formation zone of wells in group No. 1. Here ineffective cases were recorded mainly at one oil field, and effective cases at six other oil fields. For the objects of group № 2, located in the same oilfields, also regardless of the value and signs of *K* and *S*, the negative outcome of similar BZT technologies is recorded in the vast majority of cases. Assuming that the same stimulation technology was used in both cases, the question arises about possible group geological differences in reservoir structure.

In order to find out the real reasons for the registered dynamics of the results of BZT realisation, let us consider this information in the form shown in Fig. 5.

Let us use the parameter K_p, presumably capable of representing the value of $\eta f2$. This figure shows in retrospect, for example, the changes in the values of the initial productivity coefficient $\eta f1$ from the predicted $(Kp - \eta f1)/\eta f1$ – the beginning of the arrow, to the actual $(\eta f2 - \eta f1)/\eta f1$ – its end. The blue colour indicates trajectories for some wells of both groups after BZT, and the red colour indicates the period without BZT. The emergence of additional problems is shown in Fig. 6, namely, multidirectional effects on productivity dynamics were obtained both after well stimulation and under normal operating conditions, without stimulation. Also, in almost all selected wells, the predicted and actual effectiveness of well interventions on the change of $\eta f1$ significantly diverge both in sign and magnitude. In the case of widespread qualitative performance of the same technology, such results lead to doubts about the presence of a stochastic relationship between the analysed parameters. In order to possibly exclude them, similar information was used for the whole group of studied wells.

Fig. 6 shows the graphs of dependence of the actual dynamics of initial well productivity coefficients obtained after treatment, from the assumed (designed) ones determined with the help of *Z* before BZT.

The value of correlation coefficients and the shape of red graphs for groups of wells No. 1 and 2 confirm the absence of quantitative relationship between the predicted and actual results of BZT.

However, there is a logical connection between them. Thus, for group 2, negative predicted results correspond to negative actual results (*d*) after treatment. This is the evidence of a deliberately wrong decision, adopted by the technological services of oil producing companies on the use of the proposed technology for wells with negative design efficiency indicators. Some of the positive examples obtained in this group (b) may be the result of errors in interpretation of the well logging data or the result of testing a more advanced version of the stimulation technology.

The similar characteristic of the red graph for group No. 1 (*c*) is a sign of possible violation of the BZT technology since its positive outcomes (increased productivity coefficient) in this group of wells are more representative, as evidenced by the blue coloured graph (*a*), its correlation coefficient is equal to 0.95. The high value of the correlation coefficient of this graph (*a*) indicates that there is a functional dependence between the local-potential, determined with the help of *Z* before BZT and the actual coefficients of productivity of producing wells obtained after BZT, which indicates a high degree of reliability of using *Z* to predict the results of BZT on the main part of the wells in this group.

Unfortunately, information on most elements of the total sample is not included in this classical composition. The reason is the information diversity of its parts, firstly, by the qualitative characteristic of the formation continuums of the studied wells,secondly, these parts also include information on wells with positive and negative effects of the BZT on productivity, and thirdly, similar effects were obtained both in wells with OPZ, and at their normal operation. Such a variety of influencing factors led to the necessity of generalised evaluation of the noted parts of the sample by the degree of their representativeness (Figs. 7, 8).

As a result of this analysis, the following was found: the percentage of positive effects on productivity from the typical BZT is more likely to occur in wells of Group 1 than in wells of Group 2 (Fig. 8 and 10), which confirms the earlier conclusion (see Fig. 4). At the same time the negative effect after BZT is more probable for wells of group No. 2 (Fig. 7, *b* and 8, *a*).

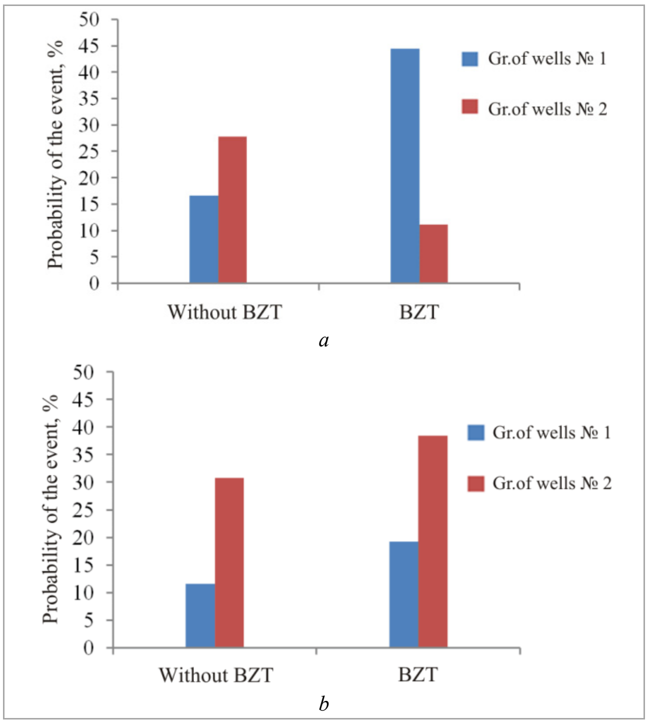

Fig. 7. Productivity effects: *a* – positive; *b* – negative

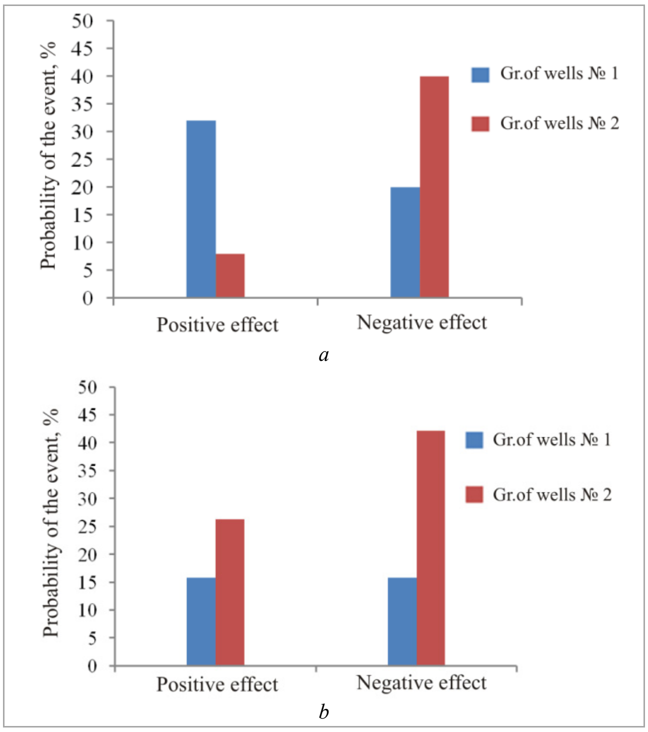

Fig. 8. Efficiency of wells operation:
a – with BZT; *b* – without BZT

For wells without BZT (Fig. 9): natural dynamics of well productivity in group 2 is higher in cases of reservoir-drainage filter self-cleaning (see Fig. 7, *a*; 8, *b*; 9, *b*) and self-clogging (see Fig. 7, *b*; 8, *b*; 9, *d*).

It is worth noting that for the wells of this group, both with (see Fig. 6, *d*) and without hydraulic stimulation (see Fig. 9, *c*) there is actually the same negative dynamics of initial productivity coefficients, but

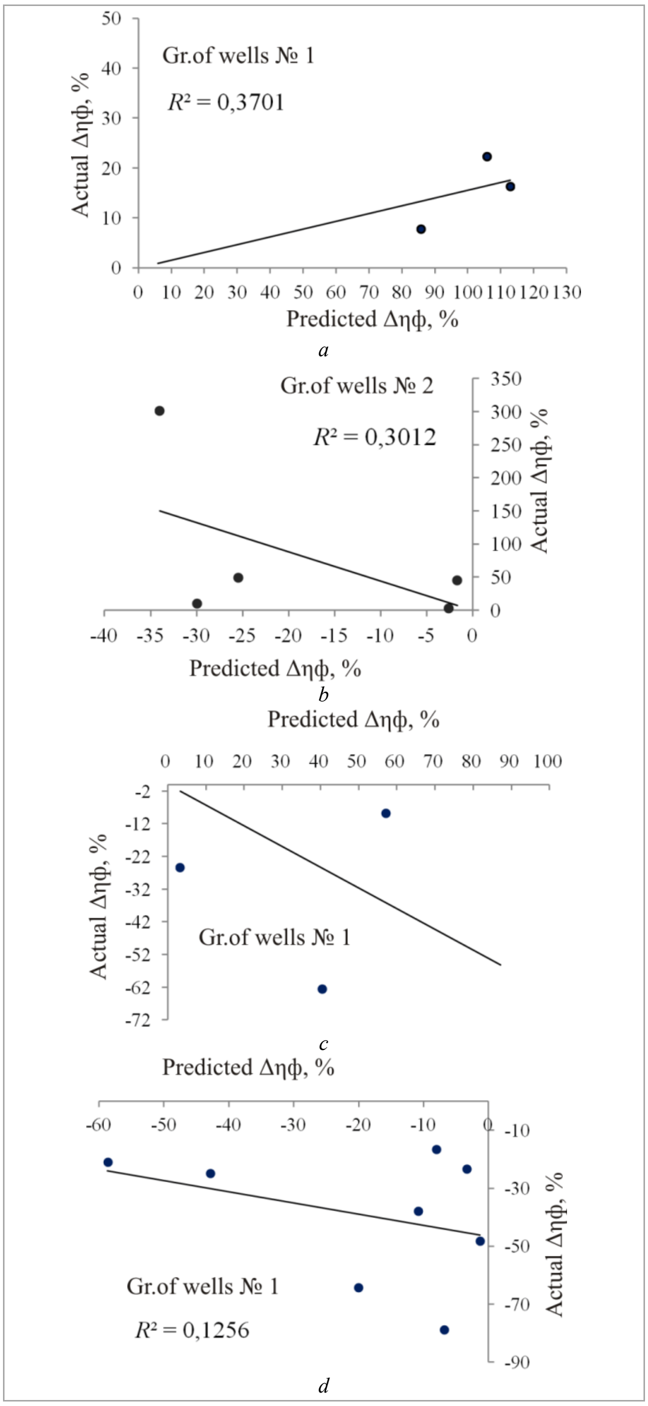

Fig. 9. Graphs of dependence of actual productivity increment ηf2 – ηf1 of wells without BZT on predicted K_p – ηf1 determined by *Z*, %

with the opposite trend which may be a sign of lack of information on wells without stimulation (see Fig. 9, *d*) or a consequence of insignificant changes in the reservoir properties of the bottomhole zone of some wells after stimulation (see Fig. 6, *d*). The dynamics of productivity in wells of group No. 1 is similar: it has a smaller but the same degree of representativeness (see Fig. 8, *b*). The same probability of origin of opposite events characterising the state of a single system of intensive fluid movement in the RDF can be explained by the fact that its physical properties remained stable during the normal operation of wells, which characterises reservoirs consisting of solid rock. At the same time, in wells of group 2 (see Fig. 8, *b*; 9, *b*, *d*) these properties are mobile, which is inherent to the products of partial fracture of the latter. During WSM these properties naturally influence both the hydrodynamics of the flow of reagents injected into the formation, transporting rock particles, and their reactivity depleted in the mixture flow. Probably, it is these properties of RDF and SSAW, including the probability of their partial clogging or cleaning, that explain the observed dynamics of productive efficiency of the utilised BZT technology. It should be recalled here that both groups of wells are located mainly in the same oil fields, i.e. they have on average the same physical properties of formation continuums.

All of the abovementioned indicates the lack of necessary in this case operational intervention in the process of well operation, which becomes noticeable only when the wells are subjected to treatment that unpredictably changes the wells' RDF properties (see Fig. 8, *a*).

As a recommendation: to implement regional technologies of geological and engineering operations, wells should be selected for which K_p > ηf1, if, of course, they are found. The analysis of the accumulated information has shown that the possibility of material damage to oil producing enterprises is quite probable due to insufficiently thought-out organisation of hydraulic fracturing operations at operating wells. At the same time, artificially created negative effects on well productivity in most cases reflect the wrong methodology of their selection for a variety of well intervention technologies.

As for one of the companies in the Perm region, in order to increase the overall productive efficiency of the used BZT technology it is most probably to be required a higher qualification of specialists involved in the organization of work on the wells of the first group, and the development of a new well intervention technology for the wells of the second group. But in order to find out the degree of influence of errors in the calculation of reservoir parameters on the results of the BZT, based on the materials of the well testing, violations of conducting the BZT technology, as well as the geological and petrographic properties of the reservoirs, the amount of information collected in this paper is insufficient. Nevertheless, the presented stochastic analysis of the available material indicates a fairly high efficiency of using the local-potential productivity coefficient wells to predict the feasibility of industrial implementation of the planned well interventions. For example, if this recommendation were implemented in the past registration of applications for the analyzed part of the BZT in the Perm region, the total savings of material resources spent by the oil producing enterprises participating in the process would be at least 40 %.

Conclusion

1. An alternative complex parameter is substantiated, designed to increase the reliability of assessing the degree of the state of the BFZ of oil-producing wells based on the results of well testing, which has a high degree of correlation with the actual coefficients of well productivity.

2. A method for predicting the expected dynamics of well productivity after well interventions.

3. The recommended method for analyzing the collected factual information obtained during the sequential performance of HDWT and WSM in the fields will improve the reliability of well selection for the priority setting of planned measures to affect the BFZ.

4. The presented methodical approach to the selection of wells to affect their BFZ will ensure the expected positive effect on oil production.

References

1. Mordvinov V.A., Ponomareva I.N., Voitenko M.A. Razrabotka usovershenstvovannoi tekhnologii provedeniia i obrabotki dannykh gidrodinamicheskikh issledovanii s tsel'iu uvelicheniia produktivnosti i optimizatsii rezhimov periodicheski rabotaiushchikh skvazhin [Development of an improved technology for conducting and processing hydrodynamic research data in order to increase productivity and optimize the modes of intermittently operating wells]. Perm': Permskii gosudarstvennyi tekhnicheskii universitet, 2004, 170 p.
2. Kochnev A.A., Kozyrev N.D., Kochneva O.E., Galkin S.V. Razrabotka kompleksnoi metodiki prognoza effektivnosti geologo-tekhnicheskikh meropriiatii na osnove algoritmov mashinnogo obucheniia [Development of a comprehensive methodology for the forecast of effectiveness of geological and technical measures based on machine learning algorithms]. *Georesursy*, 2020, no. 22 (3), pp. 79-86. DOI: 10.18599/grs.2020.3.79-86
3. Raspopov A.V., Novokreshchennykh D.V. Analiz rezul'tatov primeneniia metodov intensifikatsii na karbonatnykh kollektorakh mestorozhdenii Permskogo kraia [Results analysis of intensification methods application in carbonate reservoirs of Perm region fields]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2014, vol. 13, no. 10, pp. 73-82. DOI: 10.15593/2224-9923/2014.10.7
4. Iushkov I.R. Opyt primeneniia metodov povysheniia izvlecheniia nefti na mestorozhdeniiakh Permskogo kraia [Experience in applying methods for increasing oil recovery in the fields of the Perm region]. *Nauchnye issledovaniia i innovatsii*, 2010, vol. 4, no. 1, pp. 44-50.
5. Lake L.W. Short Course Manual, Enhanced Oil Recovery Fundamentals. *Society of Petroleum Engineers*, 1985, 449 p.
6. Iliushin P.Iu., Rakhimzianov R.M., Solov'ev D.Iu., Kolychev I.Iu. Analiz provedeniia geologo-tekhnicheskikh meropriiatii po uvelicheniiu produktivnosti dobyvaiushchikh skvazhin na neftianykh mestorozhdeniiakh Permskogo kraia [Analysis of well intervention aimed at oil production enhancement in the Perm krai's fields]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2015, vol. 14, no. 15, pp. 81-89. DOI: 10.15593/2224-9923/2015.15.9
7. Kazakov A.A. Metodika otsenki effektivnosti geologo-tekhnicheskikh meropriiatii po krivym padeniia debita nefti [Procedure for geological-technical measures efficiency evaluation using oil rates decline curves]. *Neftianoe khoziaistvo*, 1999, no. 12, pp. 31-34.
8. Kazakov A.A. Razrabotka edinykh metodicheskikh podkhodov otsenki effektivnosti geologo-tekhnicheskikh meropriiatii po povysheniiu nefteotdachi plastov i intensifikatsii dobychi nefti [Development of unified methodological approaches for assessing the effectiveness of geological and technical measures to enhance oil recovery and intensify oil production]. *Neftianoe khoziaistvo*, 2003, no. 4, pp. 26-29.
9. Poplygin V.V., Beloglazova E.A., Ivanova A.S. Analiz rezul'tatov provedeniia kislotnykh obrabotok v slozhnykh geologo-tekhnologicheskikh usloviiakh [Analysis of acid treatments in complex geological and technological conditions]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2014, no. 10. DOI: 10.15593/2224-9923/2014.10.8
10. Mordvinov V.A., Poplygin V.V., Sidorenko D.D., Shaimardanov A.R. Produktivnost' skvazhin posle kislotnykh gidrorazryvov plasta na Gagarinskom i Ozernom mestorozhdeniiakh [Wells productivity after acid fracturing in the gagarinskoye and ozernoye oilfields]. *Neftianoe khoziaistvo*, 2013, no. 4, pp. 44-45.
11. Guo Jianchun, Liu Huifeng, Zhu Yuanqiang, Liu Yuxuan Effects of acid-rock reaction heat on fluid temperature profile in fracture during acid fracturing in carbonate reservoirs. *Journal of Petroleum Science and Engineering*, 2014, vol. 122, pp. 31-37. DOI: 10.1016/j.petrol.2014.08.016
12. Piyang Liu, Yao Jun, Gary Douglas Couples, Ma Jingsheng, Sun Hai. Modeling and simulation of wormhole formation during acidization of fractured carbonate rocks. *Journal of Petroleum Science and Engineering*, 2017, vol. 154, pp. 284-301. DOI: 10.1016/j.petrol.2017.04.040
13. Ghommem Mehdi, Zhao Weishu, Dyer S., Qiu Xiangdong, Brady D. Mehdi Ghommem. Carbonate aciding: Modeling, analysis, and characterization of wormhole formation and propagation. *Journal of Petroleum Science and Engineering*, 2015, vol. 131, pp. 18-33. DOI: 10.1016/j.petrol.2015.04.021
14. RD 39-0147001-742-92. Metodika kompleksnoi otsenki kachestva vskrytiia produktivnykh plastov, zakanchivaniia skvazhin i vybora rabochikh zhidkostei dlia povysheniia kachestva vskrytiia plastov [RD 39-0147001-742-92. Methodology for a comprehensive assessment of the quality of drilling into productive formations, well completion and selection of working fluids to improve the quality of drilling into formations]. Krasnodar: VNIIKRneft', 1992.
15. Issledovanie prizaboinoi zony plastov pri intensifikatsii dobychi nefti za rubezhom [Study of the bottomhole formation zone during intensification of oil production abroad]. VNIIONG. Neftepromyslovoe delo, Moscow, 1985.
16. Amiks Dzh., Bass D., Uating R. Fizika neftianogo plasta [Oil reservoir physics]. Moscow: Gostopttekhizdat, 1962, 232 p.
17. Vasil'evskii V.N., Kamenetskii-Fedorov S.G. et al. Vremennaia instruktsiia po gidrodinamicheskim issledovaniiam plastov i skvazhin [Temporary instructions for hydrodynamic studies of formations and wells]. Moscow: Minnefteprom; Vsesoiuznyi nauchnyi issledovatel'skii institut, 1963, 68 p.
18. Stepanov V.P., Kuzmin V.M. Rukovodstvo po gidrodinamicheskim issledovaniiam neodnorodnykh plastov [Guide to hydrodynamic studies of heterogeneous formations]. Moscow: ONTI VNII, 1972, 159 p.
19. Shchelkachev V.N. Vliianie radiusa i gidrodinamicheskogo nesovershenstva skvazhiny na proizvoditel'nost' [The influence of well radius and hydrodynamic imperfection on productivity]. *Azerbaidzhanskoe neftianoe khoziaistvo*, 1950,no. 9, pp. 5-10.
20. Basovich I.B., Kaptsanov B.S. Obrabotka rezul'tatov gidrodinamicheskikh issledovanii skvazhin metodom determinirovannykh momentov [Processing the results of hydrodynamic studies of wells using the deterministic moments method]. *Azerbaidzhanskoe neftianoe khoziaistvo*, 1987.
21. Buzinov S.N., Umrikhin I.D. Issledovanie neftianykh i gazovykh skvazhin i plastov [Research of oil and gas wells and formations]. Moscow. Nedra, 1984.
22. Vol'pin S.G., Miasnikov Iu.A., Svalov A.V. Gidrodinamicheskie issledovaniia nizkopronitsaemykh kollektorov [Hydrodynamic studies of low-permeability reservoirs]. *Neftianoe khoziaistvo*, 2000, no. 12, 8 p.
23. Diiashev R.N. Gidrodinamicheskie issledovaniia skvazhin pri kontrole za razrabotkoi neftianykh mestorozhdenii [Hydrodynamic testing of wells when monitoring the development of oil fields]. Moscow: VNIIOENG, 1979, 75 p.
24. Kaiumov M.Sh. Opyt ispol'zovaniia rezul'tatov gidrodinamicheskikh issledovanii dlia optimizatsii raboty dobyvaiushchikh skvazhin [Experience in using the results of hydrodynamic studies to optimize the operation of production wells]. *Neftepromyslovoe delo*, 2002, no. 5, pp. 28-32.
25. Tokarev A.P., P'iankova E.M. Sovershenstvovanie metodov interpretatsii krivykh vosstanovleniia urovnia pri issledovanii skvazhin. [Perfection of level recovery curves interpretation methods at wells survey]. *Neftianoe khoziaistvo*, 2009, no. 3. pp. 56-58.
26. Zakirov S.N., Indrupskii I.M., Zakirov E.S., Anikeev D.P. Novyi podkhod k issledovaniiu skvazhin i plastov [A new approach to the study of wells and formations]. *Neftianoe khoziaistvo*, 2002, no. 6, pp. 113-115.
27. Lysenko V.D. Samymi ekonomicheski effektivnymi meropriiatiiami pri razrabotke neftianykh mestorozhdenii iavliaiutsia gidrodinamicheskie issledovaniia skvazhin [The most cost-effective measures in the development of oil fields are hydrodynamic testing of wells]. *Neftepromyslovoe delo*, 2006, no. 9, pp. 5-8.
28. Kul'pin L.G., Bocharov G.V. Sovremennye printsipy komp'iuternoi interpretatsii dannykh gidrodinamicheskikh issledovanii skvazhin [Modern principles of computer interpretation of well hydrodynamic data]. Neftianoe khoziaistvo, 2001, no. 10.
29. Bocharov V.V. Sozdanie i sovershenstvovanie metodov gidrodinamicheskogo izucheniia plasta i sostoianiia skvazhin v oslozhnennykh usloviiakh ekspluatatsii [Creation and improvement of methods for hydrodynamic study of the reservoir and the condition of wells in difficult operating conditions]. Abstract of Ph. D. thesis. Moscow: VNII, 1995, 20 p.
30. Ehlig Economides C.A., Hegeman P., Vik S. Guidelines simplify well test interpretation. Oil & Gas Journal, 1994, July, 18, pp. 33-40.
31. Hegeman P.S., Hallford D.L., Josef J.A. Well-test analysis with changing wellbore storage. SPE Form Eval 8 (03), 1993, Sept., pp. 201-207. DOI: 10.2118/21829-PA
32. Bourdet D. Well test analysis: the use of advanced interpretation models. Amsterdam, 2002, 426 p.
33. Vol'pin S.G. Sovremennye problemy gidrodinamicheskikh issledovanii skvazhin [Modern problems of hydrodynamic testing of wells]. Sostoianie i perspektivy nauchnykh i proizvodstvennykh rabot v OAO “RMNTK” “NEFTEOTDAChA”. Moscow: OAO “RMNTK” “NEFTEOTDAChA”, 2001, 170 p.
34. Shagiev R.G. Issledovanie skvazhin po KVD [Well testing using pressure build-up]. Moscow: Nauka, 1998, 304 p.
35. Horner D.R. Pressure build - up in wells. *Proc. Third World Petroleum Congress*. The Hague, 1951.
36. Earlaugher R.C.Jr., Kerch K.M. Analysis of short-time transient test data by type-curve matching. *Journal of Petroleum Technology*, 1974, vol. 26, pp. 793-800. DOI: 10.2118/4488-PA
37. Bourdet D. et al. A new set of type curves simplifies well test analysis. World oil. 1983. Vol. 196, iss. 6, pp. 95-106.
38. Thomas G.B. Analysis of pressure buildup data. *Petroleum Transactions of AIME*, 1953, vol. 198, pp. 126-128. DOI: 10.2118/953125-G
39. Muskat M. Use of Data on the Build up of Bottom - hole Pressures. Pressure Analysis Methods, 1967. AIMMPE, pp. 5-9.
40. Bourdet D., Ayoub J.A., Pirard Y.M. Use of pressure derivative in well-test interpretation. *SPE Formation Evaluation*, 1989, vol. 4, iss. 02, pp. 293–302. DOI: 10.2118/12777-PA
41. Miller C.C., Dyes A.B., Hutchinson C.A. The estimation from bottom-hole pressure Build-up characteristics. *Journal of Petroleum Technology*, 1950, vol. 2, no. 4, pp. 91-104. DOI: 10.2118/950091-G
42. Pollard P. Evaluation of acid treatments from pressure buildup analysis. *Petroleum Technology*, 1959, vol. 3, pp. 38-43. DOI: 10.2118/981-G
43. Savchik M.B., Ponomareva I.N. Otsenka sostoianiia priskvazhinnykh zon pri obrabotke nedovosstanovlennykh krivykh vosstanovleniia davleniia [Assessment borehole cavity conditions while processing unrepaired pressure transient technique]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2012, vol. 11, no. 2, pp. 77-82.
44. Mineev B.P. Opredelenie parametrov plasta po krivoi vosstanovleniia davleniia s uchetom gidrodinamicheskogo nesovershenstva skvazhin [Determination of reservoir parameters using the pressure recovery curve, taking into account the hydrodynamic imperfection of wells]. RNTS. VNIIOENG. *Promyslovoe delo*, 1976, no. 6, pp. 12-16.
45. Borisov Iu.P. Opredelenie parametrov plasta pri issledovanii skvazhin na neustanovivshikhsia rezhimakh s uchetom prodolzhaiushchegosia pritoka zhidkosti [Determination of formation parameters when studying wells in unsteady modes, taking into account the ongoing fluid influx]. Trudy instituta VNII, 1959, iss. 19, pp. 115-133.
46. Ponomareva I.N., Savchik M.B., Erofeev A.A. Usloviia primeneniia skin-faktora dlia otsenki sostoianiia priskvazhinnykh zon produktivnykh plastov [Conditions of skin factor use when estimating the state of the critical area of formation]. *Neftianoe khoziaistvo*, 2011, no. 7, pp. 114-115.
47. Hurst W. Esteblishment of the skin effect and its impediment to fluid flow into a well bore. The petroleum Engineer, 1953, vol. XXV, no. 11, pp. B6-B16.
48. Van Everdingen A.F. The Skin Effect and its Influence on the Productive Capacity of a Well. *Journal of Petroleum Technology*, 1953, vol. 5, iss. 06, pp. 171-176. DOI: 10.2118/203-G
49. Korn G., Korn T. Spravochnik po matematike dlia nauchnykh rabotnikov i inzhenerov [Handbook of Mathematics for Scientists and Engineers]. Moscow: Nauka, 1970.
50. Dziubenko A.I., Merson M.E., Nikonov A.N. Informatsionnyi sposob povysheniia effektivnosti metodov vozdeistviia na prizaboinuiu zonu plasta v deistvuiushchikh skvazhinakh [Increase in efficiency of methods of bottomhole formation zone treatment in active wells by information technique]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2017, no. 2, pp. 148-157. DOI: 10.15593/2224-9923/2017.2.5

Библиографический список

1. Мордвинов В.А., Пономарева И.Н., Войтенко М.А. Разработка усовершенствованной технологии проведения и обработки данных гидродинамических исследований с целью увеличения продуктивности и оптимизации режимов периодически работающих скважин. – Пермь: Перм. гос. техн. ун-т, 2004. – 170 с.
2. Разработка комплексной методики прогноза эффективности геолого-технических мероприятий на основе алгоритмов машинного обучения / А.А. Кочнев, Н.Д. Козырев, О.Е. Кочнева, С.В. Галкин // Георесурсы. – 2020. – № 22(3). – С. 79–86. DOI: 10.18599/grs.2020.3.79-86
3. Распопов А.В., Новокрещенных Д.В. Анализ результатов применения методов интенсификации на карбонатных коллекторах месторождений Пермского края // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2014. – Т. 13, № 10. – С. 73–82. DOI: 10.15593/2224-9923/2014.10.7
4. Юшков И.Р. Опыт применения методов повышения извлечения нефти на месторождениях Пермского края // Научные исследования и инновации. – 2010. – Т. 4, № 1. – С. 44–50.
5. Lake L.W. Short Course Manual, Enhanced Oil Recovery Fundamentals // Society of Petroleum Engineers. – 1985. – P. 449.
6. Анализ проведения геолого-технических мероприятий по увеличению продуктивности добывающих скважин на нефтяных месторождениях Пермского края / П.Ю. Илюшин, Р.М. Рахимзянов, Д.Ю. Соловьев, И.Ю. Колычев // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2015. – Т. 14, № 15. – С. 81–89. DOI: 10.15593/2224-9923/2015.15.9
7. Казаков А.А. Методика оценки эффективности геолого-технических мероприятий по кривым падения дебита нефти. // Нефтяное хозяйство. – 1999. – № 12. – С. 31–34.
8. Казаков А.А. Разработка единых методических подходов оценки эффективности геолого-технических мероприятий по повышению нефтеотдачи пластов и интенсификации добычи нефти. // Нефтяное хозяйство. – 2003. – № 4. – С. 26–29.
9. Поплыгин В.В., Белоглазова Е.А., Иванова А.С. Анализ результатов проведения кислотных обработок в сложных геолого-технологических условиях // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2014. – № 10. DOI: 10.15593/2224-9923/2014.10.8
10. Продуктивность скважин после кислотных гидроразрывов пласта на Гагаринском и Озерном месторождениях / В.А. Мордвинов, В.В. Поплыгин, Д.Д. Сидоренко, А.Р. Шаймарданов // Нефтяное хозяйство. – 2013. – № 4. – С. 44–45.
11. Effects of acid-rock reaction heat on fluid temperature profile in fracture during acid fracturing in carbonate reservoirs / Jianchun Guo, Huifeng Liu, Yuanqiang Zhu, Yuxuan Liu // Journal of Petroleum Science and Engineering. – 2014. – Vol. 122. – P. 31–37. DOI: 10.1016/j.petrol.2014.08.016
12. Modeling and simulation of wormhole formation during acidization of fractured carbonate rocks / Piyang Liu, Jun Yao, Gary Douglas Couples, Jingsheng Ma, Hai Sun // Journal of Petroleum Science and Engineering. – 2017. – Vol. 154. – P. 284–301. DOI: 10.1016/j.petrol.2017.04.040
13. Mehdi Ghommem Carbonate aciding: Modeling, analysis, and characterization of wormhole formation and propagation / Mehdi Ghommem, Weishu Zhao, S. Dyer, Xiangdong Qiu, Brady D. Mehdi Ghommem // Journal of Petroleum Science and Engineering. – 2015. – Vol. 131. – P. 18–33. DOI: 10.1016/j.petrol.2015.04.021
14. РД 39-0147001-742-92. Методика комплексной оценки качества вскрытия продуктивных пластов, заканчивания скважин и выбора рабочих жидкостей для повышения качества вскрытия пластов. – Краснодар: ВНИИКРнефть, 1992.
15. Исследование призабойной зоны пластов при интенсификации добычи нефти за рубежом // ВНИИОНГ. Серия: Нефтепромысловое дело. – М., 1985.
16. Амикс Дж., Басс Д., Уатинг Р. Физика нефтяного пласта. – М.: Гостопттехиздат, 1962. – 232 с.
17. Временная инструкция по гидродинамическим исследованиям пластов и скважин / В.Н. Васильевский, С.Г. Каменецкий-Федоров [и др.]. – М.: Миннефтепром; Всесоюз. науч. исслед. ин-т, 1963. – 68 с.
18. Степанов В.П., Кузмин В.М. Руководство по гидродинамическим исследованиям неоднородных пластов. – М.: ОНТИ ВНИИ, 1972. – 159 с.
19. Щелкачев В.Н. Влияние радиуса и гидродинамического несовершенства скважины на производительность // Азербайджанское нефтяное хозяйство. – 1950. – № 9. – С. 5–10.
20. Басович И.Б., Капцанов Б.С. Обработка результатов гидродинамических исследований скважин методом детерминированных моментов // Азерб. нефт. хоз-во. – 1987.
21. Бузинов С.Н., Умрихин И.Д. Исследование нефтяных и газовых скважин и пластов. – М. Недра, 1984.
22. Вольпин С.Г., Мясников Ю.А., Свалов А.В. Гидродинамические исследования низкопроницаемых коллекторов // Нефтяное хозяйство. – 2000. – № 12. – С. 8.
23. Дияшев Р.Н. Гидродинамические исследования скважин при контроле за разработкой нефтяных месторождений. – М.:ВНИИОЭНГ, 1979. – 75 с.
24. Каюмов М.Ш. Опыт использования результатов гидродинамических исследований для оптимизации работы добывающих скважин // Нефтепромысловое дело. – 2002. – № 5. – С. 28–32.
25. Токарев А.П., Пьянкова Е.М. Совершенствование методов интерпретации кривых восстановления уровня при исследовании скважин // Нефтяное хозяйство. – 2009. – № 3. – С. 56–58.
26. Закиров С.Н., Индрупский И.М., Закиров Э.С., Аникеев Д.П.: Новый подход к исследованию скважин и пластов // Нефтяное хозяйство. – 2002. – № 6. – С. 113–115.
27. Лысенко В.Д. Самыми экономически эффективными мероприятиями при разработке нефтяных месторождений являются гидродинамические исследования скважин // Нефтепромысловое дело. – 2006. – № 9. – С. 5–8.
28. Кульпин Л.Г., Бочаров Г.В. Современные принципы компьютерной интерпретации данных гидродинамических исследований скважин // Нефтяное хозяйство. – 2001. – № 10.
29. Бочаров В.В. Создание и совершенствование методов гидродинамического изучения пласта и состояния скважин в осложненных условиях эксплуатации: автореф. дис. … канд. техн. наук. – М.: ВНИИ, 1995. – 20 с.
30. Ehlig Economides C.A., Hegeman P., Vik S. Guidelines simplify well test interpretation // Oil & Gas Journal. – 1994. – July, 18. – P. 33–40.
31. Hegeman P.S., Hallford D.L., Josef J.A. Well-test analysis with changing wellbore storage // SPE Form Eval 8 (03). – 1993. – Sept. – P. 201–207. DOI: 10.2118/21829-PA
32. Bourdet D. Well test analysis: the use of advanced interpretation models. – Amsterdam, 2002. – 426 p.
33. Вольпин С.Г. Современные проблемы гидродинамических исследований скважин // Состояние и перспективы научных и производственных работ в ОАО «РМНТК» «НЕФТЕОТДАЧА». – М.: ОАО «РМНТК» «НЕФТЕОТДАЧА», 2001. – 170 с.
34. Шагиев Р.Г. Исследование скважин по КВД. – М.: Наука, 1998. – 304 с.
35. Horner D.R. Pressure build – up in wells // Proc. Third World Petroleum Congress. – The Hague, 1951.
36. Earlaugher R.C.Jr., Kerch K.M. Analysis of short-time transient test data by type-curve matching // Journal of Petroleum Technology. – 1974. – Vol. 26. – P. 793–800. DOI: 10.2118/4488-PA
37. A new set of type curves simplifies well test analysis / D. Bourdet [et al.] // World oil. – 1983. – Vol. 196, iss. 6. – P. 95–106.
38. Thomas G.B. Analysis of pressure buildup data // Petroleum Transactions of AIME. – 1953. – Vol. 198. – P. 126–128. DOI: 10.2118/953125-G
39. Muskat M. Use of Data on the Build up of Bottom - hole Pressures // Pressure Analysis Methods. – 1967. – AIMMPE. – P. 5–9.
40. Bourdet D., Ayoub J.A., Pirard Y.M. Use of pressure derivative in well-test interpretation // SPE Formation Evaluation. – 1989. – Vol. 4, iss. 02. – P. 293–302. DOI: 10.2118/12777-PA
41. Miller C.C., Dyes A.B., Hutchinson C.A. The estimation from bottom-hole pressure Build-up characteristics // Journal of Petroleum Technology. – 1950. – Vol. 2, no. 4. – P. 91–104. DOI: 10.2118/950091-G
42. Pollard P. Evaluation of acid treatments from pressure buildup analysis // Petroleum Technology. – 1959. – Vol. 3. – P. 38–43. DOI: 10.2118/981-G
43. Савчик М.Б., Пономарева И.Н. Оценка состояния прискважинных зон при обработке недовосстановленных кривых восстановления давления // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2012. – № 11 – С. 77–82.
44. Минеев Б.П. Определение параметров пласта по кривой восстановления давления с учетом гидродинамического несовершенства скважин // РНТС. ВНИИОЭНГ. Серия: Промысловое дело. – 1976. – № 6. – С. 12–16.
45. Борисов Ю.П. Определение параметров пласта при исследовании скважин на неустановившихся режимах с учетом продолжающегося притока жидкости // Тр. ин-та ВНИИ. – 1959. – Вып. 19. – С. 115–133.
46. Пономарева И.Н., Савчик М.Б., Ерофеев А.А. Условия применения скин-фактора для оценки состояния прискважинных зон продуктивных пластов // Нефтяное хозяйство. – 2011. – № 7. – С. 114–115.
47. Hurst W. Esteblishment of the skin effect and its impediment to fluid flow into a well bore // The petroleum Engineer. – 1953. – Vol. XXV, № 11. – P. B6–B16.
48. Van Everdingen A.F. The Skin Effect and its Influence on the Productive Capacity of a Well // Journal of Petroleum Technology. – 1953. – vol. 5, iss. 06. – P. 171–176. DOI: 10.2118/203-G
49. Корн Г., Корн Т. Справочник по математике для научных работников и инженеров: пер. с англ. – М.: Изд. «НАУКА», 1970.
50. Дзюбенко А.И., Мерсон М.Э., Никонов А.Н. Информационный способ повышения эффективности методов воздействия на призабойную зону пласта в действующих скважинах // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2017. – № 2 – С. 148–157. DOI: 10.15593/2224-9923/2017.2.5

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