NUMERICAL SIMULATION OF ACID INFLUENCE ON THE BOTTOM THROOM ZONE OF OIL FIELDS WITH CARBONATE RESERVOIRS TAKEN INTO ACCOUNT OF ROC FRACTURING

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Abstract

The paper considers the problem of modeling the acid impact on the bottomhole zone of oil fields with carbonate fractured-porous reservoirs. The process is modeled within the framework of the mechanics of multicomponent multiphase filtration using averaged values of filtration-capacitance parameters taking into account chemical kinetics.

Based on the proposed mathematical model in a flat-radial setting, the advancement of acid and changes in the filtration characteristics of the bottomhole zone of the formation during the injection of the reagent are studied. The influence of acid solution injection modes on the processes occurring in the near-wellbore zone of the formation is assessed. Numerical calculations were performed and the process characteristics were determined.

Key words: Absolute permeability, component, concentration, mathematical modeling, saturation, porous blocks, acid solution, cracks, phase, filtration.

1. Introduction

Acid treatment of the bottomhole formation zone (BZZ) is the most common method of intensifying oil production. In the process of developing oil fields in the reservoir zone, reservoir properties deteriorate significantly due to contamination with heavy oil components and suspended particles coming from the formation into the reservoir zone, which leads to a decrease in well productivity.

The reservoir properties of the reservoir zone can also decrease due to irreversible deformations of the rock that occur when the reservoir pressure decreases, i.e. increasing effective pressure as the reservoir is exploited.

World experience in using acid treatment shows that the effectiveness of the method remains low, ranging from 30 to 40%. This situation is explained by the fact that the process of acid exposure is determined by a large number of factors, the mechanism and degree of influence of which are not fully understood.

Such a variety of influencing factors complicates the assessment of the effectiveness of the acid treatment process, and the optimal selection of geological, physical and technical and technological parameters plays an important role for the success of the activities. The above shows the relevance of conducting research into the process of acid exposure, taking into account the main influencing factors.

Of considerable interest is the study, including mathematical modeling, of filtration processes in media with the presence of cracks - narrow, extended channels of high conductivity.

Developed fracturing, both natural and technogenic, is inherent in many types of reservoirs [1]. Despite the fact that fractures occupy a small relative volume, due to their high conductivity their influence on hydrocarbon production can be decisive [2, 3]. Fractured fields contain more than 20%

of the world's oil and gas reserves [4], however, the development of such fields is associated with a number of difficulties and is often ineffective. For example [5], the Circle Ridge field in the USA has been developed for 50 years, while the oil recovery rate is only 15%.

A similar situation is observed in the Talinskaya area of the Krasnoleninsky field [6] - most of the field has been drilled with thousands of wells, but less than 10% of the initial reserves have been produced, while high waterflooding of the reservoir has been observed over the past 20 years. Additionally, due to the high demand for hydrocarbon raw materials, fields with low porosity and permeability, as well as, for example, carbonate reservoirs prone to fractures, are included in the development process. In the first case, the formation of cracks occurs due to the so-called hydraulic fracturing, which is one of the main methods for increasing oil recovery [7]

In the second case, due to the fragility of the rock, cracks can form naturally during the development of the field [6].

The study of filtration processes in media with disturbances in the form of cracks has a broader significance: problems of multiphase multi-component filtration in such media arise, for example, when modeling processes in nuclear reactors, as well as in studying the spread of contaminants during waste disposal [8].

A distinction is made between purely fractured and fractured-porous media [9]. The first of them are blocks with cracks between them, and the blocks themselves are impenetrable and do not exchange liquid with the cracks. In a fractured-porous medium, blocks are pieces of an ordinary porous medium that has porosity and permeability. In both cases, the volume of cracks is negligible compared to the total volume occupied by the solid skeleton and voids; in most cases, it is small compared to the total volume of voids, which includes the volumes of the pore space of the pore blocks and the cracks themselves.

Filtration in purely fractured media occurs qualitatively in the same way as in conventional porous media [10], with some quantitative deviations: in particular, averaging in this case is carried out not over pore sizes, but over block sizes. In the middle of the last century, works [11, 12] proposed a model of double porosity and double permeability, in which the medium is represented as two interconnected continua, and the system of cracks is assumed to be connected.

It should be noted that when using a binary medium model in numerical calculations, the number of unknowns doubles, which may be critical for considering complex multiphase multicomponent nonisothermal flows taking into account chemical reactions. In work [13], to take into account subseismic cracks, the characteristic distance between which is quite large - about 10 m, and the length is about 102 m, a single porosity model was built, which describes the properties of the medium within a single continuum, while absolute and relative phase permeabilities had a scalar character, and to describe the stage of rapid movement of water along cracks, the latter had a specific form.

This approximation turned out to be reasonable, and the authors were able to capture in the calculations using this model the features of waterflooding in a pilot section of one of the largest fields in the Middle East. It should be noted that the dimensions of subseismic cracks, as well as the fact that, as a rule [13,14,15], at the stage of calculating filtration flows, the geometry of cracks is considered given, allows us to speak about the deterministic distribution of features in the form of cracks in a certain environment, the effective filtration parameters of which need to be determined.

It is known from practice that in many cases the medium has anisotropy, and an example of an object exhibiting significant anisotropic properties is precisely a fractured medium. An analysis of the question that arises in connection with this circumstance about an expression that takes into account anisotropy for the flow between cracks and the matrix in the dual-medium model was carried out in [16] and is limited to theoretical calculations for the case of a pressure mechanism of exchange between the matrix and cracks [17], which makes it difficult to use in the general case. The single porosity approach turns out to be effective in a number of problems, but requires a more correct account of anisotropy, especially in the multiphase case [18].

Another feature of fluid filtration processes in fractured media is the presence of many characteristic scales, both in time and space. Regarding spatial scales, in most cases the volume of fractures is significantly less than the volume of pore space. Thus, in fractured media there is a significant difference in spatial scale. Due to the fact that the permeability of the fracture system is many times greater than the permeability of the pore channels, the speed of fluid movement through the cracks is much greater than the speed of movement through the pores, which leads to different time scales.

In [19], the approach of independent filtering in two directions is used, while additional restrictions are imposed for symmetrization, leading to an overdetermined system. In [20], the medium is considered as a system of layers parallel to each other, which makes it difficult to use the method proposed in it in more complex cases. In [21], the equivalence of the two above criteria for the method proposed in [22] was proven. In addition, it is shown that the permeability tensor obtained using this method is symmetric and positive definite.

The disadvantage is the assumption of a certain type of boundary conditions, namely their periodicity, which imposes a limitation on the class of permeability fields under consideration [23].

Numerous experimental data [24, 25] demonstrate the presence of certain types of symmetry in fractured media, therefore the analysis of the filtration properties of such objects, especially in the multiphase case, is of significant interest. It is noted in [26] that the movement of liquids and gases, and especially multiphase substances, in a fractured-porous formation has a number of features. In a fractured-porous formation, both rock blocks and the fractures themselves have capacitance and conductivity.

If the rock blocks are impenetrable, then the system of cracks can be considered a kind of filtering medium. The equation of unsteady motion of a homogeneous fluid in such a medium (in the case, of course, of weak compressibility of the medium) will be quite similar to the equation of motion of a homogeneous fluid in an ordinary porous medium, i.e., an equation of the type of thermal conductivity. If cracks in a fractured-porous formation are somehow made impermeable in the longitudinal direction, but permeable in the transverse direction, then, given that the volume of cracks is usually small compared to the pore volume of blocks, the fractured-porous formation will turn into almost an ordinary porous medium.

Thus, a fractured-porous medium can, in the limit, “transform” into both a medium with purely fractured porosity and an ordinary porous medium. In the general case, this medium contains signs of both a porous and purely fractured medium. Therefore, when mathematically describing the movement of a homogeneous fluid in a fractured-porous medium, it is natural to imagine this medium in the form of porous and fractured media “nested” into each other.

With steady fluid movement in a fractured-porous medium, this medium will behave as a medium whose conductivity is equal to the sum of the conductivities of the porous and fractured media. If the fluid movement in a fractured-porous medium is unsteady, the phenomenon of fluid exchange between the system of blocks and the system of cracks will come into play.

In [25,26], it is assumed that when water is injected into a fractured-porous formation, it displaces oil from the fractures, and oil flows from the rock blocks into the fractures due to capillary impregnation.

Works [27,28] are devoted to mathematical modeling of the processes of filtration of liquids and gases in a porous medium under acidic influence.

This paper presents a mathematical model of acid impact on the reservoir zone of oil fields with carbonate fractured-porous reservoirs. Unlike [25,26], oil displacement occurs from cracks and porous blocks. Unlike [27,28], a fractured-porous reservoir is considered.

1. Construction of a mathematical model.

We believe that the filtration process in an oil-water-saturated fractured-porous porous medium involves the aqueous phase, consisting of acid, salt, gas and actual water components, and the oil phase. The rock (the skeleton of a fractured-porous medium) is separated into a separate phase that does not take part in filtration. The gas formed as a result of the reaction of acid with carbonate does not completely dissolve in water. The rock is only partially dissolved by acid. Capillary forces are not taken into account.

A mathematical model of acid treatment of the near-wellbore zone of a fractured-porous oil reservoir with a carbonate reservoir in a plane-radial formulation can be represented in the form of equations.

- Equation for the conservation of mass of the acid component introduced into the formation:

$$\frac{\partial}{\partial t}\left(m^{(i)}\rho_a c_a^{(i)} S_w^{(i)}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho_a c_a^{(i)} V_w^{(i)}\right)=-J_a^{(i)}+$$

$$+\frac{1}{r}\frac{\partial}{\partial r}\left(\rho_a D^{(i)} m^{(i)}\frac{\partial}{\partial r}(rc_a^{(i)}S_w^{(i)})\right)+(-1)^{i-1}q_a \qquad (1)$$

where $J_a^{(i)} = M_a a_v^{(i)} R_a^{(i)}$ – mass of acid consumed per unit time per unit volume,

$E_f = E_f^0 \exp\left(-\frac{\Delta E}{RT}\right)$ - the reaction rate constant is determined by the Arrhenius relation (ΔE - activation energy, R - gas constant), M_a - molecular weight of acid

$m^{(i)}$ - porosity ρ_a - true acid density; $c_a^{(i)}$ - acid mass concentration; $S_w^{(i)}$ – saturation of the pore space with an aqueous solution; $D^{(i)}$ - molecular diffusion coefficient; t – time; $a_v^{(i)} = s^{(i)} / v^{(i)}$ specific surface area of reaction, - reaction surface area, - volume of PZP

; $q_a = \begin{cases} \rho_a c_a^{(2)} \frac{\alpha_w}{\mu_w}\left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} \geq 0 \\ \rho_a c_a^{(1)} \frac{\alpha_w}{\mu_w}\left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} < 0 \end{cases}$ – mass rate of acid exchange between porous blocks and a system of cracks, - a coefficient characterizing the intensity of exchange of an aqueous solution between systems of blocks and cracks, μ_w – viscosity of aqueous solution, $p^{(i)}$ – pressure; : 1 - cracks, 2 - porous blocks. - Equation for the conservation of mass of calcium chloride salt dissolved in water resulting from a chemical reaction:

$$\frac{\partial}{\partial t}\left(m^{(i)}\rho_{sc} c_{sc}^{(i)} S_w^{(2)}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho_{sc} c_{sc}^{(i)} V_w^{(i)}\right)= J_{sc}^{(i)}+(-1)^{i-1}q_{sc} \qquad (2)$$

where $J_{sc}^{(i)} = \gamma_{sc}^{(i)} J_a^{(i)}$ – the mass of calcium chloride salt resulting from the reaction per unit time per unit volume - the ratio of the molar weights of calcium chloride salt and acid participating in the reaction; - calcium chloride salt concentration; - density of calcium chloride salt,

$$q_{sc} = \begin{cases} \rho_{sc} c_{sc}^{(2)} \dfrac{\alpha_w}{\mu_w} \left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} \ge 0 \\ \rho_{sc} c_{sc}^{(1)} \dfrac{\alpha_w}{\mu_w} \left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} < 0 \end{cases}$$ – mass rate of exchange of calcium chloride salt between porous blocks and a system of cracks.

- Equation for the conservation of mass of magnesium chloride salt dissolved in water resulting from a chemical reaction:

$$\frac{\partial}{\partial t}\left(m^{(i)} \rho_{sm} c_{sm}^{(i)} S_w^{(i)}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r \rho_{sm} c_{sm}^{(i)} V_w^{(i)}\right) = J_{sm}^{(i)} + (-1)^{i-1} q_{sm} \qquad (3)$$

where $J_{sm}^{(i)} = \gamma_{sm}^{(i)} J_a^{(i)}$ – mass of magnesium chloride salt resulting from the reaction per unit time per unit volume, $\gamma_{sm}^{(i)}$ – the ratio of the molar weights of magnesium chloride salt and acid involved in the reaction; $c_{sm}^{(i)}$ - concentration of magnesium chloride salt; - density of magnesium chloride salt;

$$q_{sm} = \begin{cases} \rho_{sm} c_{sm}^{(2)} \dfrac{\alpha_w}{\mu_w} \left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} \ge 0 \\ \rho_{sm} c_{sm}^{(1)} \dfrac{\alpha_w}{\mu_w} \left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} < 0 \end{cases}$$ – mass rate of exchange of magnesium chloride salt between porous blocks and a system of cracks.

- Equation for the conservation of mass of the water component formed as a result of a chemical reaction and introduced into the formation:

$$\frac{\partial}{\partial t}\left(m^{(i)} \rho_w^0 c_w^{(i)} S_w^{(i)}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r \rho_w^0 c_w^{(i)} V_w^{(i)}\right) = J_w^{(i)^0} + (-1)^{i-1} q_w^0 \qquad (4)$$

where $J_w^{0^{(i)}} = \gamma_w^{(i)} J_a^{(i)}$ – mass rate of exchange of magnesium chloride salt between porous blocks and a system of cracks.

- Equation for the conservation of mass of the water component formed as a result of a chemical reaction and introduced into the formation:, $\gamma_w^{(i)}$ – the ratio of the molar weights of water and acid involved in the reaction;

$c_w^{(i)}$ - mass concentration of water ; ρ_w^0 – density of water

, $$q_w^0 = \begin{cases} \rho_w^0 c_w^{(2)} \dfrac{\alpha_w}{\mu_w} \left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} \ge 0 \\ \rho_w^0 c_w^{(1)} \dfrac{\alpha_w}{\mu_w} \left(p^{(2)} - p^{(1)}\right) & npu \quad p^{(2)} - p^{(1)} < 0 \end{cases}$$ – mass rate of water exchange between porous blocks and a system of cracks.

- Equation for the conservation of the mass of carbon dioxide formed as a result of a chemical reaction:

$$\frac{\partial}{\partial t}\left(m^{(i)} \rho_g c_g^{(i)} S_w^{(i)}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r \rho_g c_g^{(i)} V_w^{(i)}\right) = J_g^{(i)} + (-1)^{i-1} q_g \qquad (5)$$

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where $c_g^{(i)}$ – concentration of carbon dioxide in water; - true density of carbon dioxide; $J_g^{(i)} = \gamma_g^{(i)} J_a^{(i)}$ – mass of carbon dioxide formed per unit time per unit volume, $\gamma_g^{(i)}$ – the ratio of the molar weights of carbon dioxide and acid involved in the reaction;

$$q_g = \begin{cases} \rho_g c_g^{(2)} \dfrac{\alpha_w}{\mu_w}\left(p^{(2)} - p^{(1)}\right) \quad npu \quad p^{(2)} - p^{(1)} \geq 0 \\ \rho_g c_g^{(1)} \dfrac{\alpha_w}{\mu_w}\left(p^{(2)} - p^{(1)}\right) \quad npu \quad p^{(2)} - p^{(1)} < 0 \end{cases}$$

– mass rate of exchange of carbon dioxide between porous blocks and a system of cracks.

- Equation for the conservation of mass of insoluble rock particles formed as a result of a chemical reaction:

$$\frac{\partial}{\partial t}\left(m^{(i)}\rho_b c_b^{(i)} S_w^{(i)}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho_b c_b^{(i)} V_w^{(i)}\right)= J_b^{(i)} +(-1)^{i-1} q_b \qquad (6)$$

where $c_d^{(i)}$ – concentration of insoluble rock particles in water; ρ_b – true density of insoluble rock particles;

$J_b^{(i)} = \gamma_b^{(i)} J_a^{(i)}$ – mass of insoluble rock particles formed per unit time per unit volume, $\gamma_b^{(i)}$ – the ratio of the molar weights of insoluble rock particles and acid involved in the reaction;

$$q_b = \begin{cases} \rho_b c_b^{(2)} \dfrac{\alpha_w}{\mu_w}\left(p^{(2)} - p^{(1)}\right) \quad npu \quad p^{(2)} - p^{(1)} \geq 0 \\ \rho_b c_b^{(1)} \dfrac{\alpha_w}{\mu_w}\left(p^{(2)} - p^{(1)}\right) \quad npu \quad p^{(2)} - p^{(1)} < 0 \end{cases}$$

– the mass rate of exchange of insoluble rock particles between porous blocks and a system of fractures.

- Equation of conservation of mass of the aqueous phase:

$$\frac{\partial}{\partial t}\left(m^{(i)}\rho_w^{(i)} S_w^{(i)}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho_w^{(i)} V_w^{(i)}\right)= J_w^{(i)} +(-1)^{i-1} q_w$$

(7)

where

$$J_w^{(i)} = -J_a^{(i)} + J_{sc}^{(i)} + J_{sm}^{(i)} + J_w^{0\,(i)} + J_b^{(i)} + J_g^{(i)},$$

$$\rho_w^{(i)} = c_A^{(i)}\rho_A + c_{sc}^{(i)}\rho_{sc} + c_{sm}^{(i)}\rho_{sm} + c_w^{(i)}\rho_w^0 + c_b^{(i)}\rho_b + c_g^{(i)}\rho_g$$

$$q_w = q_w^0 + q_a + q_{sc} + q_{sm} + q_b + q_g\,.$$

Equation for conservation of mass of the oil phase:

$$\frac{\partial}{\partial t}\left(m^{(i)}\rho_o S_o^{(i)}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho_o V_o^{(i)}\right)= (-1)^{i-1} q_o \qquad (8)$$

where $S_o^{(i)}$ – saturation of the pore space with oil;

ρ_o - oil density; $q_o = \rho_o \alpha_o \left(p^{(2)} - p^{(1)}\right)$ – mass rate of gas exchange between porous blocks and a system of cracks, $\alpha_o = K^{(2)} a_v^{(2)^2} / \mu_o$ – the coefficient characterizing the intensity of oil exchange between systems of blocks and fractures is gas viscosity.

- Equation for conservation of mass of the rock skeleton:

$$\frac{\partial}{\partial t}\left(\left(1 - m^{(2)} - m^{(1)}\right)\rho_m\right) = -J_m^{(i)} \qquad (9)$$

where $J_m^{(i)} = \gamma_m^{(i)} J_a^{(i)}$ – mass of mineral dissolved per unit time per unit volume, $\gamma_m^{(i)}$ – the ratio of the molar weights of mineral and acid involved in the reaction; ρ_m – true rock density.

Equation for changing the position of the acid front:

$$\frac{dr_f^{(i)}}{dt} = \gamma_m^{(i)} \frac{\rho_a}{\rho_m} V_{fa}^{(i)} c_{fa}^{(i)} \qquad (10)$$

where $V_{fa}^{(i)}$ и $c_{fa}^{(i)}$ – flow rate and acid concentration at the acid front.

For the rate of phase filtration, Darcy's law is used:

$$V_w^{(i)} = -\frac{K^{(i)} k_w^{(i)}}{\mu_w} \frac{\partial p^{(i)}}{\partial r}, \quad V_o^{(i)} = -\frac{K^{(i)} k_o^{(i)}}{\mu_o} \frac{\partial p^{(i)}}{\partial r}, \qquad (11)$$

where $K^{(i)}$, $k_w^{(i)}$, $k_o^{(i)}$ – absolute and relative phase permeabilities of water and oil.

To calculate absolute permeability, the following empirical relationship is used:

$$K^{(i)} = K_0^{(i)} \left(\frac{m^{(i)}}{m_0^{(i)}}\right)^{\eta^{(i)}} \qquad (12)$$

where $\eta^{(i)}$ – constants determined from experimental data;

$m_0^{(i)}$, $K_0^{(i)}$ – initial porosity and absolute permeability.

- The equation for changing the specific surface area of the reaction is taken as:

$$a_v^{(i)} = a_0^{(i)} \frac{\left(1 - m^{(2)} - m^{(1)}\right)}{\left(1 - m_0^{(2)} - m_0^{(1)}\right)} \qquad (13)$$

where $a_0^{(i)}$, $m_0^{(i)}$ – initial specific surface area and porosity.

Adding obvious equalities

$$S_o^{(i)} + S_w^{(i)} = 1,$$

$$c_a^{(i)} + c_{sc}^{(i)} + c_{sm}^{(i)} + c_w^{(i)} + c_b^{(i)} + c_g^{(i)} = 1; \qquad (14)$$

Equations of state

$$\rho_w^0 = \rho_w^0(p), \quad \rho_o = \rho_o(p), \quad \rho_\alpha = \rho_\alpha(p), \quad \alpha = \{a, sc, sm, g, b\}; \qquad (15)$$

dependencies for viscosities

$$\mu_w^{(i)} = \mu_w^{(i)}(p), \quad \mu_o = \mu_o(p) \qquad (16)$$

and relative phase permeabilities

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$$k_o^{(i)} = \begin{cases} \dfrac{(1-S_w^{(i)})}{(1-S_{we}^{(i)})} & S_w^{(i)} > S_{we}^{(i)}, \\ 1 & S_w^{(i)} \le S_{we}^{(i)} \end{cases}$$

$$k_w^{(i)} = \begin{cases} \dfrac{(S_w^{(i)} - S_{we}^{(i)})}{(1-S_{we}^{(i)})} & S_w^{(i)} > S_{we}^{(i)}, \\ 0 & S_w^{(i)} \le S_{we}^{(i)} \end{cases} \qquad (17)$$

where $S_{we}^{(i)}$ – residual water saturation; initial conditions

$$p^{(i)}(r,0) = p^{(i)^0}, m^{(i)}(r,0) = m^{(i)^0}, S_w^{(i)}(r,0) = S_w^{(i)^0},\ S_o^{(i)}(r,0) = S_o^{(i)^0}, c_\alpha^{(i)}(r,0) = c_\alpha^{(i)^0},$$
$$\alpha = \{a, sc, sm, g, b\}; \qquad (18)$$

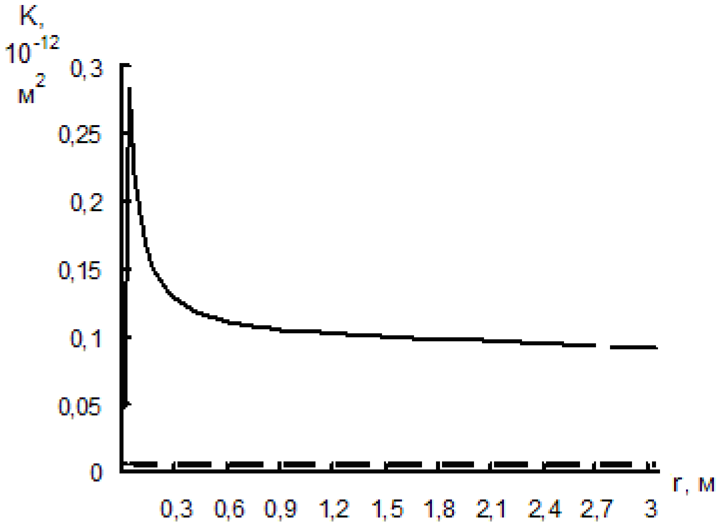
border conditions

$$V_w^{(i)}(0,t) = V_w^{(i)^c}(t),\ S_w^{(i)}(0,t) = 1,\ S_o^{(i)}(0,t) = 0,$$
$$c_\alpha^{(i)}(0,t) = c_\alpha^{(i)^c}(t), \alpha = \{o, a, sc, sm, g, b\},$$
$$p^{(i)}(L,t) = p^{(i)^0},\ \left.\frac{\partial c_a^{(i)}}{\partial r}\right|_{r=L} = 0 \qquad (19)$$

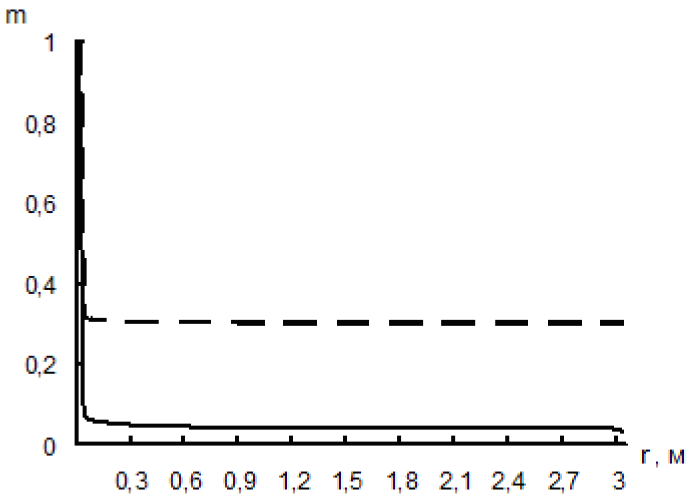
we obtain a closed system of equations (1) – (19), describing the physical and chemical processes occurring in the bottomhole zone of a fractured-porous gas formation during its acid treatment.

2. Computational experiment.

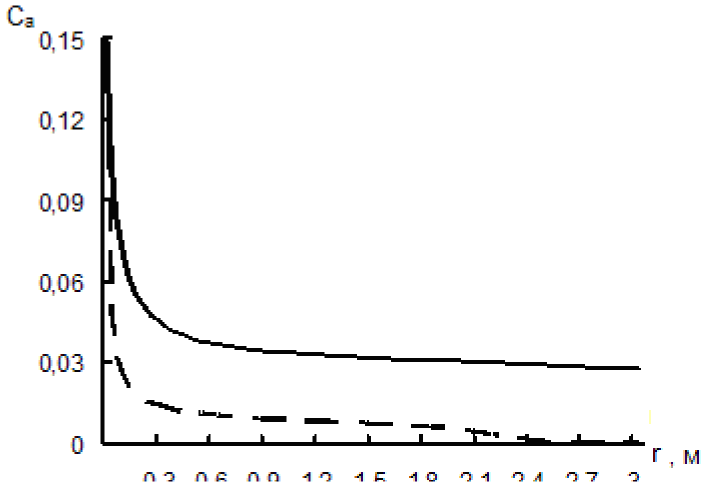
To study the influence of various modes of acid exposure on the bottom-hole zone of an oil reservoir, provided that the densities and viscosities of liquids and gases are constant, computational experiments were carried out using the following parameter values:
$\rho_a = 1190$ кг/м^3, $\rho_{sc} = 1396$ кг/м^3, $\rho_{sm} = 1396$ кг/м^3, $\rho_o = 807.2$ кг/м^3, $\rho_b = 2160$ кг/м^3, $\rho_w^0 = 1111.6$ кг/м^3, $\rho_m = 2160$ кг/м^3 , $\rho_g = 1.16$ кг/м^3 , $D = 10^{-8}$ м^2/с,, $\eta = 2$, $\alpha = 10$, $\chi_g = 10$ м$^{-1}$, $\chi_b = 1$ м$^{-1}$, $\gamma_{sc} = 0.76098$, $\gamma_{sm} = 0.65283$, $\gamma_w = 0.247051$, $\gamma_g = 0.603523$, $\gamma_b = 0.252877$, $\gamma_m = 1.011507$, $\mu_w = 1.768 \cdot 10^{-6}$ Па·с, $\mu_o = 807.2 \cdot 10^{-6}$ Па·с, $E_f^0 = 0.51 \cdot 10^{-6}$ м/с , $\Delta E = 86400$, $R = 8314$, T = 373 К, $a_0 = 0.3$ *м*$^{-1}$, $p^{(1)^0} = p^{(2)^0} = 0.1$ МПа, $c_w^{(1)^0} = 1$, $c_w^{(2)^0} = 1$, $S_o^{(1)^0} = 0.8$, $S_o^{(2)^0} = 0.8$, $V_w^c = 0.\ 135493 \cdot 10^{-5}$ м/с, $c_a^{(1)^c} = 0.15$, $c_w^{(1)^c} = 0.85$, $c_a^{(2)^c} = 0.15$, $c_w^{(2)^c} = 0.85$, L = 3 м, $t = 2592000$ с, $K_0^{(1)} = 0.048 \cdot 10^{-12}$ м^2, $K_0^{(2)} = 0.0048 \cdot 10^{-12}$ м^2, $m_0^{(1)} = 0.03$, $m_0^{(2)} = 0.3$.



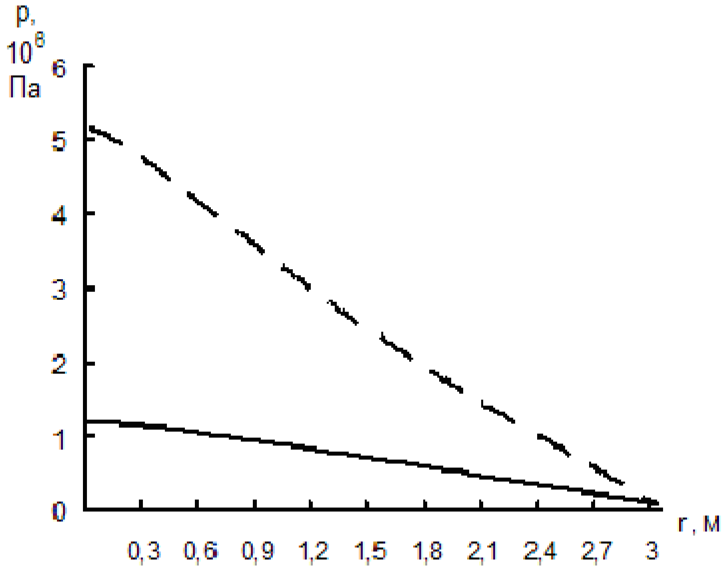
Pic. 1. Distribution of permeability in the reservoir zone during continuous injection of acid: t=10 days; solid line - cracks, dotted line - pores.



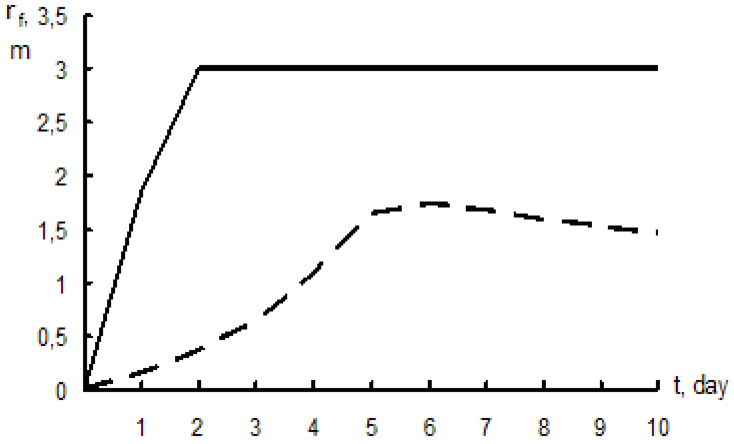
Pic. 2. Distribution of porosity in the deep-water zone during continuous injection of acid: t=10 days; solid line - cracks, dotted line - pores.



Pic.3 Distribution of acid concentration in the reservoir zone during continuous injection: t=10 days; solid line - cracks, dotted line - pores.

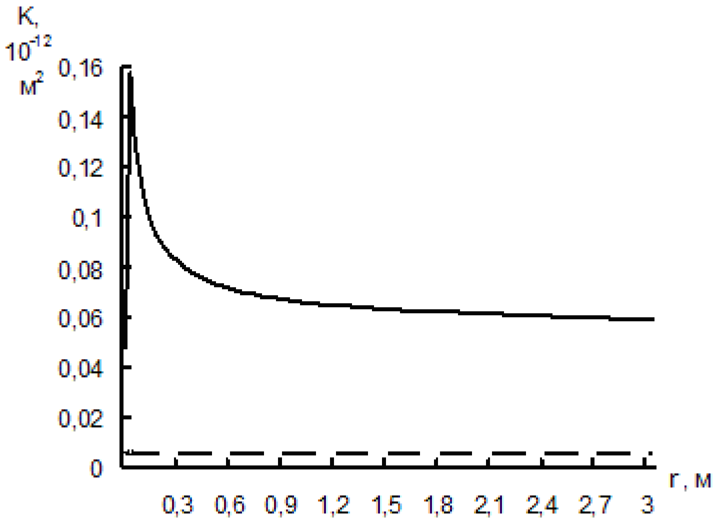


Pic.4. Pressure distribution in the reservoir zone during continuous injection of acid: t=10 days; solid line - cracks, dotted line - pores.

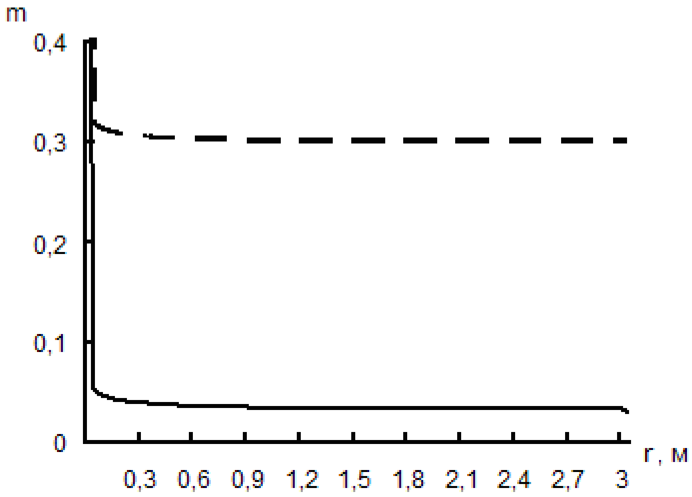


Pic.5. The position of the acid flow front in the reservoir zone during continuous injection: solid line - cracks, dotted line - pores.

In order to exclude early breakthrough of acid beyond the BFP, calculations were carried out with periodic injection of acid solution, the results of which are shown in Fig. 6-9. Changing the injection mode leads to an increase in pressure, both in porous blocks and cracks (Fig. 9). The acid front in porous blocks does not reach the PZP limits (Fig. 10). That is, all the injected acid is used to dissolve the rock.

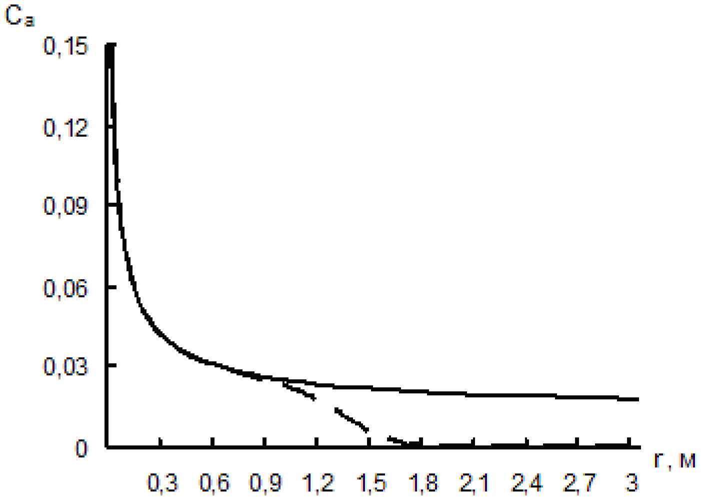


Pic.6. Distribution of permeability in the reservoir zone during periodic injection of acid: t=10 days; solid line - cracks, dotted line - pores.



Pic.7.

Distribution of porosity in the reservoir zone during periodic injection of acid: t=10 days; solid line - cracks, dotted line - pores.



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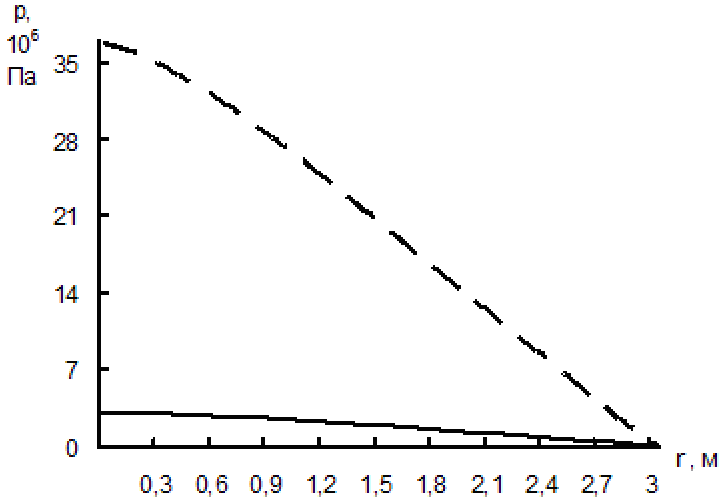
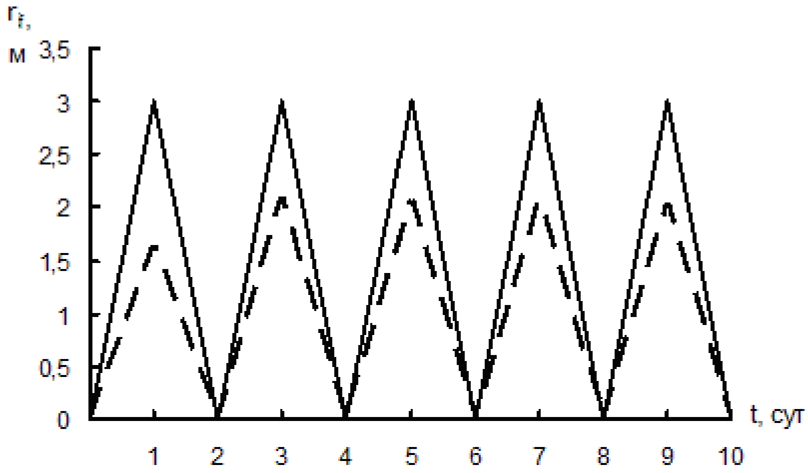
`Pic. 8.` Distribution of acid concentration in the reservoir zone during periodic injection: t=10 days; solid line - cracks, dotted line - pores.

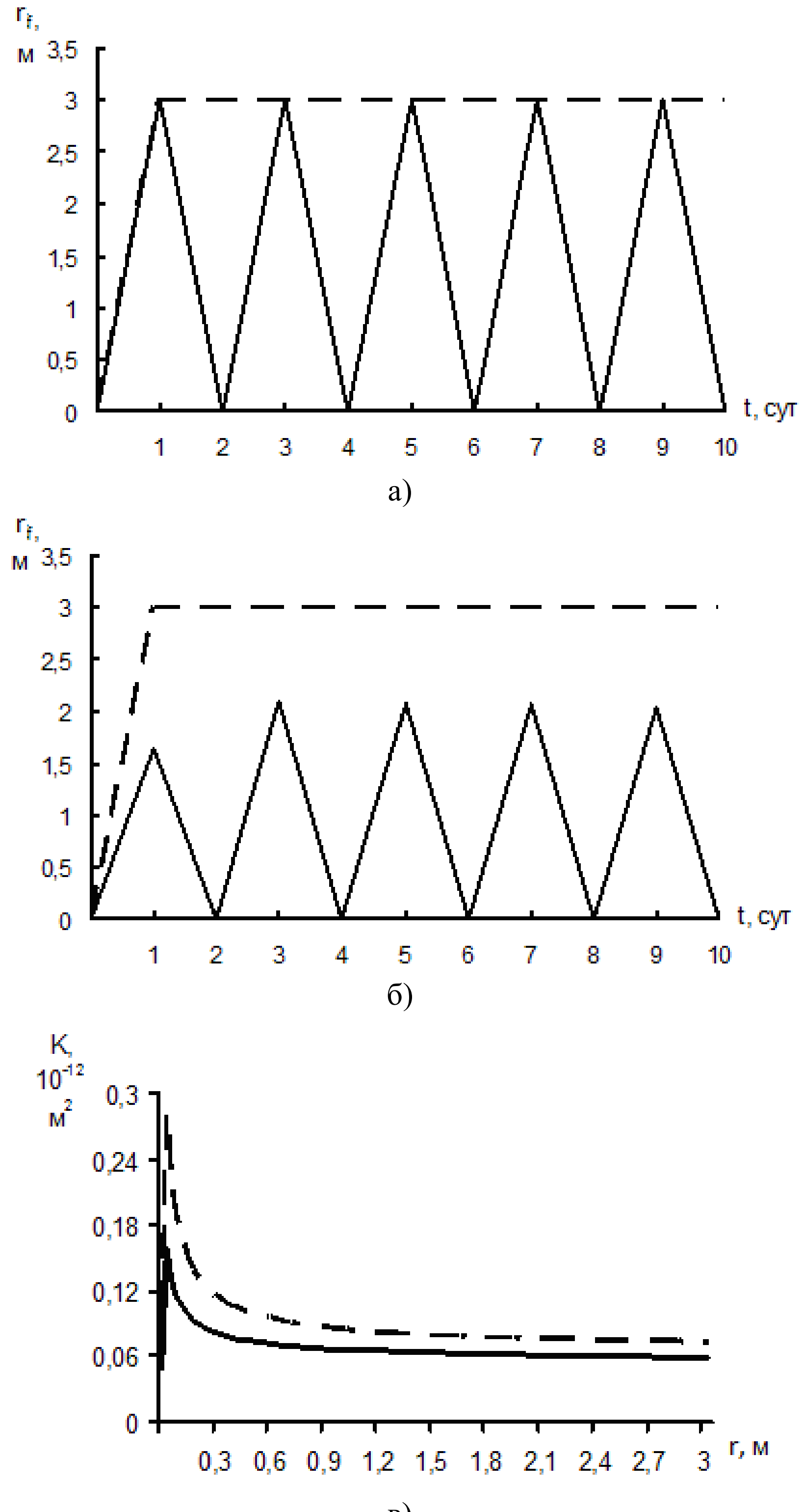


`Pic.9.` Pressure distribution in the reservoir zone during periodic injection of acid: t=10 days; solid line - cracks, dotted line - pores.



`Pic.10.` The position of the acid flow front in the reservoir zone during periodic injection: solid line - cracks, dotted line - pores.

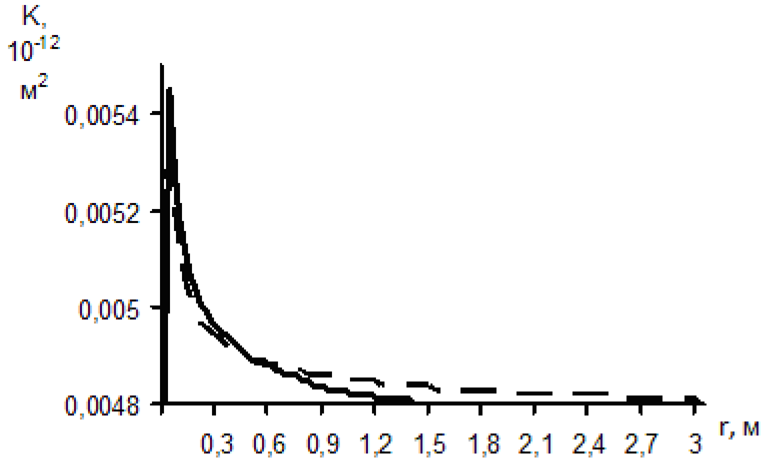
In Figure 11 shows the effect of changing the acid solution injection mode on the position of the acid flow front (Fig. 11a, 11b) and the change in absolute permeability (Fig. 11c, 11d) in porous blocks and cracks. Analysis of the results shows that the frequency of injection has the most significant impact on the processes occurring in porous blocks.


r_f, м
3,5
3
2,5
2
1,5
1
0,5
0
t, сут
1
2
3
4
5
6
7
8
9
10
K, 10^{-12} $м^2$
0,3
0,24
0,18
0,12
0,06
0
0,3
0,6
0,9
1,2
1,5
1,8
2,1
2,4
2,7
3
r, м

а)

б)

в)



г)

Pic.11. Influence of injection mode acid on: position of the acid flow front in cracks, a); in pores, b); distribution of permeability in fractures, c); in pores, d); solid line - periodic, dotted line - continuous.

5. Conclusion

A two-phase mathematical model of acid action on the reservoir zone of oil fields with carbonate fractured-porous reservoirs is presented, which is based on the model of double porosity and double permeability. A computational experiment showed that the proposed model makes it possible to calculate acid treatment indicators with given process parameters and study the influence of parameters such as acid injection rate, acid concentration, and chemical reaction rate. The model allows you to estimate the required well shutdown time for the reaction and the depth of penetration of the acid solution into the formation.

Further development of the model is associated with determining the functional relationship between the kinetic constants obtained in laboratory experiments and the intensity of the reaction in a porous medium, clarifying the description of the filtration mechanism in porous blocks and cracks, taking into account the heterogeneity of the formation.

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