UDC 622.276.6

Estimate of Radial Drilling Technology Efficiency for the Bashkir Operational Oilfields Objects of Perm Krai

Sergey V. GALKIN[1], **Alexander A. KOCHNEV**[2] ✉, **Vladimir I. ZOTIKOV**[1]
[1] *Perm National Research Polytechnic University, Perm, Russia*
[2] *Branch of LLC «LUKOIL-Engineering» «PermNIPIneft», Perm, Russia*

The radial drilling technology efficiency for carbonate bashkir deposits of Perm Krai is considered. The geological structure of a productive part of bashkir layer is characterized by high degree of heterogeneity that promotes while drilling radial channels involvement in development additional interlayers that earlier was not drained.

During the analysis the main geological process parameters affecting drilling technology efficiency were revealed. According to the dynamics of average daily oil production growth, palettes were built to forecast additional oil production as a result of radial drilling activities. Using the pallets, it is possible to predict the total additional oil production, well operating time with the effect of radial drilling and average daily oil production growth for each year.

It was found that hydrochloric acid treatments performed on wells prior to radial drilling significantly reduce the effectiveness of radial drilling technology. For such wells, the value of the correction is statistically substantiated, which reduces the predictive estimate of the increase in oil production.

A model was built to assess the increase in oil production in the first year after the event and an algorithm for calculating the total additional oil production was developed using linear discriminant analysis. For the resulting model, errors are calculated that are compared with the forecast efficiency of standard methods for oil-producing enterprises. This model shows a much more accurate correspondence of forecast results to actual technology application results.

The probability of the event high efficiency increases significantly with a more detailed approach to the selection of wells for radial drilling. According to the forecast methodology, the technology's efficiency was calculated and recommendations for its implementation for the wells of the Bashkir production objects were made in the interests of an oil-producing enterprise.

Key words: radial drilling; hydrochloric acid treatment; geological and technical operations; oil production rate; carbonate reservoir; discriminant analysis

How to cite this article: Galkin S.V., Kochnev A.A., Zotikov V.I. Estimate of Radial Drilling Technology Efficiency for the Bashkir Operational Oilfields Objects of Perm Krai. Journal of Mining Institute. 2019. Vol. 238, p. 410-414. DOI: 10.31897/PMI.2019.4.410

Introduction. Currently, in the structure of the production of geological and technical operations (GTO) of the Perm Krai, aimed at the secondary opening of formations, radial drilling takes a significant place (RD). With standard RD four radial channels are drilled in the interval of the reservoir with phasing of 90° and a length of up to 100 m. Drilling of radial shafts is supplemented by hydrochloric acid treatment (HAT) for carbonate deposits in order to intensify the influx.

The RD technology has been used at the production fund of wells in the Perm Krai since 2005, mainly for carbonate (549 GTO), much less often for terrigenous formations (41 GTO). On average, technology success in recent years has been estimated at 42 to 78 % [1]. Moreover, the efficiency of RD for carbonate reservoirs is much higher than for terrigenous. The average duration of the RB effect is 667 days for terrigenous and 818 days for carbonate objects, the average additional oil production is 3.5 thousand tons for terrigenous and 4.6 thousand tons for carbonate objects.

Currently, the share of carbonate deposits in the structure of residual recoverable reserves (RRR) of oil in the Perm Krai is 62 %, and this value increases every year due to their less intensive current production. The interest of oil producers to RD is due to the need to introduce relatively low-cost technologies for sites with low RRR. Therefore, RD technology is the most demanded in the structure of the GTO for carbonate production facilities of the Perm Krai. To date, 149 operations have been carried out using the RD method for the bashkir formation, which significantly exceeds the 49 acid hydraulic fracturing operations (AHFO) performed during the same period. The interest in RB technology is due to the fact that the number of wells with oil reserves sufficient to introduce more costly technologies (AHFO, etc.) is very limited today. According to the authors, RD technology is promising and can be widely used in conditions of carbonate reservoirs and other old oil and gas producing regions.

The analysis shows the need for a separate analysis of the RD efficiency of for various operational objects. The largest number of RD operations was carried out for deposits of Bashkir age, whose share is significant (23 %) in the current oil production of the Perm Krai. So the objective of this paper is to identify the geological and technological criteria for the RD efficiency for wells in the bashkir formation. Collectors of bashkir sediments are mainly represented by biomorphic-algal and foraminiferous pore-type limestone [11]. Productive formations have a high degree of heterogeneity that promotes while drilling radial channels involvement in development additional interlayers that earlier was not drained.

The papers [6, 7] summarize the experience of implementing RD technology in the Perm Krai. The RD in the conditions of the carbonate reservoir is more effective than the HAT and repeated perforation. However, at present time there is still uncertainty in the selection of candidate wells for the implementation of the technology. In this paper, the analysis of the RD efficiency was carried out according to the information on 01.01.2018, while 16 repeated operations were excluded from the analysis, the effectiveness of which is much lower. This is due to the fact that any previously conducted GTO take part of the remaining reserves of formations. As a result, the additional total oil production from the technology for the bashkir reservoir for the 133 examined wells varies in the range from 0 to 25 thousand tons with an average value of 4.8 thousand tons of oil per well.

The possibilities of geological and hydrodynamic modeling in forecast calculations of the RD efficiency have a number of significant limitations and uncertainties. The main problem is the complexity of a formalized assessment of the connectivity of the radial channel with the reservoir. In modern simulators (Tempest, Eclipse, etc.), when calculating RD technology, in addition to the permeability of the formation, the skin factor (S) and the coefficient of communication of the radial channels with the formation (φ) are mandatory to run the calculations. Moreover, the S values are not known for all wells, and a numerical estimate of the value of φ is always subjective. As a result, in practice, the only possible option remains to take in advance the value of the required fluid flow after the GTO, adjusting the indicators S (if it is unknown) and φ. Consequently, a single cell, characterized by subjective information, usually corresponds to a radial channel 100 m long in the model.

Development of a statistical model for evaluating the radial drilling technology efficiency. One of the effective tools for improving the quality of design decisions is the use of statistical methods, which can be successfully applied to predict the GTO efficiency, for example [3, 8, and 9]. According to the authors, precisely statistical methods can be used for summarizing field information that is applicable for evaluating the RD efficiency. Their goal is to evaluate the efficiency of RD technology implemented at oil wells for various geological and technological conditions.

At the first stage, according to the average daily oil increment for each year, a palette was built to forecast additional oil production. All wells are divided into seven classes according to the indicator of additional oil production. A line of daily average growth falling over the years has been constructed for each class.

Using the palette shown in Fig.1, it is possible to predict the average daily increase for each year, the effect time and the total additional oil production due to technology. For the practical use of the palette before the GTO, it is necessary to quantitatively assess the increase in oil production in the first year after RD (Δq_o), which will determine the further dynamics of production.

Initially, as a result of statistical analysis, it was established that previously conducted HAT on the wells (for the period from 1 to 15 years before the RD) reduces the potential increase in oil when applying the technology. So, for the bashkir reservoir, the average understatement Δq_o due to the previously conducted HAT was 1.3 tons/day (4.6 versus 5.9 tons/day) while maintaining the dynamics of production decline of more than 1 tons / day in all next years. That is why all wells with previously conducted HAT are excluded from the analysis. The forecast Δq_o for them should include

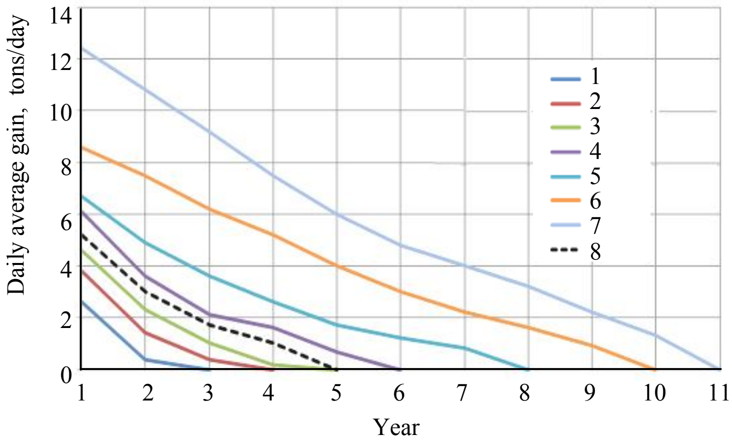

Fig.1. Daily average oil growth forecast palette from the application of RD technology for the Bashkir formation of Perm Krai [4]

1 – class 1 (additional production (AP) 50-500 tons); 2 – class 2 (AP 500-1000 tons); 3 – class 3 (AP 1000-2000 tons); 4 – class 4 (AP 2000-4000 tons); 5 – class 5 (AP 4000-8000 tons); 6 – class 6 (AP 8000-16000 tons); 7 – class 7 (AP 16000-32000 tons); 8 – forecast

a downward correction of 1.3 tons/day. Since such wells did not subsequently participate in the formation of the forecast model, in the future, after the introduction of a downward corrective correction, they can be considered as an examination sample. The training statistical sample resulted in 71 wells.

A linear discriminant analysis (LDA) was used to assess the complex effect of various geological and technological indicators on the increase in oil production in the first year after the operation. The methodology for the implementation of the LDA to solve a similar oil field problem is described in detail in the paper [2].

Taking into account the analysis of the results of [5, 10, 12], the following expanded set of parameters was considered: oil-saturated thickness h_o, м; sandiness coefficient K_{sand}, m/m; dissection coefficient K_{dis}, units; oil viscosity in reservoir conditions μ_o, mPa·s; hydroconductivity of the remote zone of the formation (RZF) ε_{RZF}, mkm^2·sm/(mPa·s); permeability coefficient RZF k_{RZF}, mkm^2; piezoconductivity χ, sm^2·s; reservoir pressure P_f, MPa; bottom hole pressure P_{bot}, MPa; saturation pressure P_{sat}, MPa; average thickness of a single oil-saturated interlayer h_{il}, m; well skin factor S; channel density ρ_{chan}, m/number of channels, oil production prior to the implementation of GTO q_{in}, tons/day.

When implementing LDA, a statistical sample is divided into wells with increments Δq_o of more and less than 7 tons/day according to the principle of the of RD technology efficiency. As a result of the LDA, the parameters that have showed the greatest significance in dividing the sample into two classes; are h_o, K_{sand}, K_{dis}, μ, χ, S, ρ_{chan}, q_{in}. Using these parameters the linear discriminant function (LDF) is constructed:

$$Z = 0.059q_{in} + 0.402h_o + 1.92K_{sand} + 0.141K_{dis} - 0.048\mu_o - 0.516\rho_{chan} + 0.000876\chi + 0.032S - 2.90,$$

if $R = 0.76$.

For the class with a more effective RD result ($\Delta q_o > 7$ tons/day), 75 % (21 out of 28 wells) were correctly classified, for the class with $\Delta q_o < 7$ tons/day, 96 % (44 out of 46 wells). It should also be noted that the +/– signs in the coefficients with LDF indices do not contradict their physical meaning. Thus, an increase in the thickness of the reservoir (h_o) and the share in the formation of reservoirs (K_{sand}) due to the large capacitive characteristics increase the estimate of the discriminant function (Z). Larger dissection (K_{dis}) corresponds to the growth of the first year (Δq_o), since the radial channel includes more new interlayers to drain. At low oil viscosity (μ_o) and high piezoconductivity of the formation (χ), the RD effect is higher due to greater oil mobility. At lower values of the channel density (ρ_{chan}), each radial channel has a large effective thickness (h_o), therefore, the increase is higher.

The physical meaning of the criterion Z in LDF is that with its growth, the probability $P(Z)$ of classifying an object as a more efficient GTO increases. The dependence $P(Z) = f(Z)$ is shown in Fig.2.

The table for the training sample contains comparative characteristics of the actual production growth of the first year in various ranges of the obtained probabilistic estimates $P(Z)$.

 DOI: 10.31897/PMI.2019.4.410

According to the table, the dependence of the growth of the first year on the value of $P(Z)$ is constructed, which is approximated by the following equation:

$$\Delta q_o = 30.7x^3 - 44.5x^2 + 22.8x + 2.84$$

(if $R = 0.98$), where x – value of $P(Z)$.

Estimation of the error of the forecast statistical model of oil production growth from RD. As a result, the predicted estimates Δq_o, as well as the errors in comparison with the actual growths, were calculated for the wells of the training sample. A comparative assessment of the obtained errors Δq_o of the proposed methodology (based on LDA) was also carried out with the growths that were predicted at oil producing enterprises when planning RD using hydrodynamic models. Figure 3 shows a comparison of the errors of the methods (LDA and standard) with the actual RD results for the wells of the training sample.

When using the LDA method, more than half of the objects fell into the error interval of less than 2 tons/day – 54 % of the wells, and in the error interval of more than 4 tons/day – only 11 % of the wells. The maximum errors in most cases underestimate the predicted effect of RD for wells with abnormally high production. Moreover, in all these cases, the wells are evaluated by the proposed methodology as the most promising for RD, which is important for the practical implementation of the methodology.

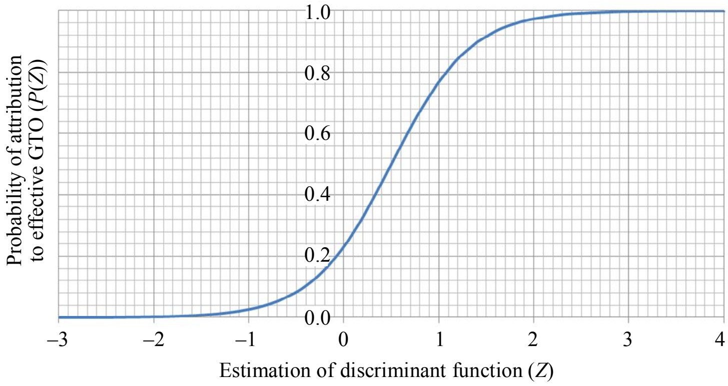

Fig.2. Probabilistic assessment of classifying an operation as effective in increasing oil production in the first year from the indicator Z

Probability distribution $P(Z)$ of wells from the training sample

Interval $P(Z)$	Number of the objects	Average actual growth, tons/day
< 0.001	6	1.7
0.001-0.01	9	3.7
0.01-0.1	14	4.7
0.1-0.2	7	5.3
0.2-0.4	8	6.0
0.4-0.8	7	7.5
0.8-0.9	3	8.9
0.9-0.95	7	9.5
0.95-1	10	11.6

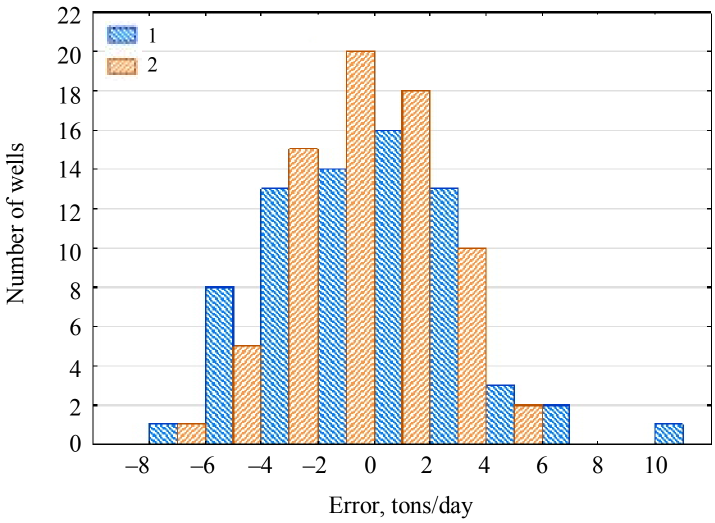

Fig.3. Distribution of the errors in the estimates of the average daily oil production growth in the first year after RB

1 – standard technique; 2 – LDA

As for the standard methodology, the results of the Δq_o similarity of the forecast to the actual results are noticeably worse. There are 42 % of the wells in the error interval of less than 2 tons/day. Errors of more than 4 tons/day are characterized by 23 % of wells, the discrepancy was more than 10 tons/day for one well (Fig.3).

A similar analysis was carried out for the wells of the test sample with previously conducted HAT, which were not involved in the construction of the forecast model. For such wells a correction of 1.3 tons/day was subtracted from Δq_o. As a result, the maximum discrepancy between the actual results and the predicted estimates of Δq_o (52 % of wells) was also in the error range of less than 2 tons/day. Only 8% of wells fell into the error interval of more than 4 tons/day.

When calculating the residuals Δq_o for the same wells which were the basis of the planned increments of the oil producing enterprise, 36 % of the wells fell into the intervals of less than 2 tons/day, 21 % of the wells were more than 4 tons/day.

Conclusion. The proposed statistical model for estimating Δq_o for the bashkir reservoir showed a high degree of correlation with actual data and allowed a significant increase in the accuracy of forecasting RD technology efficiency in comparison with the standard approach.

A more detailed selection of candidate wells is required to increase the operation efficiency, taking into account the complex of geological and technological parameters, and not just the technical requirements of the wells. According to the forecast methodology, in the interests of the oil-producing enterprise, RD technology efficiency calculations were carried out and authors have made recommendations for the introduction of technology for wells that showed the greatest potential for oil production growth.

REFERENCES

1. Ilyushin P.Yu., Rakhimzyanov R.M., Solov'ev D.Yu., Kolychev I.Yu. Analysis of geological and technical measures to increase the productivity of production wells in oil fields of the Perm Krai. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiya. Neftegazovoe i gornoe delo*. 2015. Vol. 14. N 15, p. 81-89 (in Russian).

2. Chumakov G.N., Zotikov V.I., Kolychev I.Yu., Galkin S.V. Efficiency analysis of the use of cyclic fluid injection in fields with various geological and technological conditions. *Neftyanoe khozyaistvo*. 2014. N 9, p. 96-99 (in Russian).

3. Koltyrin A.N. Improving the efficiency of fracturing technology on a carbonate type reservoir. *Neftepromyslovoe delo*. 2016. N 10, p. 29-32 (in Russian).

4. Kochnev A.A., Zotikov V.I., Galkin S.V. Analysis of the influence of geological and technological indicators on the effectiveness of radial drilling technology by the example of operational facilities in the Perm Krai. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov*. 2018. Vol. 329. N 12, p. 20-29 (in Russian).

5. Mukhametshin V.V. Elimination of uncertainties in solving problems of impact on the bottom-hole zone of wells. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov*. 2017. Vol. 328. N 7, p. 40 (in Russian).

6. Novokreshchennykh D.V., Raspopov A.V. Prospects for the development of radial drilling technologies in the Perm Krai fields. *Neftyanoe khozyaistvo*. 2014. N 3, p. 54-57 (in Russian).

7. Raspopov A.V., Novokreshchennykh D.V. Analysis of the results of the application of intensification methods on carbonate reservoirs of Perm Krai deposits. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiya. Neftegazovoe i gornoe delo*. 2014. Vol. 13. N 10, p. 73-82 (in Russian).

8. Repina V.A., Galkin V.I., Galkin S.V. The use of integrated accounting of petrophysical characteristics in the adaptation of geological and hydrodynamic models (for example, the Visean deposits of the Gondyrevsky oil field). *Zapiski Gornogo Instituta*. 2018. Vol. 231, p. 268-274. DOI: 10.25515/PMI.2018.3.268 (in Russian).

9. Rogachev M.K., Mukhametshin V.V. Monitoring and regulation of the process of hydrochloric acid impact on the bottom-hole zone of wells according to geological and field data. *Zapiski Gornogo Instituta*. 2018. Vol. 231, p. 275-280. DOI: 10.25515/RMI.2018.3.275 (in Russian).

10. Elliott S. Coiled-tubing method drills radial laterals to improve oil production from a depleted reservoir. *World Oil*. 2011. N 10. p. 57-64.

11. Efimov A.A., Galkin S.V., Savitckii Ia.V., Galkin V.I. Estimation of heterogeneity of oil & gas field carbonate reservoirs by means of computer simulation of core *x*-ray tomography data. *Ecology. Environment and Conservation*. 2015. Vol. 21. p. 79-85.

12. Dickinson W., Dykstra H., Nees J.M., Dickinson E. The Ultrashort Radius Radial System Applied to Thermal Recovery of Heavy Oil. *Society of Petroleum Engineers*. 1992. N 24087, p. 56-59. SPE-24087-MS. DOI: 10.2118/24087-MS

Authors: **Sergey V. Galkin,** *Doctor of Geological and Mineralogical Sciences*, *Professor*, *doc_galkin@mail.ru* (*Perm National Research Polytechnic University, Perm, Russia*), **Alexander A. Kochnev,** *Engineer*, *sashakoch93@gmail.com* (*Branch of LLC «LUKOIL-Engineering» «PermNIPIneft», Perm, Russia*), **Vladimir I. Zotikov,** *Senior Lecturer*, *vladimirzotikov@yandex.ru* (*Perm National Research Polytechnic University, Perm, Russia*).

The paper was received on 21 December, 2018.
The paper was accepted for publication on 7 February, 2019.