



Research article
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Scientific justification of the perforation methods for Famennian deposits in the southeast of the Perm Region based on geomechanical modelling

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Abstract. The article presents the results of analysing geological structure of the Famennian deposits (Devonian) in the Perm Region. Numerical modelling of the distribution of inhomogeneous stress field near the well was performed for the two considered types of perforation. With regard for the geometry of the forming perforation channels, numerical finite element models of near-wellbore zones were created considering slotted and cumulative perforation. It is ascertained that in the course of slotted perforation, conditions are created for a significant restoration of effective stresses and, as a result, restoration of reservoir rock permeability. Stress recovery area lies near the well within a radius equal to the length of the slots, and depends on the drawdown, with its increase, the area decreases. From the assessment of failure areas, it was found that in case of slotted perforation, the reservoir in near-wellbore zone remains stable, and failure zones can appear only at drawdowns of 10 MPa and more. The opposite situation was recorded for cumulative perforation; failure zones near the holes appear even at a drawdown of 2 MPa. In general, the analysis of results of numerical simulation of the stress state for two simulated types of perforation suggests that slotted perforation is more efficient than cumulative perforation. At the same time, the final conclusion could be drawn after determining the patterns of changes in permeability of the considered rocks under the influence of changing effective stresses and performing calculations of well flow rates after making the considered types of perforation channels.

Keywords: well completion; perforation methods; numerical simulation; effective stresses; reservoir permeability

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Introduction. Raw material complex is a very important element of the world economy [1]. At the present stage of development, the fuel and energy resource complex should ensure a rational use of natural resources by applying the most efficient technologies for the development of hydrocarbon fields [2]. High-quality perforation development of pay zones is the basis for unimpeded filtration of fluids from reservoir to the well [3]. Complexly structured carbonate deposits are among the most promising sources for increasing the resource base of hydrocarbons throughout the world [4-6]. The article considers perforation of the Famennian carbonate pays in the southeast of the Perm Region.



Famennian deposits of the Devonian system in the Perm Region only recently became a potential object for oil prospecting and production. The first oil shows in the Famennian deposits were recorded in the mid-20th century, but until the 1990s they had no commercial significance [7]. Numerous works of the Russian geologists (V.M.Provorov, V.I.Galkin, T.V.Karaseva, G.F.Ulmishek and others) are dedicated to the study of oil-and-gas potential of the Famennian in the Volga-Urals Province. The most relevant studies of the Famennian in the Volga-Urals Province are [8-10], which analyse the lithofacies and biostratigraphic features, patterns of spatial changes in the porosity and permeability properties (PPP) of the Famennian reservoirs pointing to a high potential of this interval. It is important to note that the Famennian deposits are comprised into carbonaceous carbonate-siliceous rocks of domanik type. In [11-13] geochemical features of the Famennian section, which is characterized by a high content of organic matter of sapropelic and mixed types, are considered. Oil and gas potential of the Upper Devonian carbonate deposits is also a subject of discussion in the Timan-Pechora Province. Lithogenetic features (lithotypes, secondary transformation processes), reservoir properties, patterns of structure and distribution of reservoir rocks of the Famennian deposits in the Central Khorej Ver reefogenic zone are considered in detail in [14-16]. From the analysis of the above works, it follows that the Famennian sequence is characterized by geological heterogeneity of the section which is due to the cyclical nature of the sedimentation process and various lithofacies environments. It was ascertained that the most important secondary processes of rock transformation are fracturing and leaching. The most high-capacity types of reservoirs are porous-cavernous and porous-fractured-cavernous. Taken together, the cyclicity of the section and various lithofacies zones are the main factors influencing the spatial distribution of Famennian reservoirs.

At present, the Famennian carbonate strata are not adequately studied by geophysical methods and drilling in comparison with the main oil-and-gas bearing complexes in the Perm Territory. The Famennian deposits are widespread in the study area and are composed everywhere of limestones and dolomites with a variable proportion of sulphate and clay rocks with total thickness from 100 m (in the axial zone of the Kama-Kinel trough system) to 400-500 m (within the Famennian barrier reefs) [17]. In the Famennian section, five pay formations are distinguished – from Fm1 to Fm5. Oil fields occur at depths from 1,560 to 2,355 m [18]. Until the early 1990s, in most cases, sampling, testing, and coring were not carried out in this section interval. As a result of exploration work, starting from 1990, in the southern and southeastern Perm Territory, commercial oil occurrences were discovered at 23 fields in the Famennian (Upper Devonian); total recoverable oil reserves were over 12 million tons [18]. Thus, the discovery of the Famennian deposits expands the productivity range of the section increasing the potential for prospecting and development of new pay zones in the region, which, in turn, requires a comprehensive study of the pay zones and production technologies.

The object of interest in this article is the slope bioherm type of Famennian section lying in the marginal part of the Bashkirian Vault. This zone is subdivided into two types of section: a low-permeable slope section and a paleokarst slope section [9].

In the Timan-Pechora [14, 16, 19] and Volga-Urals provinces [9, 20, 21], a specific feature of the Famennian deposits is their exceptional heterogeneity in sedimentation cycles represented by alternation (rhythms) of low-permeability and porous limestones. Low-permeability rhythms are composed of dense fine-grained limestones with a minor presence of clayey deposits. Porous limestones are characterized by a cavernous texture. Among the important features of the Famennian carbonate deposits is the development of fracture systems [22].

Predominant development of voids is associated with the structural factor, lithofacies zoning, and secondary processes (karst formation, dolomitization, sulphitization) which occurred in the carbonate sequence [23]. Reservoirs in this case are massive reefogenic carbonates and various inter-



beds among dense rocks. The presence of good reservoir zones is confirmed by high oil yields at several fields. The values of reservoir properties (porosity, permeability, and oil saturation) vary extensively.

As a whole, a complex geological structure affects the difference in the PPP even within one field (occurrence), which leads to a difference in well testing results, in terms of initial flow rates, well productivity and production dynamics.

Two wells drilled in the northern Bashkirian Vault, in the slope bioherm facies zone were selected for analysis (Fig.1). Well N 291 was drilled at the Pavlovskoye area within the Vostochno-Detkinskaya structure. The well belongs to the slope paleokarst type. Reservoirs in this type of section have a reef initial genesis, but at the same time they are intensely transformed by the secondary (karst) processes, which has a positive effect on the PPP. Well N 17 is in the Trushnikovskoye area within the local structure of the same name and corresponds to the low-permeability slope type.

Famennian deposits in the Pavlovskoye-291 well were penetrated in the interval 1,572.9-1,800.6 m. Oil-saturated reservoirs occur at depths 1,738.6-1,753.9 m and are composed of brownish-grey limestones, massive, fine- and cryptocrystalline, dense, hard, cavernous. Reservoir rocks are of mixed (porous-cavernous) type. When testing in the process of drilling the pay formation Fm4 for 13 minutes, an inflow of highly carbonated oil in the volume of 5.039 m³ was recorded. As a result of testing Fm4, an inflow of oil with water was obtained with flow rate $Q_o = 17.7$ t/day and $Q_w = 10.2$ t/day.

In Trushnikovskoye-17 well, the Famennian occurs at depths 1,470.9-1,715.3 m. In the interval of 1,618.7-1,654.0 m, oil-saturated reservoirs belonging to porous and porous-cavernous types were identified. Reservoir rocks are composed of grey, brownish-grey limestones, medium- and coarse-crystalline, massive, mostly dense, in places porous, hard. The reservoir is characterized by fracturing. Fractures are mineralized, open, subhorizontal, multidirectional, often attenuating, from 3 to 10 cm long; openness of fractures along the layer is on average to 0.25-0.3 mm; fracture walls are composed of calcite with bitumen and oil spots or filled with oil. When testing the well, a non-commercial inflow of oil with water and gas was recorded with flow rate $Q_l = 0.6$ m³/day.

Even though the reservoirs are composed of coeval rocks, well flow rates differ significantly. A possible reason for such an inflow is the pay zone perforation method. Both wells in the intervals of the pay zone were penetrated by cumulative perforation. Penetration of pay formations by cumulative perforation leads to a change in the initial stress-strain state (SSS) of productive formations near the well and, in some cases, to problems in inducing the inflow.

Considering varying degrees of success when developing coeval productive formations as well as the results of previous work on assessing the effect of the changing average effective stress on rock permeability, it is necessary to evaluate the effect of the forming perforation channels on the SSS of reservoir in near-wellbore zone [24].

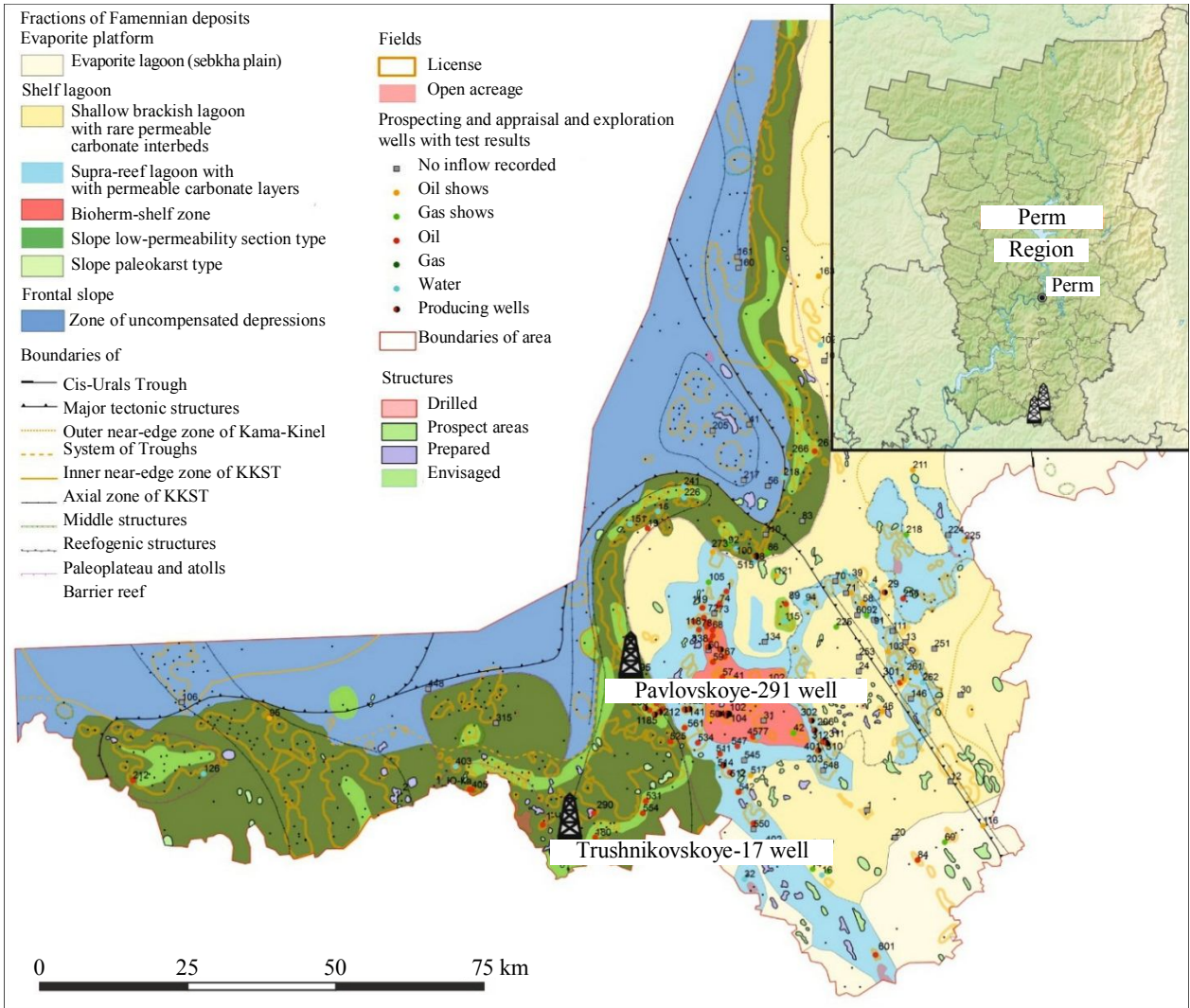
When modeling the SSS of the Famennian carbonate deposits, two types of perforation channels were considered forming during cumulative and slotted perforation [25-27].

In scientific literature, the problem of numerical modelling of SSS near perforation channels and slots is not adequately covered, except the publications on slotted [24, 28, 29] and cumulative [30-32] perforation. However, these works cover only certain aspects of modelling these types of perforation. In [32, 33], the problem of column deformation when making cumulative holes is considered, and there is no analysis of stresses in the reservoir rock. In publication [34], sand removal was modelled when making a perforation hole based on a discrete model. At the same time, there is no comparative analysis of the efficiency of slotted and cumulative perforation in relation to a specific pay zone in the above publications.

Thus, the main goal of the study is the development of numerical finite element models of near-wellbore zone considering the geometry of slotted and cumulative perforation channels, based



a



b

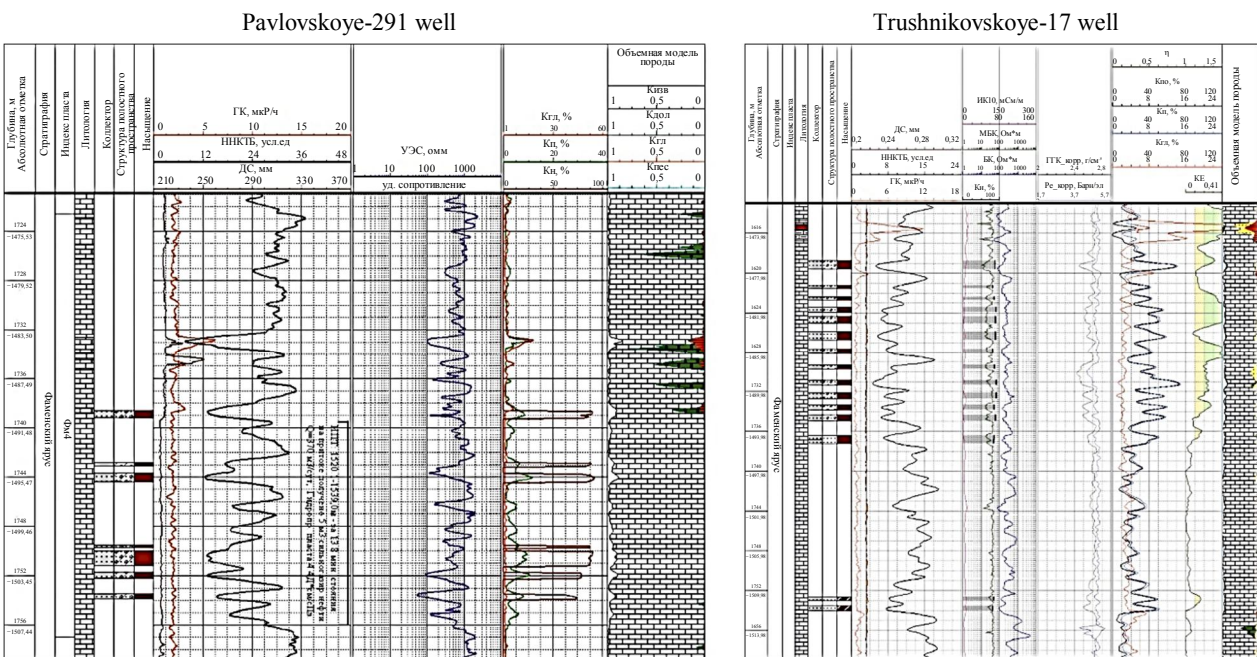


Fig. 1. Lithofacies scheme of Famennian in the southern Perm Region (a) and interpretation of Pavlovskoye-291 and Trushnikovskoye-17 wells logging (b)



on generalization of geological information and field research of wells. Multivariate numerical modelling was performed for various well operation modes, and the most efficient perforation method for the considered pay zone was determined; recommendations were drawn up on optimizing well operation modes for the two considered perforation types.

Methodology. To evaluate the efficiency of perforating productive formations represented by the Famennian carbonate deposits, using the methods of cumulative and slotted perforation, an analysis of the inhomogeneous stress field in near-wellbore zone near the perforations was performed.

ANSYS finite element modelling software package was used to calculate the stress-strain state [29, 35]. This software implements the ratios describing poroelastic behaviour of a porous medium, and it is successfully used to solve geomechanical problems when developing hydrocarbon fields [36, 37]. The software has shown itself well in numerical calculations of geomechanical modelling problems [33, 38, 39], especially when considering the complex geometry of slotted and perforated holes [32, 40].

When modelling a poroelastic body in ANSYS it is planned to use CPT215 or CPT216 finite elements which simulate a porous reservoir, while numerically calculating differential equations that describe the basic principles of Biot theory. Relationship between the effective stresses and elastic deformations of a solid body is considered. The system of numerical calculations includes the equation of Darcy's law.

For numerical modelling of SSS when performing slotted and cumulative perforation, finite element schemes of near-wellbore zones were developed (Fig.2). Symmetry of the models allows considering only a sector of the cylindrical area of 90° , while the inner radius for both models was equal to the well radius of 0.108 m; outer radius of the scheme was 5 m for the model with slotted perforation and 3 m for the model with cumulative perforation; thickness of models was 0.75 and 0.167 m, respectively. For the model with slotted channels, two slots were made with an offset of 90° , cross section was set in the form of an ellipse, which had semiaxes of 0.02 and 0.4 m, height of the slots was 0.25 m (Fig.2, a). For cumulative perforation model, two holes were also made with a 90° offset, which corresponds to perforation density of 12 holes per 1 m of wellbore length. Hole geometry was an elongated ellipsoid with radii of 0.3 and 0.006 m.

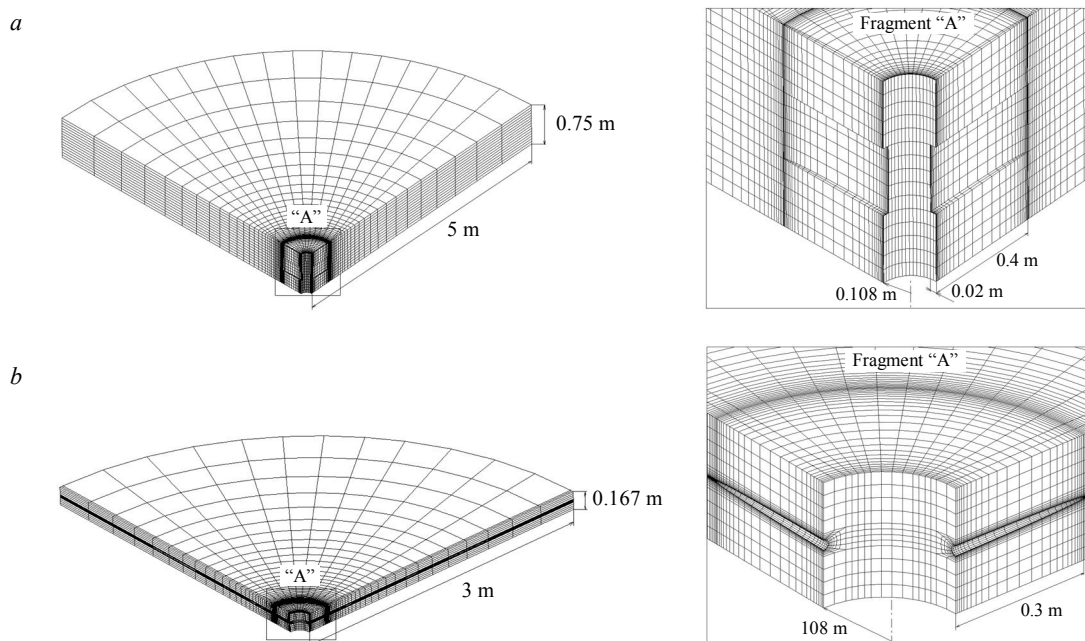


Fig.2. Finite-element scheme of near-wellbore zone used to simulate a change in SSS for slotted (a) and cumulative (b) perforation



Calculations were made on the example of Famennian deposits (Fm4) at the Trushnikovskoye and Pavlovskoye fields in the southern Perm Region. Table 1 shows the main geometric characteristics of the models. Table 2 shows the mechanical properties of rocks and pressure values used in calculations. These parameters were determined during geological field studies and laboratory tests of core samples as well as the studies of physical and mechanical properties of carbonate reservoir rocks in the fields under consideration. As can be seen from Table 2, strain-stress properties of these pay zones differ slightly, mainly because the reservoir of the Famennian deposits at the Pavlovskoye field is more porous.

In modelling, the following boundary conditions were set:

- pressure in the well (bottomhole pressure) as the difference between the initial formation pressure (pressure on external boundary of reservoir) and pressure drawdown;
- movements in the direction of x and y axes were fixed inside the well simulating a cased well;

Table 1

Geometric characteristics of finite-element models

Characteristic	Slotted perforation	Cumulative perforation
Outer radius of model, m	5	3
Thickness of model, m	0.75	0.167
Well radius, m	0.108	0.108
Radius of external boundary of reservoir, m	250	250
Perforation channel length, m	0.4	0.3
Maximum slot width, diameter of cumulative perforation, m	0.02	0.012

Table 2

Mechanical properties of rock and pressure values

Characteristic	Trushnikovskoye field	Pavlovskoye field
Elasticity modulus, GPa	30	28
Poisson's ratio, d.f.	0.3	0.3
Biot coefficient, d.f.	0.55	0.6
Ultimate stress in uniaxial compression, MPa	35	30
Angle of internal friction, deg	32	30
Formation depth, m	1,680	1,790
Vertical stress, MPa	42	45
Horizontal stress, MPa	24	25.6
Formation pressure, MPa	17.5	18.6
Drawdown pressure, MPa	2-10	2-10

- pressure on external boundary of the model was determined from the ratio

$$p = p_b - \Delta p \frac{\ln r / r_w}{\ln r_b / r_w}, \quad (1)$$

where p is the determined pressure value, MPa; p_b – pressure on external boundary, MPa; Δp – pressure drawdown, MPa; r_b – radius of external boundary, m; r_w – well radius, m; r – radius from well centre for which pressure value is determined, m;

- pressure on the surface of the slot and cumulative hole was set according to linear dependence on radial coordinate: at radius equal to that of the well, pressure was equal to bottom hole pressure, and at the top of perforations, pressure was determined from ratio (1) with radius equal to the length of the perforation channel plus well radius;

- displacements along the normal to the surface were fixed at the left, right and lower boundaries of the model (Fig.2, *b*);



- on the upper horizontal surface of the model, the value of vertical stresses from the overlying rock mass was applied.

Calculations were made for two options: for slotted perforation – cased hole calculation without perforation and with perforation; for cumulative perforation – calculation of initial stresses in the reservoir without a well and perforation holes, and with perforation. Based on these two calculation stages, the difference in average stresses between the first and second calculation options was determined for analysing the change in the stress field near perforations.

It should be noted that due to certain specific features of taking into account the cement stone and casing when modelling near-wellbore zone, at this stage of research, well casing was considered only by setting boundary conditions as zero displacements of well walls in horizontal plane as well as setting an impermeable well wall.

A change in average effective stresses was calculated in each finite element of the model from the following relationship:

$$\Delta\sigma = \frac{(\sigma_1^{(1)} + \sigma_2^{(1)} + \sigma_3^{(1)}) - (\sigma_1^{(0)} + \sigma_2^{(0)} + \sigma_3^{(0)})}{3(\sigma_1^{(0)} + \sigma_2^{(0)} + \sigma_3^{(0)})} \cdot 100, \quad (2)$$

where $\Delta\sigma$ is a change in average effective stress, %; $\sigma_1, \sigma_2, \sigma_3$ – the main effective stresses (superscripts correspond to the calculation stage), MPa.

To assess the stability of rocks and appearance of areas with plastic deformations, the Coulomb – Mohr criterion was used in the main effective stresses:

$$\sigma_1 - \alpha p = \sigma_c + (\sigma_3 - \alpha p) \frac{1 + \sin \varphi}{1 - \sin \varphi}, \quad (3)$$

where σ_1, σ_3 are the main maximum and minimum stresses, MPa; σ_c ultimate strength of rock under uniaxial compression, MPa; φ – angle of internal friction, degrees; p – formation pressure, MPa.

Results. Figures 3-6 show some of the results of numerical calculations. Based on simulation results, it was found that pressure in near-wellbore zone for cumulative and slotted perforation is distributed evenly and reflects the logarithmic dependence of this characteristic in the reservoir, in the zone remote from perforation, and corresponds to a linear dependence on the wall of slots and the wall of cumulative holes.

As can be seen from Fig.3, *a*, areas of reservoir with the minimum average stress lie on the surfaces of slot walls, i.e., they should have the maximum permeability. The maximum average stresses are concentrated at the tops of slots and, on the contrary, reflect areas with the greatest decrease in permeability.

The efficiency of applying slotted perforation is evidenced by the calculation results presented in Fig.4, which show the distribution of the stress recovery area obtained from dependence (2). As can be

seen from Fig.4, after making the slotted perforation inside the area bounded by the radius equal to the length of slots, a zone of effective stress reduction forms, i.e., permeability should be restored in this area.

The calculation results showed that with increasing drawdown on the reservoir, the magnitude and area of stress recovery decrease. Thus, for the drawdown of 2 MPa (Fig.4),

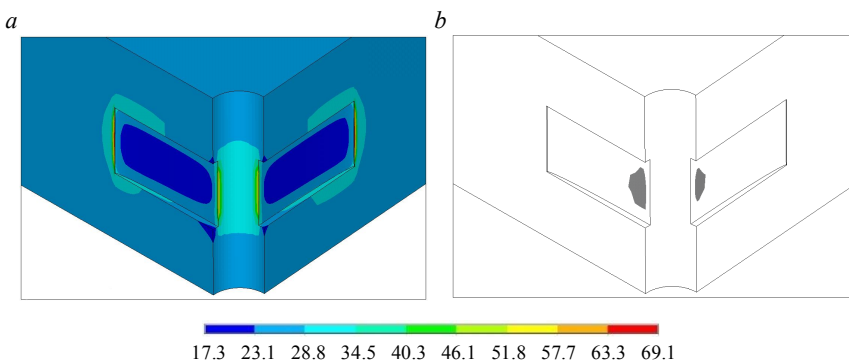


Fig.3. Distribution of average effective stresses (*a*) and failure zones according to Coulomb – Mohr criterion (*b*) near the well for slotted perforation for Famennian deposits at Pavlovskoye field and a drawdown of 10 MPa



the maximum recovery of stresses was approximately 40 %; with a drawdown of 10 MPa it decreased and amounted to about 20 %. This is quite natural, since with growing drawdown, the average effective stresses also increase, which leads to a decreasing effect of stress recovery due to slotted perforation. Areas of stress recovery when making slotted perforation for the Famennian deposits at both the Trushnikovskoye, and Pavlovskoye fields are almost identical.

In the second part of the calculations, modelling of cumulative perforation was performed. Figure 5 shows the distribution of average effective stresses determined from dependence (2). A similar stress distribution was recorded near perforations, both for conditions of the Trushnikovskoye and Pavlovskoye fields. As can be seen from Fig.5, the maximum stresses are concentrated at the sides of the perforation channel, which is caused by the effect of vertical stresses from the overlying rock mass. With growing drawdown, the value of average effective stresses increases by approximately the magnitude of the change in drawdown (Fig.5). Concentration of stresses in these areas leads to emergence of failure zones (Fig.6).

Figure 6 shows areas of reservoir rock failure determined using Coulomb – Mohr criterion in the main effective stresses (3). For comparison, the calculation results for the Famennian deposits at the Trushnikovskoye and Pavlovskoye fields are given with a drawdown value of 2-10 MPa. For the pay zone at the Pavlovskoye field, even at a drawdown of 2 MPa, there are areas with destruction of the lateral surface of cumulative perforation. These areas begin to grow with increasing drawdown, which is associated with increasing effective stresses.

A similar pattern is observed for the Famennian deposits at the Trushnikovskoye field. However, areas of broken rocks appear at a drawdown of 6 MPa, which indicates a greater strength of these carbonate deposits. Emergence of areas of broken rocks can point to both positive, and negative effects. The positive effect is because fracturing can occur in such areas that will lead to a growing

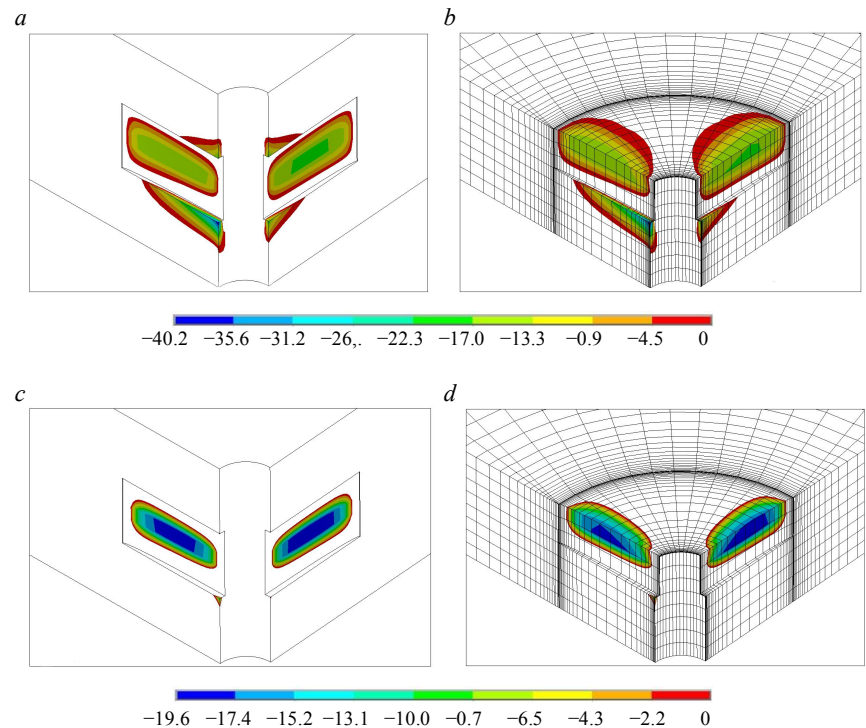


Fig.4. Distribution of effective stress change (%) in the model (a, c) and on the section in the middle of slots (b, d) near the well for slotted perforation in Famennian deposits at Pavlovskoye field for drawdown equal to 2 (a, b) and 10 (c, d) MPa

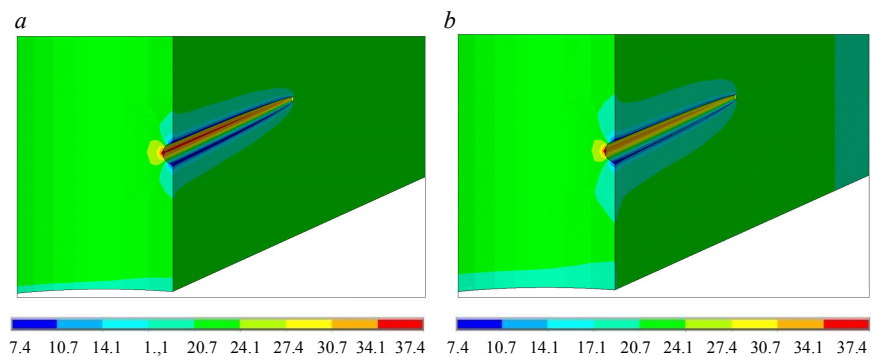


Fig.5. Distribution of average effective stresses (MPa) near the well for cumulative perforation for Famennian deposits at Pavlovskoye field at drawdown equal to 2 (a) and 10 (b) MPa

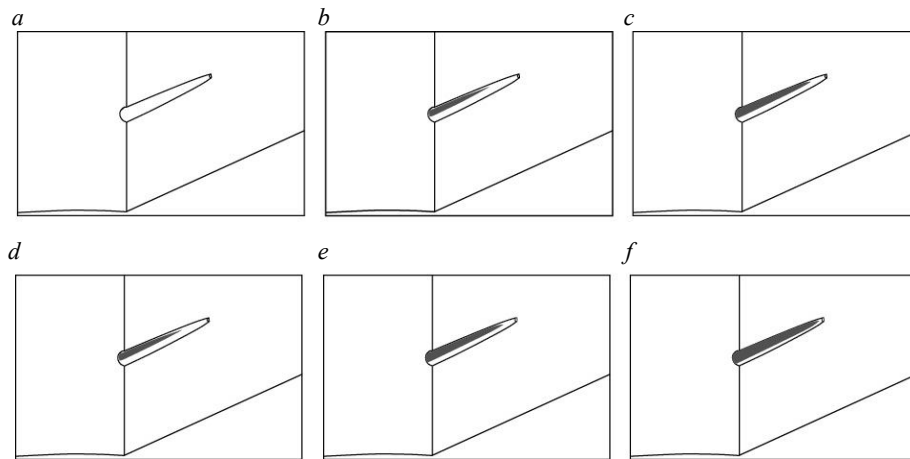


Fig.6. Dynamics of reservoir rock failure zones near cumulative perforation holes according to Coulomb – Mohr criterion for Famennian deposits at Trushnikovskoye (a, b, c) and Pavlovskoye (d, e, f) fields at drawdown equal to 2 (a, d), 6 (b, e) and 10 (c, f) MPa

permeability of rock near perforation. At the same time, the occurrence of such areas can lead to rock removal into the well and blockage of filtration channels, and even greater rock collapse in near-wellbore zone.

Simulation results showed that, unlike cumulative perforation, in case of slotted perforation, failure areas near the well appear only at high drawdowns – 10 MPa and more for the conditions of Famennian deposits at the Pavlovskoye field with lower strength properties compared to the Trushnikovskoye field, which indicates a better stability of slotted channels and the efficiency of slotted perforation.

Based on results of assessing the change in average main effective stresses in near-wellbore zone after cumulative perforation, it was found that the area of stress recovery is small. It is concentrated in the upper and lower parts of the perforation hole and is comparable in volume to the area of stress reduction at the sides of the hole. Based on comparison of similar simulation results for slotted perforation, it can be concluded that making of slotted channels leads to formation of a larger area with stress recovery (compared to cumulative perforation), which should result in partial restoration of permeability in this area and an increase in well productivity.

Discussion. Numerical calculations using the finite element model of near-wellbore zone with slotted perforation showed that on the side walls of slotted channels there are areas with the minimum value of average effective stresses (Fig.3), which indicates that in such areas the lowest compressive stresses are acting and, as a result, the maximum rock permeability should be recorded. This effect is more clearly demonstrated in Fig.4, which shows the areas and magnitude of stress reduction on the example of the Pavlovskoye field. It follows from Fig.4 that average effective stresses decrease to 40.2 % at a drawdown of 2 MPa and to 19.6 % at a drawdown of 10 MPa. This should result in a growing permeability on slot walls in near-wellbore zone after making slotted perforation. Based on calculation results shown in Fig.4, it can be noted that an increasing drawdown leads to growing effective stresses and a decrease in zones and magnitude of stress reduction (from 40.2 to 19.6 %), which should lead to a decreasing reservoir permeability in the study area. In general, the results of numerical simulation of slotted perforation for the two studied geological bodies were similar. The only difference was that for the Tournaisian-Famennian deposits at the Pavlovskoye field, at a drawdown of 10 MPa, small areas of failure appeared on walls of the perforation channels. This is due to the following: reservoir rock of the pay zone at the Pavlovskoye field has worse mechanical properties compared to the Trushnikovskoye field.



Results of numerical modelling of cumulative perforation holes for two considered pay zones showed that on the side surfaces of perforation there are areas of maximum average effective stresses, and in the upper and lower parts of the holes – minimal ones. At the same time, with drawdown growing from 2 to 10 MPa, the value of maximum average stresses increases from 37.4 to 45.5 MPa, i.e., by 22 % (Fig.5). The value of minimum average effective stresses also increases from 7.4 to 8.9 MPa, i.e., by 20 %. As in the case of slotted perforation, growing drawdown pressure leads to an increase in average effective stresses, which, in turn, should result in decreasing near-wellbore zone permeability. An increase in stresses on side surfaces of perforation channels due to growing drawdown leads to an increase of failure zones (Fig.6). The results of the stress field analysis based on Coulomb – Mohr criterion showed that for the conditions at the Pavlovskoye field, areas of rock failure appear even at drawdown of 2 MPa, and for the Trushnikovskoye field, at 6 MPa. When making cumulative perforation without considering the drawdown, effective stresses increase by 69 % on the sides of the holes; and in the upper and lower parts of the holes, on the contrary, they decrease by 66 %. This result suggests that in the upper and lower parts of cumulative perforation, an increase in rock permeability is possible, and on the side surfaces, a decrease.

Analysis of the results of numerical simulation of stress state for two simulated types of perforation suggests that in some cases slotted perforation is more efficient than cumulative perforation. The conclusion can be drawn from the results of determining the patterns of changes in permeability of the considered rocks under the influence of changing effective stresses.

Pay zones under consideration have a fractured-porous reservoir type, and a change in the stress field near perforations should lead to significant variations in permeability of fracture systems, which are very sensitive to changes in effective stresses in rock. This factor should also be considered in further investigations of the inhomogeneous stress field near perforation channels using the studied carbonate formations as an example.

Conclusion. The results obtained are of great practical importance. Based on the data of numerical modelling of near-wellbore zone, the use of slotted perforation is recommended as a sparing and most efficient method for perforation of the considered pay zones. In the presence of slotted perforation channels, it becomes possible to create a sufficiently large drawdown (to 10 MPa) excluding the risks of reservoir rock failure in near-wellbore zone. In case of using cumulative perforation, especially for the pay zone at the Pavlovskoye field, it is recommended not to create high drawdowns, as this can lead to rock failure near the perforations. The developed numerical models can be adapted and used for other productive formations for determining the most efficient methods for perforation of productive layers and optimal well operation modes.

Main conclusions were drawn:

1. As part of the work, numerical finite element models of near-wellbore zones were produced considering slotted and cumulative perforation. Multivariate numerical simulation of stress-strain state in near-wellbore zone is considered when making slotted channels and cumulative perforations.

2. Based on the obtained stress field, a significant recovery of effective stresses when making slotted perforation is shown, which should lead to restoration of reservoir rock permeability. The area of stress recovery is near the well within a radius equal to the length of slots and depends on the drawdown value; with its increase, the areas decrease. Near cumulative perforations, stress recovery area is much smaller and comparable to the reduction area, which indicates that a significant recovery of permeability with this type of perforation is hardly possible.

3. Evaluation of failure areas using Coulomb – Mohr criterion showed that when making slotted perforation, the reservoir in near-wellbore zone remains quite stable, and failure zones can appear only at sufficiently high drawdowns – from 10 MPa and higher. An opposite situation was recorded for cumulative perforation – failure zones near the holes can appear even at drawdown of 2 MPa, which can lead to negative consequences, to blockage of the perforation channels and a decrease in fluid flow through the holes into the well.



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