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# Technologies for Bottomhole Zone Treatment in the Western Siberia Fields

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# Технологии обработки призабойных зон скважин на месторождениях Западной Сибири

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The degree of oil field development efficiency in Western Siberia largely depends on the state of the bottomhole formation zone of production and injection wells. Due to the dropout of various reaction products, after the introduction of chemical reagents, filtration parameters and permeability of the bottomhole formation zone decrease during the development process. Today, various processing technologies are used to restore the filtration characteristics of the bottomhole zone, one of which is acid treatment. The pace of the oil and gas industry development in recent years leads to the fact that such stimulation methods as hydraulic fracturing or acid treatment are used in the development and commissioning of wells. Acidizing is increasingly being used to bring production wells into production after drilling or killing during workovers. Despite the fact that acid treatments have been used in the oil and gas industry for a very long time, all the problems that arise during their implementation have not been fully resolved. This treatment is one of the most effective, widely used and relatively inexpensive method of increasing the productivity of production wells or restoring the injectivity of injection wells.
In this regard, the methods of acid treatment at two fields have been studied and an analysis of their performance has been carried out.
For the target goal, the following tasks were solved: geological and production data for fields analysed; current state of fields development analyzed; acid treatment process analyzed on the basis of domestic and foreign experience for the selection of technological and process parameters taking into account specific conditions; efficacy of acid treatment at fields analyzed.

*Ключевые слова:*
кислотная обработка, эффективность, продуктивность, кислотные композиции, призабойная зона пласта, фильтрация, проницаемость, терригенный коллектор, фильтрационно-емкостные свойства, соляно-кислотная обработка, глино-кислотная обработка.

Степень эффективности разработки нефтяных месторождений Западной Сибири в большей степени зависит от состояния призабойной зоны пласта добывающих и нагнетательных скважин. Вследствие выпада различных продуктов реакции, после ввода химических реагентов в процессе разработки снижаются фильтрационные параметры и проницаемость призабойной зоны пласта. На сегодняшний день применяются различные технологии обработки для восстановления фильтрационных характеристик призабойной зоны, одна из которых – кислотная обработка. Темп развития нефтегазовой индустрии за последние годы ведет к тому, что такие методы интенсификации притока, как гидроразрыв пласта или кислотные обработки, используются при освоении и вводе скважин в эксплуатацию. Кислотная обработка все чаще применяется при вводе добывающих скважин в эксплуатацию после бурения или глушения при проведении ремонтных работ. Несмотря на то что кислотные обработки применяются в нефтегазовой промышленности очень давно, всех проблем, возникающих при их проведении, так и не удалось избежать в полной мере. Данная обработка является одной из наиболее эффективных, широко применяемой, а также относительно недорогим методом увеличения продуктивности добывающих скважин или восстановления приемистости нагнетательных.
В связи с этим изучены методы кислотной обработки на двух месторождениях и осуществлен анализ эффективности данного метода.
Для поставленной цели работы были решены следующие задачи: проведен анализ геолого-промысловых данных по месторождениям; выполнен анализ текущего состояния разработки месторождений; проанализирован процесс проведения кислотных обработок на основании отечественного и зарубежного опыта для выбора технологических и технических параметров с учетом конкретных условий; оценена эффективность применения кислотных обработок на месторождениях.

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## Introduction

The degree of oil field development efficiency in Western Siberia largely depends on the state of the bottomhole formation zone (BFZ) of production and injection wells. Due to the precipitation of various reaction products, after the introduction of chemical reagents, an increase in the water saturation of rocks and a decrease in the relative oil permeability, BFZ filtration and permeability parameters decrease during the production process. Currently, the multicomponent treatment technologies are used to restore the porosity and permeability properties of the bottom-hole zone of reservoirs with high water retaining capacity, developed specific pore surface area and clay content [1–5]. However, due to the significant content of carbonate compounds, when exposed to a hydrochloric solution, the formation of secondary sediments can occur, as well as a decrease in the relative oil permeability and the formation of a stable water barrier in the pore channels.

In this regard, it is necessary to develop an integrated approach and methods for influencing the bottomhole formation zone, which are multidimensional processes. Their positive performance is determined by precision and accuracy of determining the target properties affected (reservoir – well), as well as the state of the BFZ and the well as a whole.

The priority direction of this paper is associated with the study and development of an effective technology improving the technical means, which, in turn, ensure the recovery of well productivity with the bottomhole zone decolmatation and justification of the choice of effective chemical compositions. When producing the Nizhnevartovsk arch layers and similar deposits in Western Siberia, the implementation of an integrated technology, including physicochemical impact on the BFZ, is relevant.

## Research Procedure

Acid treatment is the process of acid solution pumping into a reservoir in order to remove the BFZ damages, as well as to expand existing channels or create new ones. In this procedure, the intensification [6] of oil production rate occurs due to an increase in the effective radius of the wells. When acid is pumped above the fracture pressure, acid treatment is called acid fracturing of formation (FF), if below the fracture pressure – matrix acid treatment [7].

Three factors contribute to the deterioration of well production: low permeability of the productive formation, narrowing of the wellbore due to the bottomhole zone damage and ineffective mechanical system [8]. Acid treatment can be used as an optimal method of well production rate recovery if the cause of well production deterioration is the bottomhole zone damage.

The optimal candidate for acid treatment will be, firstly, a well with a formation permeability higher than 10 mD, and secondly, the permeability of which in the near-wellbore or near-perforation zone was reduced by solid plugging [9].

For the efficacy of acid action, it is necessary to "properly" inject an acid solution with the "correct" amount of acid. The acid solution must fully come into contact with all the bottomhole zone channels of the well and fractures, where it must exert its effect. To avoid a decrease in the formation strength, it is required to inject a certain amount of acid solution to completely dissolve the entire part of bridging material and a part of structural materials, but, in addition, the corrosive effect of acid solution on the equipment used shall be considered during injection [10].

## Chemicals for Acid Treatment Applications

To improve the properties of acid solutions, it is necessary to add chemical additives [11, 12]. In turn, to increase the fluid permeability in relation to the formation rock, to reduce the possibility of precipitation and corrosive tendency in relation to the metal, it is required to use the additives described below.

Table 1

Inhibitor types and their ability to reduce corrosivity

| Inhibitor | Quantity, % | Reduced corrosivity, number of times |
|---|---|---|
| Formaline | 0.6 | 7–8 |
| Unicol PB-5 | 0.25–0.5 | 30–42 |
| Catapin A | 0.025 | 45 |
| Dodicor | 0.5 | Up to 300 |
| Azole (CI-130) | 1 | Up to 50 |

Inhibitor is a substance that reduces the corrosive effect of acid on equipment used for acid transportation, pumping and storage. Typically, 1 % by volume of acid is added to the composition.

The action mode of inhibitors is as follows: anodic inhibitors work in the anodic areas of the metal, and cathodic inhibitors – in cathodic ones [13]. The inhibitor types are shown in Table 1.

Flow rate, the ratio of acid volume to metal surface area, temperature, inhibitor concentration, acid spike concentration and type, acid concentration and type, metal and pressure type are factors that have a direct impact on the inhibitor efficacy [13].

Intensifiers are surfactants that reduce the surface tension at the oil boundary by 3–5 times and neutralize the acid.

Intensifiers are used to lower the surface tension of acid composition when interacting with the rock, facilitate the backflow of reaction products after treatment, and increase the penetration depth and efficacy of acid solution.

The penetration of acid solution into the microscopic rock pores is facilitated by the presence of surfactants [14]. This is necessary when processing tough rocks and when cleaning the well bottomhole from the remaining particles of cement or solid deposits. Surfactants facilitate water separation from the rock and the process of acid penetration through oil films that cover the rock surface and line the surface, which in turn allows the acid to come into contact with the rock to dissolve it.

There is a certain group of inhibitors (Catapin A, Catamine A, Mervelan K), which also act as intensifiers; surfactants (OP-10, OP-7) can also be used as intensifiers [15].

For the treatment of injection wells at the initial production stage and when transferring wells, the following list of non-ionic hydrophilic surfactants is used:

1) Neonol CHO 3B (1–2 %);
2) Prevocel (1–2 %);
3) Neftenol VVD (1–2 %);
4) Sulfanol (0.5 %).

At the third and fourth stages of field production, it is recommended to use the following hydrophobic materials as surfactants [16]:

1) Sinol KAM (1.5 %) – limited in application temperature (80 °C);
2) IVV-1 (up to 2 %);
3) Neftenol GF (up to 2 %);
4) Neftenol K (up to 3 %).

Water repellents, in turn, facilitate the acid filtration in oil-saturated inter-layers, reduce its penetration into the water-saturated part of the formation, which subsequently leads to the retention of intensive working out of water-saturated channels and accelerates the water penetration through them to oil wells.

Stabilizers are substances required to keep some of the reaction products and iron compounds present in hydrochloric acid as dissolved.

These substances significantly reduce the rate of hydrochloric acid interaction with carbonate component of the rock, for this reason the penetration rate of acid solutions increases. For displacement fluids, the following are used as stabilizers:

1) Neftenol VVD (2 %);
2) Neonol CHO 3B (2 %);
3) Anionic sulfanol (1 %);
4) Neftenol GF (2 %);
5) Sinol KAM (1 %).

### Acid Treatment of Carbonate Reservoirs

Hydrochloric acid is used in a wide concentration range. At temperatures up to 60 °C, the concentration of hydrochloric acid ranges from 6 to 24 %, and at higher temperatures, an acid with a higher concentration is mainly used, since a part of the acid is undissociated – the reaction rate of these acids will be lower than in those less concentrated [17].

The foamed acids are used [18], the advantages of this treatment method are:

1. Low rate of fluid injection into the formation, which, in turn, reduces the risk of BFZ contamination.
2. High foam acid viscosity, which provides deeper acid penetration into the formation.
3. Low density of the foam acid composition, which contributes to easy well development.
4. Foam acid washes out the BFZ contaminants more intensively due to the fact that the solid phase of contamination is properly carried away by the foam.

Nitrogen is used as a gas phase for foams. It is formed by mixing nitrogen and acid treated with a foaming agent. The volumetric content of nitrogen in the foam determines its quality, which is regulated by the feed rates of gas and fluid phase.

Application of acid emulsions [19]. Emulsions are highly viscous compositions that increase the coverage of action across the formation thickness. Their penetrating power can determine the degree of dispersion, limiting the scope due to increased viscosity.

The TatNIPIneft R&D Institute developed the composition of an oil-distillate [20] hydrophobic emulsion, which has been widely used in locations of Western Siberia, Udmurtia and Tatarstan. This inverse emulsion has the following ratios:

– hydrocarbon / water phase – 50/50;

– hydrocarbons in a dispersed "oil/distillate" medium – 50/50.

Concentration of surfactant – emulsifier "ES – 2" – 1–1.5 %.

The application of gelled and thickened acids is intended to increase the depth of solution penetration into the low-permeability formations. When using thickened or gelled acid systems, there are no intermediate stages of neutral gel injection, and acid thickening also eliminates the acid leakage into highly permeable parts of the formation and fractures [21].

When using xanthan polymer as a thickener, the BFZ cleaning is reduced and simplified [22], and this allows to produce the stable high-viscosity gels of acid solutions for variable conditions of the formation. For example, hydrochloric acid solution 15 % was well thickened with xanthan polymer and retained its properties with an increase in temperature up to 100 °C [23, 24].

### Acid Treatment of Terrigenous Reservoirs

The presence of feldspar, clay, quartz, etc., causes contamination in the terrigenous reservoir formation [25]. To remove these contaminants, the treatment with mud acid, which is a mixture of hydrochloric and hydrofluoric acid, in various concentrations not exceeding 12 wt %. for HCl and 3 % wt. for HF, respectively, is used [26].

The formation of numerous reaction products with an increase in pH (as the acid is consumed), which can precipitate as insoluble and poorly soluble precipitates, is a distinctive feature of hydrofluoric acid [13]. With a salt and hydrofluoric mixture production, pH shall be brought to the required interval, not exceeding the value of pH = 2 [23].

The side reactions that occur when silicates come into contact with hydrofluoric acid lead to unnecessary waste of funds and an effect on the overall stoichiometry.

The dissolving capacity can be interpreted as a way of expressing stoichiometry [27]. This capacity is the amount of a mineral that can be dissolved by a certain amount of acid (weight/volume). Initially, before measuring the dissolving capacity, the gravimetric dissolving capacity, which is the weight of a mineral dissolved by a certain weight of acid, shall be determined and calculated by the formula

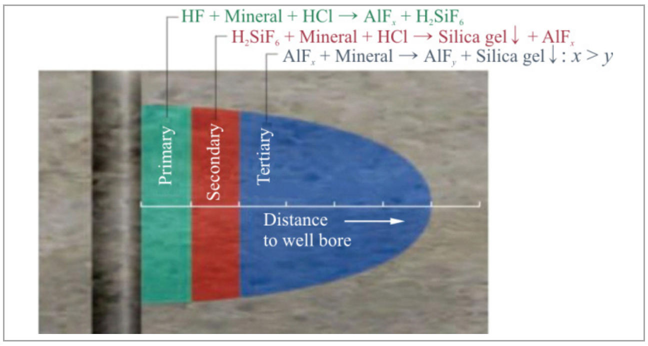


Fig. 1. Diagram of the passage of primary, secondary and tertiary reactions in the BFZ during the mud acid treatment [32]

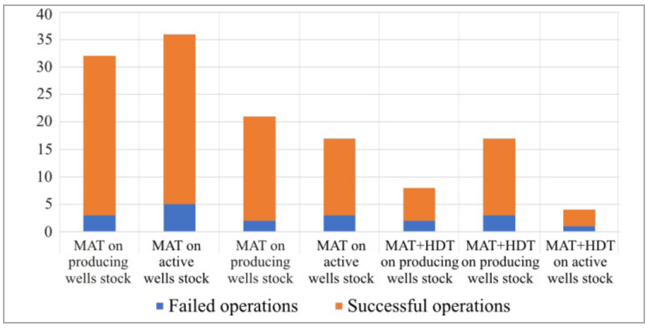


Fig. 2. The success of acid treatments in the field No. 1 for 2007 to 2010

$$\beta = \frac{v_{мин} MW_{мин}}{v_{мин} MW_{мин}}, \quad (1)$$

where β – gravimetric dissolving capacity of the acid; $v$ – stoichiometric coefficients of the reaction of mineral and acid interaction; $MW$ – molecular weights of mineral and acid.

$$X = \beta \frac{\rho_{раствора\ к\text{-}ты}}{\rho_{минерала}}, \quad (2)$$

where $X$ – volumetric dissolving capacity; ρ – density rates of mineral and acid; β – dissolving capacity for hydrofluoric acid [13].

The side reactions caused by various factors, which arise in the course of acid action [28, 29] on the rock, tend to cause secondary and tertiary sedimentation. For example, at the primary reaction occurring in the BHZ area, aluminum and silicon fluoride are formed (3), in secondary reactions – the interaction of hexafluorosilicic acid with rocks, which proceed more slowly than the primary one. And tertiary reactions, in turn, are the reaction of minerals with aluminum fluoride (4), which are subsequently transfered into aluminum and silica gel complexes. Due to the rapid rate of secondary and tertiary reactions at high formation temperatures, acid treatments of terrigenous rocks can end negatively (Fig. 1) [30, 31].

$$H_2SiF_6 + \text{mineral} + H^+ \rightarrow Si(OH)_4\downarrow + AlF_3, \quad (3)$$

$$AlF_3 + \text{mineral} \rightarrow Si(OH)_4\downarrow + AlF_n(OH)_{3-n}, \quad (4)$$

where $n < 3$.

For avoiding sedimentation during the interaction of formation rocks with mud acid, R&D institutes and companies develop a variety of acid compositions in various concentrations to obtain the best results of acid treatment for terrigenous reservoirs as they settle, permeability [33] and porosity.

Table 2

Success rate of ATs in the field No. 1 for 2007 to 2010

| Parameter | MAT on producing wells stock | MAT on active wells stock | HCT on producing wells stock | HCT on active wells stock | MAT + HDT on producing wells stock | HCT + HDT on producing wells stock | MAT + HDT on active wells stock |
|---|---|---|---|---|---|---|---|
| Failed operations | 3 | 5 | 2 | 3 | 2 | 3 | 1 |
| Successful operations | 29 | 31 | 19 | 14 | 6 | 14 | 3 |
| Success rate, % | 91 | 86 | 90 | 82 | 75 | 82 | 75 |

Table 3

The number of bottomhole cleaning operations at producing wells and average starting production gains by year

| Parameter | Year | | |
|---|---|---|---|
| | 2007 | 2008 | 2009 |
| Number of operations | 13 | 21 | 23 |
| Average starting oil production gain, t/day | 2.1 | 5.7 | 4.5 |

Table 4

Injection well operation parameters before bottomhole cleaning operations

| Treatment date | Field | Well | Operation type | $Q_{fluid}$, m$^3$/day | $Q_{oil}$, m$^3$/day | Wat. cut, % | $P_{bottomhole}$, atm. | $K_{productivity}$, mD |
|---|---|---|---|---|---|---|---|---|
| 22/05/2009 | No.1 | 2034 | MAT | 14 | 4 | 67.2 | 51.0 | 0.11 |
| 22/05/2009 | No.1 | 2036 | MAT | 14 | 4 | 65.0 | 100.0 | 0.10 |
| 14/06/2009 | No.1 | 1223 | MAT | 7 | 5 | 21.0 | 56.0 | 0.05 |

Notes: here and in Table 5: $Q_{fluid}$ – increase in fluid production rate; $Q_{oil}$ – increase in oil production rate; Wat. cut – water cut; $P_{bottomhole}$ – bottomhole pressure; $K_{productivity}$ – productivity index.

Table 5

Injection well operation parameters after bottomhole cleaning operations

| Date | $Q_{fluid}$, m$^3$/day | $Q_{oil}$, m$^3$/day | Wat. cut, % | $P_{bottomhole}$, atm. | $K_{productivity}$, mD |
|---|---|---|---|---|---|
| 22/05/2009 | 14 | 4 | 67.2 | 51.0 | 0.11 |
| 22/05/2009 | 14 | 4 | 65.0 | 100.0 | 0.10 |
| 14/06/2009 | 7 | 5 | 21.0 | 56.0 | 0.05 |

Table 6

Well B baseline data

| Parameter | Value |
|---|---|
| Oil production rate, m$^3$/day | 15.9 |
| Amount of carbonates, % | 5 |
| Amount of clay in the rock, % | 4 |
| Permeability, μm$^2$ | 0.026 |
| $BS_9$ formation thickness, m | 38 |
| Well injection capacity, m$^3$/day | 100 |
| Formation pressure, MPa | 23.0 |
| Oil viscosity, mPas | 2.02 |
| Well depth, m | 2564 |
| Rock density, kg/m$^3$ | 2100 |
| Matrix density of the rock dissolving into a weakly carbonate solution (WCS), kg/m$^3$ | 2400 |
| Well inner diameter $D_{in}$, m | 0.146 |

The mud acid retarder reduces the acid consumption rate into the matrix around the channels during their production, provides deeper penetration and expansion of the formed flow channels, and increases the depth of acid penetration by blocking or slowing down the acid reaction [34].

## Results and Discussion

Application of acid treatments for the bottomhole formation zone in the oil field No. 1.

Hydrochloric (HCT) and mud acid (MAT) treatments were carried out in the field No. 1 [35]. The state of acid treatments in the field No. 1 for the reporting period from 2007 to 2010 is reflected in Table 2.

From 2007 to 2010, 135 acid treatment operations were carried out in the field No. 1 at the production and injection well stocks, of which 85.9 % were successful (Fig. 2).

In a significant number of wells, hydraulic fracturing was previously carried out, and a large number of hydrochloric and mud acid treatment operations were carried out. In the production well stock, the effect of bottomhole zone cleaning can be traced in the interval from 2 to 13 months; in turn, in the injection wells, the effect can be traced up to 15 months. The number of cleaning operations performed in the producing well stock and the average starting production gain for 2007 to 2009 are shown in Table 3.

After reviewing the data provided in Table 3, it can be concluded that the increase in oil production per well decreased in 2009 compared to 2008, the reason for that is the increase in bottomhole cleaning operations at marginal wells.

Information on the efficacy of bottomhole zone cleaning in some wells is given in Tables 4, 5.

According to data in Fig. 4, it can be seen that the fluid flow rate increased by 5.7 times, the oil flow rate increased by 3.6 times and the water cut increased by 2.1 times; in turn, the bottomhole pressure dropped by up to 1.8 times, and the productivity factor increased by six times.

In the field No. 2, acid treatment is one of the most efficacy methods of stimulating oil inflows due to the fact that the productive formations of this field are composed of low-permeable carbonate rocks, and the fractures, which are noted throughout the section, have little opening [36].

The efficacy of hydrochloric acid treatment at well B, for which a solution of 6 m$^3$ was used, was estimated.

Table 7

Parameters of hydrochloric treatment of the well at different volumes of hydrochloric solution

| Volume | $r_{inj.\ rate}$ | $r_{prod.\ rate}$ | $Q$ | Incremental production |
|---|---|---|---|---|
| 6 m³ | 1 m | 3.4 m | 24.09 m³/day | 130.79 t |
| 18 m³ | 1.8 m | 6.9 m | 26.57 m³/day | 170.31 t |
| 34 m³ | 2.6 m | 10 m | 27.92 m³/day | 191.95 t |

Table 8

Results of hydrochloric treatment at the wells of field No. 2

| Well No. | $Q_0$, m³/day | $k_0$, μm² | $m_0$, % | $V_{WCS}$, m³ | $P_{inj.}$, MPa | $K$, μm² | $As$ | $Q$, m³/day | $\Delta Q$, m³/day |
|---|---|---|---|---|---|---|---|---|---|
| 651 | 15.9 | 0.026 | 11 | 6 | 8.89 | 0.063 | 1.51 | 24.090 | 8.190 |
| 670 | 11.8 | 0.024 | 10.9 | 6 | 8.85 | 0.059 | 1.48 | 17.464 | 5.664 |
| 675 | 14.1 | 0.03 | 11.3 | 6 | 8.82 | 0.064 | 1.52 | 21.432 | 7.332 |
| 980 | 12.5 | 0.024 | 9.8 | 6 | 8.78 | 0.061 | 1.57 | 19.625 | 7.125 |
| 995 | 9.7 | 0.019 | 9.7 | 6 | 8.77 | 0.063 | 1.6 | 15.520 | 5.820 |
| 1071 | 12.6 | 0.026 | 10.4 | 6 | 8.91 | 0.061 | 1.54 | 19.908 | 7.308 |
| 1090 | 17.3 | 0.022 | 10.1 | 6 | 8.93 | 0.059 | 1.55 | 26.642 | 9.342 |
| 1094 | 11.5 | 0.028 | 9.9 | 6 | 8.93 | 0.062 | 1.55 | 17.825 | 6.325 |
| Σ | – | – | – | – | | – | – | – | 57.106 |

Radius of the dissolution zone was 1 m, radius of the reaction product zone was 3.4 m, and acid concentration was 12 % [37] (Table 6).

Cation A in the amount of 0.01 % by volume of the acid solution was taken as an inhibitor. To lower the surface tension, the SD (Soviet detergent) reagent was used. In addition to being an intensifier, it also acted as an inhibitor [38]. Its amount was 0.06 m³, or 1 % by volume of HCl solution.

After reviewing the final data on acid solution with a volume of 6 m³, it was concluded that the porosity and permeability in well B increased after the hydrochloric treatment of the well: porosity after treatment increased by 1.28 times (11 to 14.06 %); permeability coefficient increased by 2.34 times (0.026 to 0.063 μm²). The well production rate increased by 24.09, which is 8.19 m³/day more than the initial value, and the treatment effect itself has a long-term nature, which brought an additional 130.79 tons of oil.

The results of calculating the production rate for different volumes of acid solution are shown in Table 7.

Reviewing the data provided in Table 7, we can conclude that the optimal volume of acid solution is 18 m³: with an increase in the solution volume, the dissolution and reaction product zone radius also increases [39], and injection over 18 m³ into the formation is unprofitable and impractical.

The summary results of hydrochloric treatment at other wells of field No. 2 are shown in Table 8.

After a summary review of Table 8, the increased porosity, permeability can be recorded, as well as an increased oil production rate can be noted for the wells of field No. 2. The increased production rate is noticeable at well No. 1090, where the absolute increase was 9.342 m³/day. The used stimulation method [40] is considered efficient and recommended for use at other wells of this field, which pass the selection criteria for hydrochloric treatments [41].

The comparative diagram, which illustrates the changes in the increased oil production rate as a result of hydrochloric treatment at the wells of field No. 2, is shown in Fig. 5.

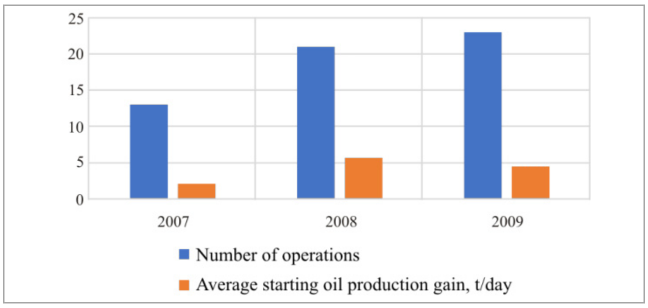


Fig. 3. The number of bottomhole cleaning operations at producing wells and average starting production gains by year

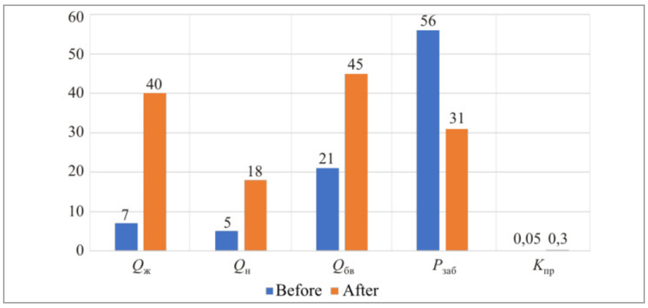


Fig. 4. Main parameters of the well A before and after cleaning the bottomhole zone

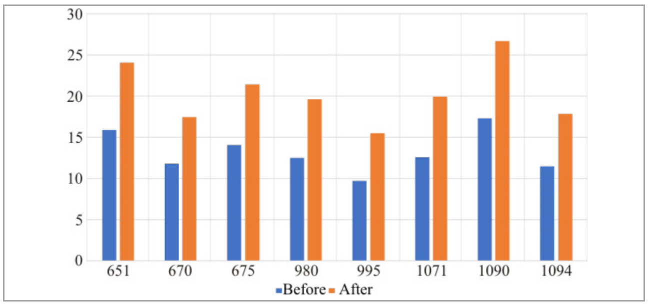


Fig. 5. Changes in the increased oil production rate as a result of hydrochloric treatment at the wells of field No. 2

## Conclusion

In this paper, the geological and field data, the current state of field production and the acid treatment process were reviewed (considered: the essence of acid treatments; various types of acids and chemical reagents used in acid compositions; equipment for acid operations; technology of acid treatment at wells) on the basis of domestic and foreign experience, as well as taking into account the choice of process and technical parameters for specific conditions.

The method of affecting the bottomhole formation zone is chosen [42–47] based on the composition of rocks, properties of formation fluids, characteristics of the productive formation structure and other formation conditions. During the acid treatment, it is necessary to consider the compatibility of rock compositions and acid solutions, as well as the sensitivity of this rock to solution. In these fields, to obtain the efficacy acid treatments, due to the fact that the wells have a high water cut, it is necessary to modernize the technologies of acid solutions processing.

### References

1. Sagirova L.R., Vliianie sostava porod kollektorov na snizhenie pronitsaemosti prizaboinoi zony skvazhiny na primere Priobskogo mestorozhdeniia [Influence of the reservoir rock composition on a decrease in the permeability of the bottomhole zone of a well using the example of the Priobskoye field]. *Neft'. Gaz. Novatsii*, 2011, no 2, pp. 10-12.
2. Shchelkachev V.N., Lapuk B.B. Podzemnaia gidravlika [Underground hydraulics]. Moscow, Izhevsk: PXD, 2001, 735 p.
3. Sinclair A. Richard, Pittard J. Frederick, Hanold, Robert J. Geothermal well stimulation. Transactions - Geothermal Resources Council, 1980, vol. 4, pp. 423-426.
4. Sneddon I.N., Lowengrud M. Crack Problems in the Classical Theory of Elasticity. New York: SIAM Series in Applied Mathematics, John Wiley & Sons, 1979, pp. 29-30.
5. Van Domelen, Mary S., Jennings Jr., Alfred R. Alternate acid blends for HPHT applications. *Offshore Europe Conference - Proceedings*, 1995, pp. 523-530. DOI: 10.2118/30419-MS
6. Ibragimov L.Kh., Mishchenko I.T., Cheloiants D.K. Intensifikatsiia dobychi nefti [Stimulation of oil production]. Moscow: Nauka, 2000, 414 p.
7. Aboud R., Smith K., Forero L., Kalfayan L. Effective matrix acidizing in high-temperature environments. *SPE Annual Technical Conference Proceedings*, 2007, no. 2, pp. 1066-1075. DOI: 10.2118/109818-MS
8. Yudovich A., Chin L.Y., Morgan D.R. Casing deformation in Ekofisk. *Journal of Petroleum Technology*, 1989, vol. 41 (7), pp. 729-734. DOI: 10.2118/17856-PA
9. Al-Dahlan M.N., Nasr-El-Din H.A., Al-Qahtani A.A. Evaluation of Retarded HF Acid Systems. *Proceedings - SPE International Symposium on Oilfield Chemistry*, 2001, pp. 457-476. DOI: 10.2118/65032-MS
10. Shumilov V.A., Aristov V.N., Grigor'ian N.A. Predokhranenie i vosstanovlenie pronitsaemosti prizaboinoi zony pri razrabotke mestorozhdenii Zapadnoi Sibiri [Preservation and restoration of bottomhole zone permeability during field development in Western Siberia]. Moscow: VNIIOENG, 1980, 55 p.
11. Fakhretdinov R.I., Nigmatullina R.F. Novye fiziko-khimicheskie aspekty povysheniia effektivnosti khimreagentov v neftedobyche [New physical and chemical aspects of increasing the efficiency of chemicals in oil production]. Ufa: Gil em, 1996, 191 p.
12. Fakhretdinov R.I., Nigmatullina R.F. Novye fiziko-khimicheskie aspekty povysheniia effektivnosti khimreagentov v neftedobyche [New physical and chemical aspects of increasing the efficiency of chemicals in oil production]. Moscow: Nedra, 1986, pp. 6-17.
13. Gadiev S.M. [Vibrovozdeistvie na prizaboinuiu zonu skvazhinu [Vibration impact on the bottomhole zone of the well]. *Neft' i gaz*, 1973, no. 5, pp. 47-50.
14. Kabirov M.M., Persiiantsev M.N., Gafarov Sh.A., Sultanov V.G. Kompleksnaia tekhnologiia uvelicheniia nefteotdachi plasta pri zavodnenii s primeneniem poverkhnostno-aktivnogo sostava (PAS) [Integrated technology for enhanced oil recovery during waterflooding using a surfactant composition]. *Neftepromyslovoe delo*, 1999, no. 10, pp. 45-47.
15. Kuznetsova A.N., Rogachev M.K. Regulirovanie fil'tratsionnykh kharakteristik neftianykh kollektorov s ispol'zovanie poverkhnostno-aktivnykh veshchestv [Regulation of filtration characteristics of oil reservoirs using surfactants]. *International research journal*, 2015, no. 10, vol. 4, pp. 98-99.
16. Fakhretdinov R.N., Zemtsov Iu.V., Novoselov T.S. Gidrofobizatsiia prizaboinoi zony gidrofil'nykh kollektorov [Hydrophobization of the bottomhole zone of hydrophilic reservoirs]. *Neftianoe khoziaistvo*, 1999, no. 4, p. 29-30.
17. Safin S.G. Fiziko-khimicheskie issledovaniia dlia kachestvennogo upravleniia vozdeistviem na prizaboinuiu zonu plasta [Physical and chemical studies for high-quality control of the impact on the bottomhole formation zone]. *Neftianoe khoziaistvo*, 2003, no. 2.
18. Di Lullo, Gino, Rae, Phil New acid for true stimulation of sandstone reservoirs. *SPE - Asia Pacific Oil & Gas Conference*, 1996, pp. 477-486. DOI: 10.2118/37015-MS
19. McLeod H.O. Significant Factors for Successful Matrix Acidizing. *SPE Centennial Symposium at New Mexico Tech. Society of Petroleum Engineers*, 1989. DOI: 10.2118/20155-MS
20. Rogachev M.K., Mukhametshin V.V., Kuleshova L.S. Povyshenie effektivnosti ispol'zovaniia resursnoi bazy zhidkikh uglevodorodov v iurskikh otlozheniiakh Zapadnoi Sibiri [Improving the efficiency of using resource base of liquid hydrocarbons in Jurassic deposits of Western Siberia]. *Zapiski Gornogo instituta*, 2019, vol. 240, 711 p. DOI: 10.31897/pmi.2019.6.711
21. Shagiakhmetov A.M., Petrakov D.G., Riazanov A.A. Razrabotka vodoizoliatsionnogo sostava dlia treshchinovatykh i treshchinno-porovykh kollektorov na osnove karboksimetiltselliulozy [Development of a waterproofing composition for fractured and fractured porous reservoirs based on carboxymethyl cellulose]. *Neftepromyslovoe delo*, 2016, no. 3, pp. 30-35.
22. Motta E.P. da, Plavnik B., Schechter R.S. Optimizing Sandstone Acidization. *SPE Reserv. Eng.*, 1992, vol. 7, no. 01, pp. 149-153. DOI: 10.2118/19426-PA
23. Tananykhin D.S., Shagiakhmetov A.M. Justification of technology and fluids for treatment of the unconsolidated carbonate reservoirs. *International Journal of Applied Engineering Research*, 2016, vol. 11, no. 1, pp. 744-748.
24. Tananykhin D.S., Shagiakhmetov A.M., Korablev E.M. Laboratornye issledovaniia energoeffektivnoi tekhnologii povysheniia koeffitsienta izvlecheniia nefti iz karbonatnykh obvodnennykh kollektorov [Laboratory studies of an energy efficient technology for increasing the oil recovery factor from carbonate flooded reservoirs]. *Mir nauki*, 2015, no. 2, pp. 214-217.
25. Magadova L.A., Silin M.A., Tropin E.Iu. Kislotnaia kompozitsiia "Khimeko TK-2" dlia nizkopronitsaemykh terrigennykh kollektorov [Acid composition *Himeko TK-2* for low-permeability terrigenous reservoirs]. *Neftianoe khoziaistvo*, 2003, pp. 80-81.
26. Dopolnenie k tekhnologicheskoi skheme razrabotki Khokhriakovskogo mestorozhdeniia [Supplement to the technological scheme for the development of the Khokhryakovskoye field]. Ed. L.S. Brilliant. Tiumen': Sibirskii nauchno-issledovatel'skii institut neftianoi promyshlennosti (SibNIINP)1994, 180 p.
27. Acidizing - Schlumberger Oilfield Glossary, available at: http://www.glossary.oilfield.slb.com/Terms/a/acidizing.aspx (accessed 17 May 2018).
28. Rae P., Di Lullo G. Achieving 100 Percent Success in Acid Stimulation of Sandstone Reservoirs. *SPE - Asia Pacific Oil and Gas Conference*, 2002, pp. 127-133. DOI: 10.2118/77808-MS
29. Shafiq M.U., Mahmud H. Ben. Sandstone matrix acidizing knowledge and future development. *J. Pet. Explor. Prod. Technol. Springer Berlin Heidelberg*, 2017, vol. 7, no. 4, pp. 1205-1216. DOI: 10.1007/s13202-017-0314-6
30. Podoprigora D.G., Mardashov D.V. Razrabotka kislotnogo sostava dlia uslovii vysokotemperaturnykh terrigennykh porod-kollektorov [Development of acid composition for high-temperature terrigenous reservoir rocks]. *Neftegazovoe delo*, 2015, no. 6, pp. 162-178.
31. Podoprigora D.G., Shangaraeva L.A. Razrabotka kislotnogo sostava dlia obrabotki prizaboinoi zony skvazhin v usloviiakh vysokikh plastovykh temperatur [Development of an acid composition for treatment of the bottomhole zone of wells in conditions of high reservoir temperatures]. *Neftianoe khoziaistvo*, 2016, no. 4, pp. 122-124.
32. Armirola F., Machacon M., Pinto C., Milne A., Lastre M., Miquilena E. Combining matrix stimulation and gravel packing using a non-acid based fluid. *Society of Petroleum Engineers - 9th European Formation Damage Conference*, 2011, vol. 1, pp. 502-515. DOI: 10.2118/143788-MS
33. Rogov E.A. Issledovanie pronitsaemosti prizaboinoi zony skvazhin pri vozdeistvii tekhnologicheskimi zhidkostiami [Study of the well near-bottomhole zone permeability during treatment by process fluids]. *Zapiski Gornogo instituta*, 2020, vol. 242, 169 p. DOI: 10.31897/pmi.2020.2.169
34. Dyk V.K. Analiz primeneniia kislotnykh obrabotok prizaboinoi zony plasta na Y neftianom mestorozhdenii (Tomskaia oblast') [Analysis of the application of acid treatment of the bottomhole formation zone in the Y oil field (Tomsk region)]. Tomsk, 2015.
35. Kovalev E.N. Otsenka effektivnosti primeneniia soliano-kislotnykh obrabotok na Kh neftianom mestorozhdenii (KhMAO) [Evaluation of the effectiveness of the use of hydrochloric acid treatments at the X oil field (XMAO)]. Tomsk, 2016.
36. Pykhachev G.B., Isaev R.G. Podzemnaia gidravlika [Underground hydraulics]. Moscow: Nedra, 1973, 359 p.
37. Giliazov Sh.Ia., Manapov R.Z., Safiulin R.A., Volkova N.I., Vakhitov M.F. Analiz effektivnosti metodov OPZ ekspluatatsionnykh i nagnetatel'nykh skvazhin NGDU "Nurlatneft'" [Analysis of the effectiveness of bottom hole treatment methods of production and injection wells of *NGDU Nurlatneft*]. *Neftepromyslovoe delo*,, 2000, no. 6.
38. Verderevskii Iu.L., Aref'ev Iu.N., Naganov M.S., Asmolovskii B.C., Saifutdinov F.Kh. Uvelichenie produktivnosti skvazhin v karbonatnykh kollektorakh sostavami na osnove solianoi kisloty [Increasing the productivity of wells in carbonate reservoirs with compositions based on hydrochloric acids]. *Neftianoe khoziaistvo*, 2000, no. 1, pp. 39-40.
39. Amiian V.A., Vasil'eva N.P., Dzhavadian A.A. Povyshenie neftegazootdachi plastov putem sovershenstvovaniia ikh vskrytiia i osvoeniia [Enhancing oil and gas recovery of reservoirs by improving their opening and development]. Moscow, 1977, 80 p.
40. Suchkov B.M. Povyshenie proizvoditel'nosti malo debetnykh skvazhin [Increasing the productivity of small debit wells]. Izhevsk: UdmurtNIPIneft', 1999, 645 p.
41. Rogachev M.K., Mukhametshin V.V. Kontrol' i regulirovanie protsessa solianokislotnogo vozdeistviia na prizaboinuiu zonu skvazhin po geologo-promyslovym dannym [Control and regulation of the hydrochloric acid treatment of the bottomhole zone based on field-geological data]. *Zapiski Gornogo instituta*, 2018, vol. 231, 275 p. DOI: 10.25515/pmi.2018.3.275
42. Akhundov M.S. O vybore reshenii pri provedenii obrabotok prizaboinykh zon skvazhinu [On the choice of solutions when carrying out treatments of bottomhole zones of a well]. *Azerbaidzhanskoe neftianoe khoziaistvo*, 1990, no. 10, pp. 30-33.
43. Loginov B.G., Malyshev L.G., Garifullin Sh.S. Rukovodstvo po kislotnym obrabotkam skvazhin [Acid Wells Guide]. Moscow: Nedra, 1966, 219 p.
44. Silin M.A. et al. Kislotnye obrabotki plastov i metodiki ispytaniia kislotnykh sostavov [Acid treatment of reservoirs and methods of testing acid compositions]. Ed. V.S. Golubev. Moscow: Rossiiskii gosudarstvennyi universitet nefti i gaza imeni I.M. Gubkina, 2011, 120 p.
45. Morita N., Doi T., Kinoshita T. Stability of an open hole completed in a limestone reservoir with and without acid treatments. *SPE Journal*, 2005, vol. 10 (2), pp. 105-114. DOI: 10.2118/77776-PA
46. Rignol J., Ounsakul T., Kharrat W., Fu D., Teng L.K., Lomovskaya I., Boonjai P. Improved fluid technology for stimulation of ultrahigh-temperature sandstone formation. *Proceedings - SPE International Symposium on Oilfield Chemistry*, 2015, vol. 2, pp. 685-695. DOI: 10.2118/173755-MS
47. Shuchart, Chris E. Chemical study of organic-HF blends leads to improved fluids. *Proceedings - SPE International Symposium on Oilfield Chemistry*, 1997, pp. 675-678. DOI: 10.2118/37281-MS

### Библиографический список

1. Сагирова Л.Р., Влияние состава пород коллекторов на снижение проницаемости призабойной зоны скважины на примере Приобского месторождения // Нефть. Газ. Новации. – 2011. – № 2. – С. 10–12.
2. Щелкачев В.Н., Лапук Б.Б. Подземная гидравлика. – М. – Ижевск: РХD, 2001. – 735 с.
3. Geothermal well stimulation / Sinclair, A. Richard, Pittard, J. Frederick, Hanold, J. Robert // Transactions – Geothermal Resources Council. – 1980. – Vol. 4. – P. 423–426.
4. Sneddon I.N., Lowengrud M. Crack Problems in the Classical Theory of Elasticity. – New York: SIAM Series in Applied Mathematics, John Wiley & Sons, 1979. – P. 29–30.
5. Van Domelen, Mary S., Jennings Jr., Alfred R.Alternate acid blends for HPHT applications // Offshore Europe Conference – Proceedings. – 1995. – P. 523–530. DOI: 10.2118/30419-MS
6. Ибрагимов Л.Х., Мищенко И.Т., Челоянц Д.К. Интенсификация добычи нефти. – М. Наука. 2000. – 414 с.
7. Effective matrix acidizing in high-temperature environments / R. Aboud, K. Smith, L. Forero, L. Kalfayan // SPE Annual Technical Conference Proceedings. – 2007. – № 2. – P. 1066–1075. DOI: 10.2118/109818-MS
8. Yudovich A., Chin L.Y., Morgan D.R. Casing deformation in Ekofisk // Journal of Petroleum Technology. – 1989. – Vol. 41 (7). – P. 729–734. DOI: 10.2118/17856-PA
9. Al-Dahlan M.N., Nasr-El-Din H.A., Al-Qahtani A.A. Evaluation of Retarded HF Acid Systems // Proceedings – SPE International Symposium on Oilfield Chemistry. – 2001. – P. 457–476. DOI: 10.2118/65032-MS
10. Шумилов В.А., Аристов В.Н., Григорьян Н.А. Предохранение и восстановление проницаемости призабойной зоны при разработке месторождений Западной Сибири. – М.: Изд-во ВНИИОЭНГ, 1980. – 55 с.
11. Фахретдинов Р.И., Нигматуллина Р.Ф. Новые физико-химические аспекты повышения эффективности химреагентов в нефтедобыче. – Уфа: Гил ем, 1996. – 191 с.
12. Фахретдинов Р.И., Нигматуллина Р.Ф. Новые физико-химические аспекты повышения эффективности химреагентов в нефтедобыче. – М.: Недра, 1986. – С. 6–17.
13. Гадиев С.М. Вибровоздействие на призабойную зону скважину // Нефть и газ. – 1973. – № 5. – С. 47–50.
14. Комплексная технология увеличения нефтеотдачи пласта при заводнении с применением поверхностно-активного состава (ПАС) / М.М. Кабиров, М.Н. Персиянцев, Ш.А. Гафаров, В.Г. Султанов // Нефтепромысловое дело. – 1999. – № 10. – С. 45–47.
15. Кузнецова А.Н., Рогачев М.К. Регулирование фильтрационных характеристик нефтяных коллекторов с использование поверхностно-активных веществ / International research journal. – 2015. – № 10, Т 4. – С. 98–99.
16. Фахретдинов Р.Н., Земцов Ю.В., Новоселов Т.С. Гидрофобизация призабойной зоны гидрофильных коллекторов // Нефтяное хозяйство. – 1999. – № 4. – С. 29–30.
17. Сафин С.Г. Физико-химические исследования для качественного управления воздействием на призабойную зону пласта // Нефтяное хозяйство. – 2003. – № 2.
18. Di Lullo, Gino, Rae, Phil New acid for true stimulation of sandstone reservoirs // SPE – Asia Pacific Oil & Gas Conference. – 1996. – P. 477–486. DOI: 10.2118/37015-MS
19. McLeod H.O. Significant Factors for Successful Matrix Acidizing // SPE Centennial Symposium at New Mexico Tech. Society of Petroleum Engineers. – 1989. DOI: 10.2118/20155-MS
20. Рогачев М.К., Мухаметшин В.В., Кулешова Л.С. Повышение эффективности использования ресурсной базы жидких углеводородов в юрских отложениях Западной Сибири // Записки Горного института. – 2019. – Т. 240. – С. 711. DOI: 10.31897/pmi.2019.6.711
21. Шагиахметов А.М., Петраков Д.Г., Рязанов А.А. Разработка водоизоляционного состава для трещиноватых и трещинно-поровых коллекторов на основе карбоксиметилцеллюлозы // Нефтепромысловое дело. – 2016. – № 3. – С. 30–35.
22. Motta E.P. da, Plavnik B., Schechter R.S. Optimizing Sandstone Acidization // SPE Reserv. Eng. – 1992. – Vol. 7, № 01. – P. 149–153. DOI: 10.2118/19426-PA
23. Тананыхин Д. С., Шагиахметов А. М. Justification of technology and fluids for treatment of the unconsolidated carbonate reservoirs // International Journal of Applied Engineering Research. – 2016. – Vol. 11, № 1. – P. 744–748.
24. Тананыхин Д.С., Шагиахметов А.М., Кораблев Е.М. Лабораторные исследования энергоэффективной технологии повышения коэффициента извлечения нефти из карбонатных обводненных коллекторов // Мир науки. – 2015. – № 2. – С. 214–217.
25. Магадова Л.А., Силин М.А., Тропин Э.Ю. Кислотная композиция «Химеко ТК-2» для низкопроницаемых терригенных коллекторов // Нефтяное хозяйство. – 2003. – С. 80–81.
26. Дополнение к технологической схеме разработки Хохряковского месторождения / Сибирский науч.-исслед. ин-т нефтяной пром-сти (СибНИИНП); рук. Л.С. Бриллиант. – Тюмень, 1994. – 180 с.
27. Acidizing – Schlumberger Oilfield Glossary [Электронный ресурс]. – URL: http://www.glossary.oilfield.slb.com/Terms/a/acidizing.aspx (дата обращения: 17.05.2018).
28. Rae P., Di Lullo G. Achieving 100 Percent Success in Acid Stimulation of Sandstone Reservoirs // SPE – Asia Pacific Oil and Gas Conference. – 2002. – P. 127–133. DOI: 10.2118/77808-MS
29. Shafiq M.U., Mahmud H. Ben. Sandstone matrix acidizing knowledge and future development // J. Pet. Explor. Prod. Technol. Springer Berlin Heidelberg. – 2017. – Vol. 7, № 4. – P. 1205–1216. DOI: 10.1007/s13202-017-0314-6
30. Подопригора Д.Г., Мардашов Д.В. Разработка кислотного состава для условий высокотемпературных терригенных пород-коллекторов / Нефтегазовое дело. – 2015. – № 6. – С. 162–178.
31. Подопригора Д.Г., Шангараева Л.А. Разработка кислотного состава для обработки призабойной зоны скважин в условиях высоких пластовых температур // Нефтяное хозяйство. – 2016. – № 4. – С. 122–124.
32. Combining matrix stimulation and gravel packing using a non-acid based fluid / F. Armirola, M. Machacon, C. Pinto, A. Milne, M. Lastre, E. Miquilena // Society of Petroleum Engineers – 9th European Formation Damage Conference. – 2011. – Vol. 1. – P. 502–515. DOI: 10.2118/143788-MS
33. Рогов Е.А. Исследование проницаемости призабойной зоны скважин при воздействии технологическими жидкостями // Записки Горного института. – 2020. – Т. 242. – С. 169. DOI: 10.31897/pmi.2020.2.169
34. Дык В.К. Анализ применения кислотных обработок призабойной зоны пласта на Y нефтяном месторождении (Томская область). – Томск, 2015.
35. Ковалев Е.Н. Оценка эффективности применения соляно-кислотных обработок на X нефтяном месторождении (ХМАО). – Томск, 2016.
36. Пыхачев Г.Б., Исаев Р.Г. Подземная гидравлика. – М.: Недра, 1973. – 359 с.
37. Анализ эффективности методов ОПЗ эксплуатационных и нагнетательных скважин НГДУ «Нурлатнефть» / Ш.Я. Гилязов, Р.З. Манапов, Р.А. Сафиулин, Н.И. Волкова, М.Ф. Вахитов // Нефтепромысловое дело. – 2000. – № 6.
38. Вердеревский Ю.Л. Увеличение продуктивности скважин в карбонатных коллекторах составами на основе соляной кислоты / Ю.Л. Вердеревский, Ю.Н. Арефьев, М.С. Наганов, В.С. Асмоловский, Ф.Х. Сайфутдинов // Нефтяное хозяйство. – 2000. – № 1. – С. 39–40.
39. Амиян В.А., Васильева Н.П., Джавадян А.А. Повышение нефтегазоотдачи пластов путем совершенствования их вскрытия и освоения. – М., 1977. – 80 с.
40. Сучков Б.М. Повышение производительности мало дебетных скважин. – Ижевск: УдмуртНИПИнефть, 1999. – 645 с.
41. Рогачев М.К., Мухаметшин В.В. Контроль и регулирование процесса солянокислотного воздействия на призабойную зону скважин по геолого-промысловым данным // Записки Горного института. – 2018. – Т. 231. – С. 275. DOI: 10.25515/pmi.2018.3.275
42. Ахундов М.С. О выборе решений при проведении обработок призабойных зон скважину // Азербайджанское нефтяное хозяйство. – 1990. – № 10. – С. 30–33.
43. Логинов Б.Г., Малышев Л.Г., Гарифуллин Ш.С. Руководство по кислотным обработкам скважин. – М.: Недра, 1966. – 219 с.
44. Кислотные обработки пластов и методики испытания кислотных составов: Учебное пособие для студентов вузов / М.А. Силин [и др.]; ред. В.С. Голубев. – М.: РГУ нефти и газа имени И.М. Губкина, 2011. – 120 с.
45. Morita N., Doi T., Kinoshita T. Stability of an open hole completed in a limestone reservoir with and without acid treatments // SPE Journal. – 2005. – Vol. 10 (2). – P. 105–114. DOI: 10.2118/77776-PA
46. Improved fluid technology for stimulation of ultrahigh-temperature sandstone formation / J. Rignol, T. Ounsakul, W. Kharrat, D. Fu, L.K. Teng, I. Lomovskaya, P. Boonjai // Proceedings – SPE International Symposium on Oilfield Chemistry. – 2015. – Vol. 2. – P. 685–695. DOI: 10.2118/173755-MS
47. Shuchart, Chris E. Chemical study of organic-HF blends leads to improved fluids // Proceedings – SPE International Symposium on Oilfield Chemistry. – 1997. – P. 675–678. DOI: 10.2118/37281-MS