



UDC 622.276.66(470.1)

Article / Статья

© PNRPU / ПНИПУ, 2020

WAYS OF IMPROVING THE FORMATION HYDRAULIC FRACTURING EFFECTIVENESS IN CARBONATE DEPOSITS OF FIELDS OF THE REPUBLIC OF KOMI AND NENETS AUTONOMOUS OKRUG

Dmitrii V. Novokreshchennykh, Aleksei V. Raspopov

PermNIPIneft branch of LUKOIL-Engineering LLC in Perm (3a Permskaya st., Perm, 614015, Russian Federation)

НАПРАВЛЕНИЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ ГИДРОРАЗРЫВА ПЛАСТА В КАРБОНАТНЫХ ОТЛОЖЕНИЯХ МЕСТОРОЖДЕНИЙ РЕСПУБЛИКИ КОМИ И НЕНЕЦКОГО АВТОНОМНОГО ОКРУГА

Д.В. Новокрещенных, А.В. Распов

Филиал ООО «ЛУКОЙЛ-Инжиниринг» «ПермНИПИнефть» в г. Перми (614015, Россия, г. Пермь, ул. Пермская, 3а)

Received / Получена: 17.02.2020. Accepted / Принята: 15.04.2020. Published / Опубликована: 15.06.2020

Key words:

Carbonate reservoir, oil production stimulation methods, formation hydraulic fracturing, technology optimization, increase of the formation hydraulic fracturing technological effectiveness, increase of fracture conductivity in formation hydraulic fracturing, horizontal and vertical sweep increase, reduction of uncontrolled leakage of fracturing fluid, fracture height reduction.

The study presents an overview of the formation hydraulic fracturing application in carbonate deposits of fields of the Republic of Komi and Nenets Autonomous Okrug. The formation hydraulic fracturing technology has become widely used in carbonate reservoirs since 2012, with over three hundred well jobs performed. A significant share of residual recoverable reserves in carbonate deposits needs to be withdrawn; production rates need to be increased, inter alia, by way of the formation hydraulic fracturing. In the conditions of gradual deterioration of porosity and permeability of candidate wells, maintaining a steady level of technological effectiveness of hydraulic fracturing is ensured by implementing new technologies and optimizing standard processes. The hydraulic fracturing implementation issues are inextricably connected to the main issues of oilfield developments and specific structural features of carbonate reservoirs. Taking into account the specific structural features of carbonate reservoirs and existing development issues, the main objectives of the formation hydraulic fracturing have been determined: fracture conductivity increase; horizontal and vertical sweep increase; reduction of uncontrolled leakage of fracturing fluid; reduction of fracture height in conditions of adjacent water- and gas-saturated interbeds.

Presently, a number of technologies has been successfully adapted and is used at the Republic of Komi and Nenets Autonomous Okrug sites. Due to the implementation of the integral approach to selection of the hydraulic fracturing technology modifications, taking into account the existing oilfield development issues and structural peculiarities of carbonate reservoirs, the reliable effectiveness of the method has been ensured in the conditions of deteriorating candidate wells; the technology application range has been extended. The study suggests expanding the range of the existing laboratory analyses to include such aspects as determination of stress intensity factor – fracture resistance and Biot's poroelastic parameter, study of leakage rate dynamics in regard to various fracturing fluids, depending on the reservoir properties of core samples at given gradients, determination of dependence of proppants dynamic transfer on rheological properties of fracturing fluids and their filtration rates for various degrees of fracture model opening.

Ключевые слова:

карбонатный коллектор, методы интенсификации добычи нефти, гидроразрыв пласта, оптимизация технологии, увеличение технологической эффективности гидроразрыва пласта, увеличение проводимости трещины гидроразрыва пласта, увеличение охвата по площади и разрезу, сокращение неконтролируемых утечек жидкости разрыва, сокращение высоты трещины.

Рассматривается опыт проведения гидроразрыва пласта в карбонатных отложениях месторождений Республики Коми и Ненецкого автономного округа. Массовое применение технологии гидроразрыва пласта на карбонатных коллекторах началось с 2012 г., выполнено более трехсот скважино-операций. Значительная доля остаточных извлекаемых запасов в карбонатных отложениях предопределяет необходимость их вовлечения и увеличения темпов выработки, в том числе за счет применения гидроразрыва пласта. В условиях постепенного ухудшения фильтрационно-емкостных свойств скважин-кандидатов поддержание стабильного уровня технологической эффективности гидроразрыва пласта обеспечивается за счет внедрения новых и оптимизации стандартных технологий. Проблемы реализации гидроразрыва пласта тесно связаны с основными вопросами разработки месторождений и особенностями строения карбонатных коллекторов. С учетом особенностей строения карбонатных коллекторов и существующих проблем разработки определены основные задачи при реализации гидроразрыва пласта: увеличение проводимости трещин; увеличение охвата по площади и разрезу; сокращение неконтролируемых утечек жидкости разрыва; сокращение высоты трещины в условиях близлежащих водо- и газонасыщенных пропластков.

На текущий момент ряд технологий успешно адаптирован и применяется на объектах месторождений Республики Коми и Ненецкого автономного округа. За счет реализации комплексного подхода при подборе модификаций технологии гидроразрыва пласта, учитывающего существующие проблемы разработки месторождений и особенности строения карбонатных объектов, обеспечено поддержание стабильной эффективности метода в условиях ухудшающейся структуры фонда скважин-кандидатов, а также расширение области применения технологии. Предложены направления расширения спектра выполняемых лабораторных исследований: определение коэффициента интенсивности напряжений – трещиностойкости и пороупругого параметра Био, исследование динамики интенсивности утечек различных жидкостей разрыва в зависимости от коллекторских свойств образцов керн при заданных перепадах, определение зависимости динамического переноса пропантов от реологических свойств жидкостей разрыва и скоростей их фильтрации для различных раскрытостей модели трещины разрыва.

Dmitrii V. Novokreshchennykh (Scopus ID 55531158400) – Lead Engineer of OPIGRP (tel: +007 342 233 63 91, e-mail: Dmitriy.Novokreschennykh@pnn.lukoil.com). The contact person for correspondence.

Aleksei V. Raspopov (Scopus ID 30267829600) – PhD in Engineering, Deputy Director of the Branch for Scientific Work in the Area of Field Development (tel.: +007 342 219 82 92, e-mail: aleksej.raspov@pnn.lukoil.com).

Новокрещенных Дмитрий Вячеславович – ведущий инженер отдела планирования и сопровождения гидроразрыва пластов (тел.: +007 342 233 63 91, e-mail: Dmitriy.Novokreschennykh@pnn.lukoil.com). Контактное лицо для переписки.

Распов Алексей Владимирович – кандидат технических наук, заместитель директора филиала по научной работе в области разработки месторождений (тел.: +007 342 219 82 92, e-mail: aleksej.raspov@pnn.lukoil.com).

Introduction

The major part (more than 60 %) of residual recoverable reserves in the Republic of Komi and Nenets Autonomous Okrug (NAO) is concentrated in carbonate reservoirs. Therefore, the effective recovery of the reserves from carbonate reservoirs is highly relevant today.

Productive deposits with carbonate-type reservoirs are associated with Silurian, Lower Devonian, Upper Devonian-Tournasian, Serpukhovian, Middle- and Upper Carboniferous, Lower Permian deposits. The production facilities have widely ranging geological and physical parameters (Table).

A significant share of the residual recoverable reserves in carbonate deposits needs to be withdrawn; production rates need to be increased, inter alia, by way of the formation hydraulic fracturing (FHF). In the fields of the Republic of Komi and NAO, the formation hydraulic fracturing technology has been widely used in the carbonate reservoirs since 2012, with over three hundred well jobs performed. Fig. 1 shows the dynamics of the main geological and physical parameters of the formations covered with FHF [1].

Under gradual deteriorations of porosity and permeability of candidate wells, maintaining a steady level of technological effectiveness of hydraulic fracturing is ensured by means of new technologies and optimized standard processes.

Over the period from 2012 to 2018, eight FHF modifications were tested at carbonate production sites of the Republic of Komi and NAO. Out of this number, four technologies have been implemented in scope of pilot production works (PPW), and two technologies have been accepted for commercial use. Besides, three technologies have been tested outside PPW.

FHF implementation issues are inextricably connected to the main issues of oilfield developments and specific structural features of carbonate reservoirs. For instance, reservoirs with non-draining areas due to low reservoir properties and proximity of gas- or water-saturated

interbeds are exposed to risks of FHF fracture vertical rupture due to poor filtration of the fracturing fluid and low contrast of stresses even at minor treatment volumes. In case of inferior energy states of the deposits, the risks are associated with high leakages of the fracturing fluid, incomplete vertical sweep and low conductivity of the created fractures [2].

Taking into account the specific structural features of the carbonate reservoirs and existing oilfield development issues, the main objectives of the formation hydraulic fracturing have been determined:

- 1) fracture conductivity increase
- 2) horizontal and vertical sweep increase
- 3) reduction of uncontrolled leakages of the fracturing fluid
- 4) reduction of fracture height in conditions of adjacent water- and gas-saturated interbeds.

Presently, a number of technologies has been successfully adapted and used at the Republic of Komi and NAO sites. Further discussed are examples of FHF implementation to achieve the aforementioned objectives.

Fracture Conductivity Increase

At the first stage of the FHF technology implementation in the carbonate reservoirs, the acid FHF (AFHF) technology was extensively used, with a gelled cross-linked acid as a diverter. During further replication of the FHF technology at the sites with high formation compartmentalization, the proppant FHF technology was tested. Notably, according to the results of laboratory studies, the value of proppant embedment into the carbonate rock in the conductivity cells appeared to be comparable to terrigenous-type reservoirs, and thus the possibility to use proppant to stabilize fractures in the carbonate deposits was confirmed.

The previously implemented AFHF technologies at the carbonate sites often had low effectiveness: over the first months of the well operation, the oil output increment tended to sharply decrease. Probable causes of AFHF low

Geological and physical parameter variation ranges in oil-gas plays with the carbonate-type reservoir

Oil-gas play	Depth of occurrence, m	Net thickness, m	Porosity, %	Oil viscosity, mPa·s	Formation temperature, °C	Formation pressure, MPa	Permeability, $\mu\text{m}^2 \cdot 10^{-3}$
Republic of Komi, Nenets AO							
Silurian	3310–4160	2.39–15.1	8.3–18.3	0.5–1.8	89–97	34.5–62.8	11–193
Lower Devonian	3340–4110	1.0–26.5	5.5–16.0	0.7–6.9	61–92.8	32.5–64.6	1.2–19.3
Middle- and Upper Frasnian, Famennian, Tournasian	885–4060	0.4–51.1	4.4–19.0	0.2–152.6	19–98	8.5–42.1	0.7–320
Serpukhovian, Middle- and Upper Carboniferous, Lower Permian	860–3360	1.6–28.4	8.5–26.4	0.5–710	17–73	9.5–34.3	0.5–402

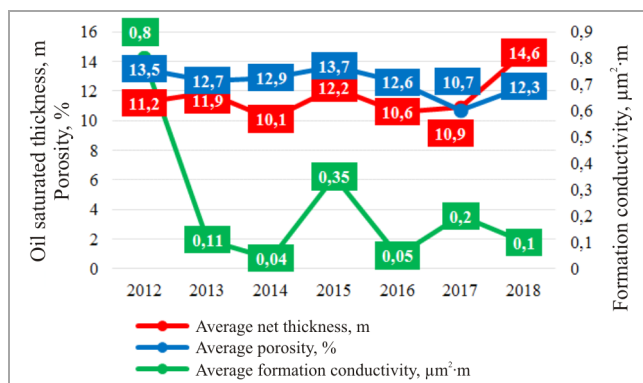


Fig. 1. Dynamics of the main geological and physical parameters of formations in the Republic of Komi and Nenets Autonomous Okrug covered by FHF

effectiveness were selective etching with the acid of the most permeable interbeds and, consequently, the incomplete vertical sweep; the reservoir clogging with gelled acid destruction products. The proppant FHF helped to reduce the oil output increment reduction rates. By now, more than one hundred proppant FHF were performed at 25 sites with the carbonate-type reservoir. Additionally, the enzymatic destructor is used to increase conductivity of fractures in the carbonate formations; the specific consumption of proppant is gradually increased, and the polymer concentration in the fracturing fluid is reduced.

The Horizontal and Vertical Sweep Increase, The Uncontrolled Leakage Reduction of the Fracturing Fluid

Carbonate formations of Silurian, Lower Devonian and Upper Devonian-Tournasian oil-gas plays of the Republic of Komi and NAO have low porosity and permeability (P&P) (permeability of some of the wells is less than $0.001 \mu\text{m}^2$), high compartmentalization in combination with high P&P vertical contrast across the section, significant thickness (more than 30 m), and substantial depth of occurrence (up to 4200 m). During FHF, the following parameters had high values: fracture closing gradient was more than 0.20 atm/m, the fracturing fluid effectiveness was more than 70 %, net pressure was up to 300 atm, and the presence of the pressure-dependent leakage (pdl).

The implemented acid FHF technologies appeared to have low effectiveness due to the insignificant vertical sweep and presence of residual viscosity of the applied gelled acid compound. The standard proppant FHF technology also appeared to have low effectiveness; the planned geometry of the FHF fracture was not achieved due to premature injection stoppages. The complications were caused by use of highly viscous fracturing fluids (absence of their filtration to

the formation) and high rate of the concentration increase of proppant. The injected proppant weight in the standard approach did not exceed 20 t.

Taking into account the learnings from previously performed jobs, in 2017, for the first time in the oilfields of the Republic of Komi and NAO, high volume proppant FHF technology was implemented, where proppant weight was increased to 40 t. Additionally, the following technological solutions were implemented: in order to reduce the formation fluid leakage, the combination buffer was used (the linear+cross-linked gel, proppant plug pack 100 mesh), the standard size reduction (the major part of proppant was 30/50, the minor part was 20/40) and proppant concentration (a reduction from 900 to 350 kg/m^3), the injection rate increase (from 2.5 to $4.0 \text{ m}^3/\text{min}$). The FHF implementation according to the optimized technology resulted in a significant increase of the producing formation thickness by 6.9 times and the technological effectiveness increase by 2.5 times, compared to standard proppant and acid FHF technologies [3].

Fracture Height Reduction

In one of the previous studies, carbonate deposits of the Artinskian and Kungurian stages in one of the fields of the Republic of Komi responded with low effectiveness to standard acid and proppant FHF treatments due to the absence of the vertical stress contrast and bottom water eruption. In order to reduce the fracture height, the FHF technological parameters were optimized. We had the laboratory analysis of the fracturing fluid, which resulted in reduction of the polymer fraction in the fracturing fluid from 3.6 to 2.6 kg/m^3 and in decrease of the injection rate from 3.5 to $2.6 \text{ m}^3/\text{min}$. To improve fracture conductivity, the maximum proppant concentration was increased from 800 to 1000 kg/m^3 , the combination buffer was used at the main FHF, the enzymatic destructor was used. The works made it possible to reduce the wellbore fluid watercut on average by 6.1 %, and increase the technological effectiveness by 1.8 times, compared to the standard proppant FHF. The technology comprehensive implementation at 25 wells resulted in an increase of the overall oil recovery rate from the deposit by 9.4 % in 2018.

Due to the implementation of the integral approach to selecting the hydraulic fracturing technology modifications, taking into account the existing oilfield development issues and structural peculiarities of the carbonate reservoirs, reliable effectiveness of the method has been ensured in the conditions of the deteriorating candidate wells; the technology application range has been extended (fig. 2).

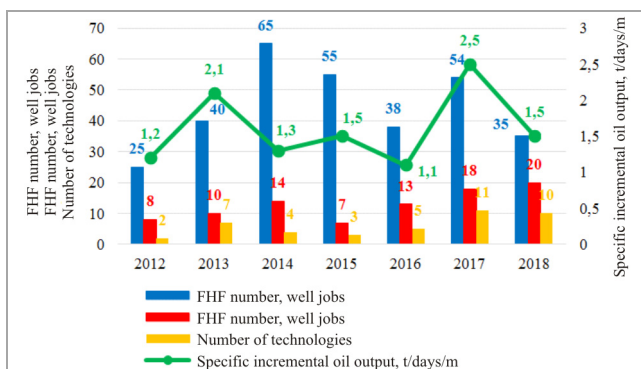


Fig. 2. Dynamics in the number of performed FHF works, the number of engaged sites, the number of the FHF technologies and specific incremental oil output after the FHF implementation in the oilfields of the Republic of Komi and Nenets AO from 2012 to 2018

In order to improve the FHF technology effectiveness in the carbonate reservoirs, more work has to be done in order to implement effective modifications of the method in scope of the aforementioned aspects. Another topical issue is increasing the prediction reliability pertaining to the fracture vertical and horizontal propagation using geomechanical modeling, which would take into account the stress state dynamics of a strata in the course of oilfield development.

Expanding the Range of the Performed Laboratory Analyses

To increase effectiveness of FHF, it is suggested to expand the range of the performed laboratory analyses. First of all it is advisable to study the stress intensity factor, i.e. fracture resistance and Biot's poroelastic parameter (stress relaxation factor) required to specify the stress profile and FHF design modeling. It is also recommended to study the leakage rate dynamics in regard to various fracturing fluids, depending on the reservoir properties of core samples at given pressure gradients, to provide a rationale for fracturing fluid viscosity values required to ensure filtration in various reservoir permeability conditions. Finally, it is reasonable to determine the dependence of proppants dynamic transfer on rheological properties of the fracturing fluids and their filtration rates for various degrees of the fracture model opening, to determine the limit values of the fracturing fluid viscosity and injection rate required to transfer the necessary proppant concentration to the fracture.

Conclusion

The study made it possible to conclude that the reservoir-focused selection of the FHF technology parameters for specific geological and physical formation

conditions helps to create fractures with required geometries, providing for the cost-effective recovery of reserves associated with low permeability carbonate-type reservoirs in the Republic of Komi and NAO. As part of this work, we have established the main technology improvement objectives, taking into account the specific structural features of the carbonate reservoirs and existing development issues. It is advisable to perform continuous optimizations of the studied technology in order to ensure effectiveness of the proposed method.

References

1. Voevodkin V.L., Aleroev A.A., Baldina T.R., Raspopov A.V., Kazantsev A.S., Kondrat'ev S.A. Razvitiye tekhnologii gidravlicheskogo razryva plasta na mestorozhdeniiakh Permskogo kraia [The development of hydraulic fracturing technologies in the Perm region]. Moscow: Neftianoe khoziaistvo, 2018, 108 p.
2. Kondrat'ev S.A., Zhukovskii A.A., Kochneva T.S., Malysheva V.L. Opyt provedeniia proppantnogo gidrorazryva plasta v karbonatnykh kollektorakh mestorozhdenii Permskogo kraia [Some experience of the formation proppant fracture in carbonate reservoirs of Perm region deposits]. Moscow: VNIOENG, 2016, 68 p.
3. Aleroev A.A., Kondrat'ev S.A., Sharafiev R.R., Novokreshchennykh D.V., Zhigalov V.A. Provedenie proppantnykh gidrorazryvov nizkopronitsaemykh plastov na neftianykh mestorozhdeniiakh Nenetskogo avtonomnogo okruga [Performance of proppant hydraulic fracturing in low-permeability oil reservoirs of the Nenets autonomous district]. Moscow: Neftianoe khoziaistvo, 2017, 108 p.
4. Bakirov E.A., Ermolkin V.I., Larin V.I. Geologiya nefi i gaza [Geology of oil and gas]. Moscow: Nedra, 1980, 240 p.
5. Gimatudinov Sh.K. Ekspluatatsiia i tekhnologiiia razrabotki neftianykh i gazovykh mestorozhdenii [Operation and technology for the development of oil and gas fields]. Moscow: Nedra, 1978, 357 p.
6. Barenblatt G.I., Engov V.M., Ryzhin V.M. Teoriia nestatsionarnoi fil'tratsii zhidkosti i gaza [Theory of unsteady fluid and gas filtration]. Moscow: Nedra, 1972.
7. Zheltov Iu.P., Khristianovich S.A. O gidravlicheskom razryve neftenosnogo plasta [About hydraulic fracturing of oil reservoir]. *Izvestiia AN SSSR. OTN*, 1955, no. 5, pp. 3-41.
8. Zheltov Iu.P. Gidravlicheski razryv plasta [Hydraulic fracturing]. Moscow: Gostoptekhizdat, 1957, 98 p.
9. Zheltov Iu.P. Deformatsiia gornykh porod [Rock deformation]. Moscow: Nedra, 1966, 198 p.
10. Zheltov Iu.P. Razrabotka neftianykh mestorozhdenii [Oil field development]. Moscow: Nedra, 1986, 332 p.
11. Economides M.J., Nolte K.G. Rezervoir stimulation. *New Jersey. Eglewood cliffs 01632*, 1989, 430 p.

12. Ekonomidis M., Olin R., Val'ko P. Unifitsirovannyi dizain gidrorazryva plasta: ot teorii k praktike [Unified fracturing design: from theory to practice]. Moscow – Izhevsk: Institut komp'yuternykh issledovaniy, 2007, 236 p.
13. Ivanov S.I. Intensifikatsiia pritoka nefti i gaza k skvazhinam [Intensification of oil and gas inflow to wells]. Moscow: Nedra – Biznessentr, 2006, 565 p.
14. Clark J.B. Hydraulic process for increasing productivity of wells. *Trans. AIME*, 1949, vol. 186, pp. 1-8.
15. Kanevskaia R.D. Zarubezhnyi i otechestvennyi opyt primeneniia gidrorazryva plasta [Foreign and domestic experience in the use of hydraulic fracturing]. Moscow: VNIIOENG, 1998, 40 p.
16. Charnyi I.A. Podzemnaia gidrogazodinamika [Underground hydrodynamics]. Moscow: Gostoptekhizdat, 1963, 346 p.
17. Zheltov Iu.P. Mekhanika neftegazonosnogo plasta [Oil and gas reservoir mechanics]. Moscow: Nedra, 1975, 207 p.
18. Khellan K. Vvedenie v mekhaniku razrusheniia [Introduction to fracture mechanics]. Moscow: Mir, 1998, 364 p.
19. Maxwell S.C., Urbancic T.I. The role of passive microseismic monitoring in the instrumented oil field. *The Leading Edge*, 2001, no. 6, pp. 636-639.
20. Urbancic T.I., Maxwell S.C., Steinsberger N., Zinno R.J. Microseismic imaging of hydraulic fracture complexity in a naturally fractured reservoir. *EAGE 64 Conference & Exhibition*. Florence, 2002. 43 p.
21. Landau L.D., Livshits E.M. Teoreticheskaia fizika. Tom VII. Teoriia uprugosti [Theoretical physics. Volume VII. Elasticity theory]. Moscow: Nauka, 1987, 248 p.
22. Telkov A.P., Gracheva N.S., Kashirina K.O. Obrazovanie treshchin v produktivnom plaste pri gidravlicheskom razryve [The formation of cracks in the reservoir during hydraulic fracturing]. *Gazovaia promyshlennost'*, 2008, no. 3, pp. 17-20.
23. Chemysheva T.L., Timashev G.V., Mishchenko A.Iu., Strogii A.Ia. Intensifikatsiia dobychi nefti i gaza metodom razryva plasta [Intensification of oil and gas production by fracturing]. Moscow: VNIIGazprom, 1987, 43 p.
24. Kobranova V.N. Fizicheskie svoistva gornykh porod [Physical properties of rocks]. Moscow: Gostoptekhizdat, 1962.
25. Lewis L. Laei. Dynamic rock mechanics testing for optimized fracture design. *SPE 38716*, 1997.
26. Shumilov V.A., Shalinov V.P., Azamatov V.V. Issledovanie prizaboinoi zony plastov pri intensifikatsii dobychi nefti i gaza za rubezhom [Investigation of the bottom-hole formation zone during the intensification of oil and gas production abroad]. *Obz. inform. Neftepromyslovoe delo*. Moscow: VNIIOENG, 1985, 33 p.
27. Shirgazin R.G., Isiangulova R.Kh., Zalevskii O.A., Lysenko V.N., Zemtsov Iu.V. Modelirovanie GRP po eksperimental'nym zavisimostiam geomekhanicheskikh kharakteristik kollektora [Hydraulic fracturing modeling by experimental dependences of reservoir biomechanical characteristics]. *Oil Gas conference*, 2008, no. 6, pp. 41-43.
28. John L., Gidley. Recent advances in hydraulic fracturing. Monograph. Henry L. Doherty Memorial Fund of AIME Society of Petroleum Engineers Richardson. TX. U.S.A, 1989.
29. Aleksandrov S.I., Mishin V.A., Burov D.I. Mikroiseismicheskii monitoring gidrorazryva plasta: uspekhi i problemy [Microseismic monitoring of hydraulic fracturing: successes and challenges]. *Tekhnologii dobychi i ispol'zovaniia uglevodorodov*, 2014, no. 2, pp. 39-43.
30. Baikin A.N. Dinamika treshchiny gidrorazryva plasta v neodnorodnoi porouprugoi srede [The dynamics of hydraulic fracturing in an inhomogeneous porous-elastic medium]. Ph. D. Thesis. Novosibirsk: Novosibirskii natsional'nyi issledovatel'skii gosudarstvennyi universitet, 2016.
31. Valeev A.S., Dulkarnaev M.R., Salimov F.S., Bukharov A.V., Kotenev A.V. Povyshenie effektivnosti gidrorazryva v usloviakh vysokoi obvodnenennosti plasta BV-8 Povkhovskogo mestorozhdeniia [Improving efficiency of hydraulic fracturing under high watercut reservoir conditions of bv-8 formation, povkhovskoe field]. *Neftegazovoe delo*, 2014, no. 6, pp. 154-174.
32. Barker B.J., Ramey H.J.Jr. Transient Flow to Finite Conductivity Vertical Fractures. *SPE 7489*, 1978.
33. Economides M.J., Nolte K.G. Reservoir Stimulation. *Schlumberger Educational Services*. Houston, Texas, 1987, pp. 11-3.
34. Raghavan R., Hadinoto Nico. Analysis of Pressure Data for Fractured Wells: The Constant- Pressure Outer Boundary. *SPEJ*, 1978, April, pp. 139-149.
35. Tinsley J.M., Williams J.R., Tiner R.L., Malone W.T. Vertical Fracture Height—Its Effect on Steady State Production Increase. *SPE 1900. Journal of Petroleum Technology*, 1969, vol. 21, pp. 633-638.
36. Weijers L. The Near-Wellbore Geometry of Hydraulic Fractures Initiated from Horizontal and Deviated Wells. Delft. Netherlands, Delft University Press, 1995.
37. Bredi B., Elvel Dzh., Mak M., Moralen X., Nolte K. Gidrorazryv plasta. Sovremennye dostizheniia v oblasti proektirovaniia obrabotki skvazhin [Hydraulic fracturing. Modern advances in the design of well treatment]. *Oilfield Review*, October, 1992.
38. Davlenie razryva kak tekhnologicheskii faktor, ogranichivaiushchii repressiiu na plast [Burst pressure as a technological factor limiting repression on the formation]. *Trudy SibNIINP. Voprosy geologii i razrabotki mestorozhdenii Zapadnoi Sibiri*. Tiumen', 1985, pp. 86-94.
39. Zankiev M.Ia. Klassifikatsiia i diagnostirovanie effektivnosti tekhnologii gidravlicheskogo razryva plastov v usloviakh OAO "Slavneft'-Megionneftegaz" [Classification and diagnosis of the effectiveness of hydraulic fracturing technology in the conditions of OAO Slavneft'-Megion-

neftegaz”]. Abstract Ph. D. thesis. Tiumen': Tiumenskii gosudarstvennyi neftegazovyi universitet, 1998, 24 p.

40. Kuramshin P.M., Ivanov S.V., Kuz'michev A.P. Effektivnost' provedeniia gidrorazryvov plasta na mestorozhdeniakh Noiabr'skogo raiona [The effectiveness of hydraulic fracturing in the fields of the Noyabrsky district]. *Neftianoe khoziaistvo*, 1997, no. 12, pp. 58-64.

41. Loginov B.G., Blazhevich V.A. Gidravlicheskiy razryv plastov [Hydraulic fracturing]. Moscow: Nedra, 1966, 148 p.

42. Malyshev G.A., Malyshev A.G., Zhurba V.N., Sal'nikova N.H. Analiz tekhnologii provedeniia GRP na mestorozhdeniakh OAO “Surgutneftegaz” [Analysis of hydraulic fracturing technology in the fields of OJSC “Surgutneftegaz”]. *Neftianoe khoziaistvo*, 1997, no. 9, pp. 46-52.

43. Malyshev A.G., Malyshev G.A., Sonich V.P., Sedach V.F., Zhurba V.N. Analiz vlianiia tekhnologicheskikh faktorov i mekhanicheskikh svoystv gornykh porod na effektivnost' provedeniia GRP [Analysis of the influence of technological factors and the mechanical properties of rocks on the effectiveness of hydraulic fracturing]. *Neft' Surguta. Sbornik statei posviashchennyi dobyche 1 mlrd t nefi na mest. OAO “Surgutneftegaz”*. Moscow: *Neftianoe khoziaistvo*, 1997, pp. 224-238.

44. Usachev P.M., Pesliak Iu.A., Konstantinov S.V., Kiseleva G.S., Krikunov N.V., Lesik N.P., Migadova L.A., Miklin V.A., Rudnev V.A., Savrasov L.A., Galiev F.F., Syskov V.V. Instruksii po tekhnologii glubokopornikaiushchego gidravlicheskogo razryva plasta. RD 39-0147035-236-89 [Instructions for the technology of deep-fracturing hydraulic fracturing. RD 39-0147035-236-89]. Moscow: VNIИ, 1989, 52 p.

45. Usachev P.M. Gidravlicheskiy razryv plasta [Hydraulic fracturing]. Moscow: Nedra, 1986, 166 p.

Библиографический список

1. Развитие технологий гидравлического разрыва пласта на месторождениях Пермского края / В.Л. Воеводкин, А.А. Алероев, Т.Р. Балдина, А.В. Распопов, А.С. Казанцев, С.А. Кондратьев. – М.: Нефтяное хозяйство, 2018. – 108 с.

2. Опыт проведения проппантного гидроразрыва пласта в карбонатных коллекторах месторождений Пермского края / С.А. Кондратьев, А.А. Жуковский, Т.С. Кочнева, В.Л. Малышева. – М.: Изд-во ВНИИОЭНГ, 2016. – 68 с.

3. Проведение проппантных гидроразрывов низкопроницаемых пластов на нефтяных месторождениях Ненецкого автономного округа / А.А. Алероев, С.А. Кондратьев, Р.Р. Шарафеев, Д.В. Новокрещенных, В.А. Жигалов. – М.: Нефтяное хозяйство, 2017. – 108 с.

4. Бакиров Э.А., Ермолкин В.И., Ларин В.И. Геология нефти и газа. – М.: Недра, 1980. – 240 с.

5. Гиматудинов Ш.К. Эксплуатация и технология разработки нефтяных и газовых месторождений. – М.: Недра, 1978. – 357 с.

6. Баренблатт Г.И., Енгов В.М., Рыжин В.М. Теория нестационарной фильтрации жидкости и газа. – М.: Недра, 1972.

7. Желтов Ю.П., Христианович С.А. О гидравлическом разрыве нефтеносного пласта // Известия АН СССР. ОТН. – 1955. – № 5. – С. 3–41.

8. Желтов Ю.П. Гидравлический разрыв пласта. – М.: Гостоптехиздат, 1957. – 98 с.

9. Желтов Ю.П. Деформация горных пород. – М.: Недра, 1966. – 198 с.

10. Желтов Ю.П. Разработка нефтяных месторождений: учеб. для вузов. – М.: Недра, 1986. – 332 с.

11. Economides M.J., Nolte K.G. Reservoir stimulation // New Jersey. Eglewood cliffs 01632, 1989. – 430 p.

12. Экономидис М., Олин Р., Валько П. Унифицированный дизайн гидроразрыва пласта: от теории к практике. – Москва – Ижевск: Институт компьютерных исследований, 2007. – 236 с.

13. Иванов С.И. Интенсификация притока нефти и газа к скважинам: учеб. пособие. – М.: Недра – Бизнесцентр, 2006. – 565 с.

14. Clark J.B. Hydraulic process for increasing productivity of wells // Trans. AIME. – 1949. – Vol. 186. – P. 1–8.

15. Каневская Р.Д. Зарубежный и отечественный опыт применения гидроразрыва пласта. – М.: Изд-во ВНИИОЭНГ, 1998. – 40 с.

16. Чарный И.А. Подземная гидрогазодинамика. – М.: Гостоптехиздат, 1963. – 346 с.

17. Желтов Ю.П. Механика нефтегазоносного пласта. – М.: Недра, 1975. – 207 с.

18. Хеллан К. Введение в механику разрушения. – М.: Мир, 1998. – 364 с.

19. Maxwell S.C., Urbancic T.I. The role of passive microseismic monitoring in the instrumented oil field // The Leading Edge. – 2001. – № 6. – P. 636–639.

20. Microseismic imaging of hydraulic fracture complexity in a naturally fractured reservoir / T.I. Urbancic, S.C. Maxwell, N. Steinsberger and R.J. Zinno // EAGE 64 Conference & Exhibition. – Florence, 2002. – 43 p.

21. Ландау Л.Д., Лившиц Е.М. Теоретическая физика. Т. VII. Теория упругости. – М.: Наука, 1987. – 248 с.

22. Телков А.П., Грачева Н.С., Каширина К.О. Образование трещин в продуктивном пласте при гидравлическом разрыве // Газовая промышленность. – 2008. – № 3. – С. 17–20.

23. Интенсификация добычи нефти и газа методом разрыва пласта / Т.Л. Чернышева, Г.В. Тимашев, А.Ю. Мищенко, А.Я. Строгий. – М.: Изд-во ВНИИГазпром, 1987. – 43 с.

24. Кобранова В.Н. Физические свойства горных пород. – М.: Гостоптехиздат, 1962.
25. Lewis L. Laei. Dinamic rock mechanics testing for optimized fracture design // SPE 38716. – 1997.
26. Шумилов В.А., Шалинов В.П., Азаматов В.В. Исследование призабойной зоны пластов при интенсификации добычи нефти и газа за рубежом // Обз. информ. Серия: Нефтепромысловое дело. – М.: Изд-во ВНИИОЭНГ, 1985. – 32 с.
27. Моделирование ГРП по экспериментальным зависимостям геомеханических характеристик коллектора / Р.Г. Ширгазин, Р.Х. Исянгулова, О.А. Залевский, В.Н. Лысенко, Ю.В. Земцов // OilGas conference. – 2008. – № 6. – P. 41–43.
28. John L, Gidley. Recent advances in hydraulic fracturing. Monograph. Henry L. Doherty Memorial Fund of AIME Society of Petroleum Engineers Richardson. TX. U.S.A, 1989.
29. Александров С.И., Мишин В.А., Буров Д.И. Микросейсмический мониторинг гидроразрыва пласта: успехи и проблемы // Технологии добычи и использования углеводородов. – 2014. – № 2. – С. 39–43.
30. Байкин А.Н. Динамика трещины гидроразрыва пласта в неоднородной пороупругой среде: дис. ... канд. физ.-мат. наук / МО и НРФ ФГАОУ ВО Новосибирский национальный исследовательский государственный университет. – Новосибирск, 2016.
31. Повышение эффективности гидроразрыва в условиях высокой обводненности пласта БВ-8 Повховского месторождения / А.С. Валеев, М.Р. Дулкарнаев, Ф.С. Салимов, А.В. Бухаров, А.В. Котенев // Нефтегазовое дело. – 2014. – № 6. – С. 154–174.
32. Barker V.J., Ramey H.J. Jr. Transient flow to finite conductivity vertical fractures // SPE 7489. – 1978.
33. Economides, M.J., and Nolte, K.G. Reservoir stimulation // Schlumberger Educational Services. – Houston, Texas. – 1987. – P. 11–3.
34. Raghavan R. Analysis of pressure data for fractured wells: the constant-pressure outer boundary R. Raghavan, Hadinoto, Nico // SPEJ. – 1978. – April. – P. 139–149.
35. Vertical fracture height – its effect on steady state production increase / J.M. Tinsley, J.R. Williams, R.L. Tiner, W.T. Malone // SPE 1900. Journal of Petroleum Technology. – 1969. – Vol. 21. – P. 633–638.
36. Weijers L. The Near-wellbore geometry of hydraulic fractures initiated from horizontal and deviated wells. – Delft, Netherlands, Delft University Press, 1995.
37. Гидроразрыв пласта. Современные достижения в области проектирования обработки скважин / Б. Брэди, Дж. Элвел, М. Мак, Х. Морален, К. Нолте // Oilfield Review. – 1992. – October.
38. Давление разрыва как технологический фактор, ограничивающий репрессию на пласт // Труды СибНИИИП. Вопросы геологии и разработки месторождений Западной Сибири. – Тюмень, 1985. – С. 86–94.
39. Занкиев М.Я. Классификация и диагностирование эффективности технологии гидравлического разрыва пластов в условиях ОАО «Славнефть-Мегионнефтегаз»: автореф. дис. канд. техн. наук / Тюм. гос. нефтегазовый ун-т. – Тюмень, 1998. – 24 с.
40. Курамшин Р.М., Иванов С.В., Кузьмичев А.П. Эффективность проведения гидроразрывов пласта на месторождениях Ноябрьского района // Нефтяное хозяйство. – 1997. – № 12. – С. 58–64.
41. Логинов Б.Г., Блажевич В.А. Гидравлический разрыв пластов. – М: Недра, 1966. – 148 с.
42. Анализ технологии проведения ГРП на месторождениях ОАО «Сургутнефтегаз» / Г.А. Малышев, А.Г. Малышев, В.Н. Журба, Н.Н. Сальникова // Нефтяное хозяйство. – 1997. – № 9. – С. 46–52.
43. Анализ влияния технологических факторов и механических свойств горных пород на эффективность проведения ГРП / А.Г. Малышев, Г.А. Малышев, В.П. Сонич, В.Ф. Седач, В.Н. Журба // Нефть Сургута: сб. статей посвященный добыче 1 млрд т нефти на мест. ОАО «Сургутнефтегаз». – М.: Нефтяное хозяйство, 1997. – С. 224–238.
44. Инструкции по технологии глубокопроникающего гидравлического разрыва пласта. РД 39-0147035-236-89 / П.М. Усачев, Ю.А. Песляк, С.В. Константинов, Г.С. Киселева, Н.В. Крикунов, Н.П. Лесик, Л.А. Мигадова, В.А. Миклин, В.А. Руднев, Л.А. Саврасов, Ф.Ф. Галиев, В.В. Сысков. – М.: ВНИИ, 1989. – 52 с.
45. Усачев П.М. Гидравлический разрыв пласта. – М: Недра, 1986. – 166 с.

Please cite this article in English as:

Novokreshchennykh D.V., Raspopov A.V. Trends in improving hydraulic fracturing efficiency in carbonate deposits at Komi Republic and Nenets Autonomous District fields. *Perm Journal of Petroleum and Mining Engineering*, 2020, vol.20, no.2, pp.175-181. DOI: 10.15593/2224-9923/2020.2.7

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:

Новокрещенных Д.В., Распопов А.В. Направления повышения эффективности гидроразрыва пласта в карбонатных отложениях месторождений Республики Коми и Ненецкого автономного округа // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2020. – Т.20, №2. – С.175–181. DOI: 10.15593/2224-9923/2020.2.7