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ARTIFICIAL INTELLIGENCE (AI) EVALUATION OF CURRENT RESERVOIR PRESSURE DISTRIBUTION BASED ON OIL PRODUCTION DATA

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Summary. The paper investigates a quick-look approach for the assessment of the distribution of current reservoir pressure based on production data. The method is based on an algorithm that includes calculation of the current distribution of values of stream functions, potentials and flow velocity in a selected area. The method allows monitoring the factual distribution of the current reservoir pressure of the producing horizon in the area under consideration, as well as evaluating the effectiveness of the impact on the reservoir in order to maintain reservoir pressure.

Based on the proposed method, it is possible to create Artificial Intelligence (AI) technologies for analyzing operational data, machine learning to predict changes in reservoir pressure. The use of neural networks in the integration of geological, geophysical and operational data, operational risk management allows to create automatic expert systems to optimize the process of development and operation of oil and gas fields in conditions of insufficient information.

The accomplishment of the investigated approach carried out applying data samples from Oil Rocks field (Horizon X, Block V) provided high accuracy for values obtained by calculations. The average relative error rate of the calculated values of reservoir pressure to the actual values of bottomhole pressure measurements in wells is no more than 1%, and the average calculated value of reservoir pressure in the productive strata in the study area is in conformity with its actual reduced value.

Introduction

At any stage of field development, the distribution of reservoir pressure in productive formations is an important energy characteristic of the reservoir, both as a whole and in its individual sections. Reservoir pressure in the productive horizon for a certain period of time, taking into account the well interventions, is called current or dynamic formation pressure. Typically, the distribution of current reservoir pressure is determined by constructing isobar maps at the current time based on data from almost simultaneous (as soon as possible) systematic selective pressure measurements on the maximum possible number of idled (nonoperating) or specially shut-in wells for measurements using deep pressure gauges, which requires significant amount of money and time. If it is impossible to use deep pressure gauges (compressor or flowing wells operation), the pressure at the wells is estimated by calculation. The choice of the most correct calculation method depends on many factors – the well design, the distribution of flow properties of the formation and the geological and field conditions of reservoir development (Сулейманов, Гусейнова, 2023а; Suleimanov et al., 2022; Rasulov, Jalalov, 2023; Ибрагимов и др., 2021; Jamalbayov, Ibrahimov, 2023; Choubey, Karmakar, 2021; Khan et al., 2020; Li et al., 2021; Gupta, Shah, 2022; Koroteeva, Tekic, 2021; Weiss et al., 2002; Дмитриевский и др., 2020; Сулейманов, Гусейнова, 2023б; Hung et al., 2023; Шиланбаев и др., 2023; Велиев и др., 2022; Дмитриевский и др., 2022; Велиев и др., 2021; Велиев, 2021; Джамалбеков и др., 2023).

This paper sets forth an AI approach which provides a means for the calculation and visualization of the current distribution of reservoir pressure in a selected section of a productive formation based on the results of calculating the distribution of such hydrodynamic parameters as flow functions, potentials, and the modulus of the formation fluid velocity at a certain point in time, which, in turn, are determined from conventionally measured current well productivity data. At the same time, systematic automated control over the distribution of current reservoir pressure in the field offers the prospect of rational use of reservoir energy during the development and operation of the field.

Statement of the Problem

In order to determine the pressure distribution in the porous medium of a productive formation containing a moving fluid, it is proposed to consider the formation as a set of small elements (cells), for each of which the corresponding values of mass, pore volume, force, pressure and other indicators that determine the movement of the fluid are recorded, which, due to the comparative smallness of the volumes and edges of the elements, within the framework of the element under consideration can be considered uniformly and equally distributed at the moment within the period of review. In an effort to determine the above fixed values, it is put forward to use the results of calculating the distribution of hydrodynamic indicators by solving a plane filtration problem applying the methods of functions of complex variable theory (Suleimanov et al., 2022). It should also be noted that during the development of oil and gas fields, the fluid filtration communications in the horizon occurs due to the pressure difference that exists between the formation elements interacting with each other in the course of flow of the fluid and having different potentials. In those formation elements in which wells are located, the pressure drop between the formation and the well arises due to the difference between the pressures in a given cell and the neighboring ones that make up the external boundary of the well.

Assuming that a certain number of production and injection wells were operated in the area of the reservoir under consideration. As is known, the distribution of such hydrodynamic parameters as flow functions, potentials, complex potential, and the modulus of the velocity of formation fluid at a certain point in time characterizes the corresponding filtration state of the formation system (Сулейманов, Гусейнова, 2023a). Supposing that the distribution of the corresponding hydrodynamic parameters over the area be calculated for two certain successive periods of time $\varDelta t_1$ and $\varDelta t_2$, (respectively, for oil $F^{t_1}{}_{1_o}$, $F^{t_2}{}_{1_o}$, $F^{t_1}{}_{2_o}$, $F^{t_2}{}_{2_o}$, $F_o{}^{t_1}, F_o{}^{t_2}$, $W_o{}^{t_1}$, $W_o{}^{t_2}$, $grad\left(F_o{}^{t_1}\right)$, $grad(F_o{}^{t_2})$ for water $F^{t_1}{}_{1_w}$, $F^{t_2}{}_{1_w}$, $F^{t_1}{}_{2_w}$, $F^{t_2}{}_{2_w}$, $F_w{}^{t_1}$, $F_w{}^{t_2}$, $W_w{}^{t_1}$, $W_w{}^{t_2}$, $grad\left(F_w{}^{t_1}\right)$, $grad(F_w{}^{t_2})$ and for the reservoir fluid as a whole $F^{t_1}{}_{1_f}$, $F^{t_2}{}_{1_f}$, $F^{t_1}{}_{2_f}$, $F^{t_2}{}_{2_f}$, $F_f{}^{t_1}$, $F_f{}^{t_2}$, $W_f{}^{t_1}$, $W_f{}^{t_2}$, $grad(F_f{}^{t_1})$, $grad(F_f{}^{t_2})$ with subsequent representation in the form tensors of dimension $n\times m$, where $n\times m$ is the number of grid cells, n is the number of partition nodes in the grid along the OX axis, m is the number of partition nodes along the OY, axis $j=1, \ldots, n\times m$ is the serial number of the cell. The elements of each of the tensors are the total for all wells corresponding values of the stream function and potentials in each j -th grid cell theory (Suleimanov et al,, 2022), depending on the flow rate of each i -th well, the distance r_{ij} from the i -th well to an arbitrary point of the reservoir with coordinates (x_j, y_j), where $i=1, \ldots \kappa$ is the number of operating wells in the field area allocated for research:

As per oil, in the period of time $\varDelta t_1$:

$$F^{t_1}{}_{1_o} = \begin{bmatrix} (F^{t_1}{}_{1_o})_{1,1} & \cdots & (F^{t_1}{}_{1_o})_{1,n} \\ \ldots. & \cdots & \cdots \\ (F^{t_1}{}_{1_o})_{m,1} & \cdots & (F^{t_1}{}_{1_o})_{m,n} \end{bmatrix};$$

$$F_{2_o}{}^{t_1} = \begin{bmatrix} (F_{2_o}{}^{t_1})_{1,1} & \cdots & (F_{2_o}{}^{t_1})_{1,n} \\ \ldots. & \cdots & \cdots \\ (F_{2_o}{}^{t_1})_{m,1} & \cdots & (F_{2_o}{}^{t_1})_{m,n} \end{bmatrix};$$

$$F_o{}^{t_1} = \begin{bmatrix} (F_o{}^{t_1})_{1,1} & \cdots & (F_o{}^{t_1})_{1,n} \\ \ldots. & \cdots & \cdots \\ (F_o{}^{t_1})_{m,1} & \cdots & (F_o{}^{t_1})_{m,n} \end{bmatrix};$$

$$W_o{}^{t_1} = \begin{bmatrix} (W_o{}^{t_1})_{1,1} & \cdots & (W_o{}^{t_1})_{1,n} \\ \ldots. & \cdots & \cdots \\ (W_o{}^{t_1})_{m,1} & \cdots & (W_o{}^{t_1})_{m,n} \end{bmatrix};$$

$$grad(F_o{}^{t_1}) = \begin{bmatrix} (grad(F_o{}^{t_1}))_{1,1} & \cdots & (grad(F_o{}^{t_1}))_{1,n} \\ \ldots. & \cdots & \cdots \\ (grad(F_o{}^{t_1}))_{m,1} & \cdots & (grad(F_o{}^{t_1}))_{m,n} \end{bmatrix} \quad (1)$$

As per water, in the period of time $\varDelta t_1$:

$$F^{t_1}{}_{1_w} = \begin{bmatrix} (F^{t_1}{}_{1_w})_{1,1} & \cdots & (F^{t_1}{}_{1_w})_{1,n} \\ \ldots. & \cdots & \cdots \\ (F^{t_1}{}_{1_w})_{m,1} & \cdots & (F^{t_1}{}_{1_w})_{m,n} \end{bmatrix};$$

$$F_{2_w}{}^{t_1} = \begin{bmatrix} (F_{2_w}{}^{t_1})_{1,1} & \cdots & (F_{2_w}{}^{t_1})_{1,n} \\ \ldots. & \cdots & \cdots \\ (F_{2_w}{}^{t_1})_{m,1} & \cdots & (F_{2_w}{}^{t_1})_{m,n} \end{bmatrix};$$

$$F_w{}^{t_1} = \begin{bmatrix} (F_w{}^{t_1})_{1,1} & \cdots & (F_w{}^{t_1})_{1,n} \\ \ldots. & \cdots & \cdots \\ (F_w{}^{t_1})_{m,1} & \cdots & (F_w{}^{t_1})_{m,n} \end{bmatrix};$$

$$W_w{}^{t_1} = \begin{bmatrix} (W_w{}^{t_1})_{1,1} & \cdots & (W_w{}^{t_1})_{1,n} \\ \ldots. & \cdots & \cdots \\ (W_w{}^{t_1})_{m,1} & \cdots & (W_w{}^{t_1})_{m,n} \end{bmatrix};$$

$$grad(F_w{}^{t_1}) = \begin{bmatrix} (grad(F_w{}^{t_1}))_{1,1} & \cdots & (grad(F_w{}^{t_1}))_{1,n} \\ \ldots. & \cdots & \cdots \\ (grad(F_w{}^{t_1}))_{m,1} & \cdots & (grad(F_w{}^{t_1}))_{m,n} \end{bmatrix} \quad (2)$$

As per fluid, in the period of time $\varDelta t_1$:

$$F^{t_1}{}_{1_f} = \begin{bmatrix} (F^{t_1}{}_{1_f})_{1,1} & \cdots & (F^{t_1}{}_{1_f})_{1,n} \\ \ldots. & \cdots & \cdots \\ (F^{t_1}{}_{1_f})_{m,1} & \cdots & (F^{t_1}{}_{1_f})_{m,n} \end{bmatrix};$$

$$F_{2_f}{}^{t_1} = \begin{bmatrix} (F_{2_f}{}^{t_1})_{1,1} & \cdots & (F_{2_f}{}^{t_1})_{1,n} \\ \dots & \cdots & \cdots \\ (F_{2_f}{}^{t_1})_{m,1} & \cdots & (F_{2_f}{}^{t_1})_{m,n} \end{bmatrix};$$

$$F_f{}^{t_1} = \begin{bmatrix} (F_f{}^{t_1})_{1,1} & \cdots & (F_f{}^{t_1})_{1,n} \\ \dots & \cdots & \cdots \\ (F_f{}^{t_1})_{m,1} & \cdots & (F_f{}^{t_1})_{m,n} \end{bmatrix};$$

$$W_f{}^{t_1} = \begin{bmatrix} (W_f{}^{t_1})_{1,1} & \cdots & (W_f{}^{t_1})_{1,n} \\ \dots & \cdots & \cdots \\ (W_f{}^{t_1})_{m,1} & \cdots & (W_f{}^{t_1})_{m,n} \end{bmatrix};$$

$$grad(F_f{}^{t_1}) = \begin{bmatrix} (grad(F_f{}^{t_1}))_{1,1} & \cdots & (grad(F_f{}^{t_1}))_{1,n} \\ \dots & \cdots & \cdots \\ (grad(F_f{}^{t_1}))_{m,1} & \cdots & (grad(F_f{}^{t_1}))_{m,n} \end{bmatrix} \quad (3)$$

And

As per oil, in the period of time Δt_2:

$$F^{t_2}{}_{1_o} = \begin{bmatrix} (F^{t_2}{}_{1_o})_{1,1} & \cdots & (F^{t_2}{}_{1_o})_{1,n} \\ \dots & \cdots & \cdots \\ (F^{t_2}{}_{1_o})_{m,1} & \cdots & (F^{t_2}{}_{1_o})_{m,n} \end{bmatrix};$$

$$F_{2_o}{}^{t_1} = \begin{bmatrix} (F_{2_o}{}^{t_1})_{1,1} & \cdots & (F_{2_o}{}^{t_1})_{1,n} \\ \dots & \cdots & \cdots \\ (F_{2_o}{}^{t_1})_{m,1} & \cdots & (F_{2_o}{}^{t_1})_{m,n} \end{bmatrix};$$

$$F_o{}^{t_1} = \begin{bmatrix} (F_o{}^{t_1})_{1,1} & \cdots & (F_o{}^{t_1})_{1,n} \\ \dots & \cdots & \cdots \\ (F_o{}^{t_1})_{m,1} & \cdots & (F_o{}^{t_1})_{m,n} \end{bmatrix};$$

$$W_o{}^{t_2} = \begin{bmatrix} (W_o{}^{t_2})_{1,1} & \cdots & (W_o{}^{t_2})_{1,n} \\ \dots & \cdots & \cdots \\ (W_o{}^{t_2})_{m,1} & \cdots & (W_o{}^{t_2})_{m,n} \end{bmatrix};$$

$$grad(F_o{}^{t_2}) = \begin{bmatrix} (grad(F_o{}^{t_2}))_{1,1} & \cdots & (grad(F_o{}^{t_2}))_{1,n} \\ \dots & \cdots & \cdots \\ (grad(F_o{}^{t_2}))_{m,1} & \cdots & (grad(F_o{}^{t_2}))_{m,n} \end{bmatrix} \quad (4)$$

As per water, in the period of time Δt_2:

$$F^{t_2}{}_{1_w} = \begin{bmatrix} (F^{t_2}{}_{1_w})_{1,1} & \cdots & (F^{t_2}{}_{1_w})_{1,n} \\ \dots & \cdots & \cdots \\ (F^{t_2}{}_{1_w})_{m,1} & \cdots & (F^{t_2}{}_{1_w})_{m,n} \end{bmatrix};$$

$$F_{2_w}{}^{t_2} = \begin{bmatrix} (F_{2_w}{}^{t_2})_{1,1} & \cdots & (F_{2_w}{}^{t_2})_{1,n} \\ \dots & \cdots & \cdots \\ (F_{2_w}{}^{t_2})_{m,1} & \cdots & (F_{2_w}{}^{t_2})_{m,n} \end{bmatrix};$$

$$F_w{}^{t_2} = \begin{bmatrix} (F_w{}^{t_2})_{1,1} & \cdots & (F_w{}^{t_2})_{1,n} \\ \dots & \cdots & \cdots \\ (F_w{}^{t_2})_{m,1} & \cdots & (F_w{}^{t_2})_{m,n} \end{bmatrix};$$

$$W_w{}^{t_2} = \begin{bmatrix} (W_w{}^{t_2})_{1,1} & \cdots & (W_w{}^{t_2})_{1,n} \\ \dots & \cdots & \cdots \\ (W_w{}^{t_2})_{m,1} & \cdots & (W_w{}^{t_2})_{m,n} \end{bmatrix};$$

$$grad(F_w{}^{t_2}) = \begin{bmatrix} (grad(F_w{}^{t_2}))_{1,1} & \cdots & (grad(F_w{}^{t_2}))_{1,n} \\ \dots & \cdots & \cdots \\ (grad(F_w{}^{t_2}))_{m,1} & \cdots & (grad(F_w{}^{t_2}))_{m,n} \end{bmatrix} \quad (5)$$

As per fluid, in the period of time Δt_2:

$$F^{t_2}{}_{1_f} = \begin{bmatrix} (F^{t_2}{}_{1_f})_{1,1} & \cdots & (F^{t_2}{}_{1_f})_{1,n} \\ \dots & \cdots & \cdots \\ (F^{t_2}{}_{1_f})_{m,1} & \cdots & (F^{t_2}{}_{1_f})_{m,n} \end{bmatrix};$$

$$F_{2_f}{}^{t_2} = \begin{bmatrix} (F_{2_f}{}^{t_2})_{1,1} & \cdots & (F_{2_f}{}^{t_2})_{1,n} \\ \dots & \cdots & \cdots \\ (F_{2_f}{}^{t_2})_{m,1} & \cdots & (F_{2_f}{}^{t_2})_{m,n} \end{bmatrix}$$

$$F_f{}^{t_2} = \begin{bmatrix} (F_f{}^{t_2})_{1,1} & \cdots & (F_f{}^{t_2})_{1,n} \\ \dots & \cdots & \cdots \\ (F_f{}^{t_2})_{m,1} & \cdots & (F_f{}^{t_2})_{m,n} \end{bmatrix};$$

$$W_f{}^{t_2} = \begin{bmatrix} (W_f{}^{t_2})_{1,1} & \cdots & (W_f{}^{t_2})_{1,n} \\ \dots & \cdots & \cdots \\ (W_f{}^{t_2})_{m,1} & \cdots & (W_f{}^{t_2})_{m,n} \end{bmatrix};$$

$$grad(F_f{}^{t_2}) = \begin{bmatrix} (grad(F_f{}^{t_2}))_{1,1} & \cdots & (grad(F_f{}^{t_2}))_{1,n} \\ \dots & \cdots & \cdots \\ (grad(F_f{}^{t_2}))_{m,1} & \cdots & (grad(F_f{}^{t_2}))_{m,n} \end{bmatrix} \quad (6)$$

Applying the algorithm provided in (Сулейманов, Гусейнова, 2023a,), tensors (1) - (6) are calculated, characterizing the distribution of the above filtration characteristics in the field area allocated for study within the period of time under study. As initial data, the results of measurements at wells operating from the studied productive horizon on the current date are used, namely: the flow rate of production wells (the volume of oil and water produced per unit of time), the injectivity of injection wells (the volume of injection per layer of working agent per unit time), filter length values, conditional coordinates of the location of the corresponding wells in the studied area of the productive formation.

As is known, the distribution of acceleration values of a fluid flow $\vec{a}$ over a certain period of time $\Delta t=t_1-t_2$ in a selected area is defined as the ratio of the change in the true speed of the flow to the time interval:

$$\vec{a} = \frac{v^{t_2}-v^{t_1}}{t_2-t_1} \quad (7)$$

The rate of percolation is expressed through the actual flow velocity and rock porosity *K* as follows (Rasulov, Jalalov, 2023):

$$W = v \cdot K \tag{8}$$

The volume of fluid located at this moment in time in the porous medium of the formation, limited by each of the grid cells superimposed on the area under consideration, is determined by the value of the stream function in each grid cell, that is, the volumetric distribution of fluid in the area at the current time is determined by the tensor ${F^{t_1}}_{1_f}$. Knowing that the volume of the cell under consideration consists of rock and the liquid saturating it, we can determine the volume occupied by the rock as the difference between the volume of a parallelepiped 1m high and a rectangular surface, the dimensions of which are determined by the choice of grid scale.

Using these data, it is also possible to estimate the distribution of effective porosity during the period of time under consideration in the studied area of the productive formation. As is known, the current effective porosity *K* means the ratio of the volume of interconnected voids V_1 filled with fluid to the total volume *V*. The total volume of the cell in which the effective porosity $V_я$ is determined is known, since it is determined by the scale of the grid superimposed on the area. The change in the volume of pore space filled with formation fluid over a period of time Δt is determined by the difference in the tensor elements ${F^{t_1}}_{1_f}$ and ${F^{t_1}}_{1_f}$ in the time period under consideration:

$$dV_f = \left({F_1}^{t_2}{}_f - {F_1}^{t_1}{}_f\right) \cdot dt = K \cdot a \cdot b \cdot h$$

From here the value of the current effective porosity K^{t_2} is determined:

$$K^{t_2} = \frac{\left({F_1}^{t_2}{}_f - {F_1}^{t_1}{}_f\right) \times dt}{a \times b \times h} = \frac{({F_1}^{t_2}{}_f - {F_1}^{t_1}{}_f) \times (t_2 - t_1)}{a \times b \times h} \tag{9}$$

Where:
h =1м – height of the cell, presented in the form of a rectangular parallelepiped, *a* and *b*- sides, depending on the choice of the scale of the grid superimposed on the area under study.

Then formula (7) can be rewritten as:

$$\vec{a} = \frac{W^{t_2}/K^{t_2} - W^{t_1}/K^{t_1}}{t_2 - t_1} \tag{10}$$

It is impossible to determine the mass of liquid distributed over the area based on the values ${F^{t_1}}_{1_f}$, since the liquid is two-phase and consists of oil and water distributed in the pore space of the formation, conventionally divided into cells. Knowing that $m = \rho \cdot V$, where *m* is mass, ρ is density, *V* is volume, to determine the mass of liquid contained in each fixed cell, based on the values of ${F^{t_1}}_{1_o}$,${F^{t_1}}_{1_w}$ and ${F^{t_2}}_{1_o}$,${F^{t_2}}_{1_w}$, we separately determine the volume of oil and the volume of water contained in each of these moments in time in each of the grid cells superimposed on the site. Next, based on the data obtained for each of the considered moments of time, we determine the tensor characterizing the distribution of liquid mass in the area:

$$\begin{aligned} {m^{t_1}}_f = {\mathrm{m}^{t_1}}_o + {\mathrm{m}^{t_1}}_w = \rho_o \cdot {\mathrm{V}^{t_1}}_o + \rho_w \cdot \\ {\mathrm{V}^{t_1}}_w = (\rho_o \cdot {\mathrm{F}^{t_1}}_{\mathrm{o1}} + \rho_w \cdot {\mathrm{F}^{t_1}}_{\mathrm{1w}}) \cdot dt \end{aligned} \tag{11}$$

$$\begin{aligned} {m^{t_2}}_f = {\mathrm{m}^{t_2}}_o + {\mathrm{m}^{t_2}}_w = \rho_o \cdot {V^{t_2}}_o + \rho_w \cdot {V^{t_2}}_w \\ = (\rho_o \cdot {\mathrm{F}^{t_2}}_{\mathrm{o1}} + \rho_w \cdot {\mathrm{F}^{t_2}}_{\mathrm{1w}}) \cdot dt \end{aligned}$$

With a knowledge of the density of oil and water, as well as the volume of each phase located at this moment in time in each of the grid cells superimposed on the area, it is possible to determine the distribution of the mass of liquid saturating the pore space of the productive formation in this area.

Next, in accordance with Newton's law, the distribution of the force exerted on the surface of the pore space is determined:

$$F = {m^{t_2}}_f \cdot \vec{a} \tag{12}$$

Knowing the area of the gaps whereby the liquid to which the force is applied enters the cell, we can determine the pressure that the liquid exerts on the cell during its movement:

$$P = F / S_n \tag{13}$$

The area of the gaps S_n on the lateral surface of a cell with area *S* at time *t* is determined as follows (Rasulov, Jalalov, 2023):

$$S_n = S \cdot K^t \tag{14}$$

Determining the lateral surface area of a cell *S* is not difficult:

$$S = 2 \cdot h \cdot (a + b) \tag{15}$$

Taking into account correlations (10)-(12) in (13), we obtain:

$$P^{t_2} = \frac{F}{S_п} = \left({m^{t_2}}_f \cdot \vec{a}\right) \cdot \frac{1}{S \cdot \mathrm{K}^{t_2}}$$

$$= \left(\rho_o \cdot \ F^{t_2}{}_{\mathrm{o1}} + \rho_w \cdot \ F^{t_2}{}_{1w}\right) \cdot (t_2 - t_1) \cdot \frac{1}{t_2 - t_1} \cdot \left(\frac{W^{t_2}}{K^{t_2}} - \frac{W^{t_1}}{K^{t_1}}\right) \cdot \frac{1}{S \cdot \mathrm{K}^{t_2}}$$

$$= \left(\rho_o \cdot F^{t_2}{}_{\mathrm{o1}} + \rho_w \cdot F^{t_2}{}_{\mathrm{1w}}\right) \cdot \frac{1}{K^{t_2} \cdot K^{t_1}} \cdot \left(W^{t_2} \cdot K^{t_1} - W^{t_1} \cdot K^{t_2}\right) \cdot \frac{1}{2 \cdot h \cdot (a+b) \cdot \mathrm{K}^{t_2}}$$

$$= \left(\rho_o \cdot F^{t_2}{}_{\mathrm{o1}} + \rho_w \cdot F^{t_2}{}_{\mathrm{1w}}\right) \cdot \frac{h^2 \cdot a^2 \cdot b^2}{\left(F^{t_2}{}_f - F^{t_1}{}_f\right) \cdot (t_2 - t_1) \cdot \left(F^{t_1}{}_f - F^{t_0}{}_f\right) \cdot (t_1 - t_0)}$$

$$\cdot \frac{\left(W^{t_2} \cdot \left(F^{t_1}{}_f - F^{t_0}{}_f\right) \cdot (t_1 - t_0) - W^{t_1} \cdot \left(F^{t_2}{}_f - F^{t_1}{}_f\right) \cdot (t_2 - t_1)\right)}{h \cdot a \cdot b}$$

$$\cdot \frac{h \cdot a \cdot b}{2 \cdot h \cdot (a+b) \cdot \left(F^{t_2}{}_f - F^{t_1}{}_f\right) \cdot (t_2 - t_1)}$$

$$= \frac{(\rho_o \cdot F^{t_2}{}_{o1} + \rho_w \cdot F^{t_2}{}_{1w}) \cdot (W^{t_2} \cdot (F^{t_1}{}_f - F^{t_0}{}_f) \cdot (t_1 - t_0) - W^{t_1} \cdot (F^{t_2}{}_f - F^{t_1}{}_f) \cdot (t_2 - t_1)) \cdot h \cdot a^2 \cdot b^2}{2 \cdot (a+b) \cdot (t_2 - t_1)^2 \cdot (t_1 - t_0) \cdot (F^{t_2}{}_f - F^{t_1}{}_f)^2 \cdot (F^{t_1}{}_f - F^{t_0}{}_f)} \tag{16}$$

where:

$$K^{t_2} = \frac{\left(F^{t_2}{}_f - F^{t_1}{}_f\right) \cdot (t_2 - t_1)}{a \cdot b \cdot h}$$

$$K^{t_1} = \frac{(F^{t_1}{}_f - F^{t_0}{}_f) \cdot (t_1 - t_0)}{a \cdot b \cdot h}.$$

$F^{t_2}{}_{\mathrm{o1}}$, $\mathrm{F}^{t_2}{}_{\mathrm{1w}}$ – distribution of current function over oil and water, m^3/day;

W^{t_1}, W^{t_2} – distribution of flow velocity by liquid, m^3/day;

$F^{t_1}{}_{1f}, F^{t_0}{}_{1_f} F^{t_2}{}_{1_f}$ – distribution of current function over liquid, m^3/day;

ρ_o, ρ_w – density of oil and water, kg/m^3

$\Delta t_1 = t_1 - t_0$, day

$\Delta t_2 = t_2 - t_1$, day

h, a, b – respectively, the height and length of the sides of a scale grid cell superimposed on the study area, m.

Field Application

In order to automate the calculations and visualize the results obtained, a special software module has been developed on the basis of the "Matlab" engineering and scientific calculation system package, which makes it possible to calculate and visualize the pressure distribution in the area under study at the current time in accordance with the algorithm proposed above. In an effort to demonstrate the calculation results, data from the "Oil Rocks" field (horizon X, block V), which has been under development from 1957 to the present, were used (Fig. 1). The initial reservoir pressure at the horizon X was 21 MPa. During the period of formation stimulation, the average reduced pressure in block V was about 12 MPa. In individual wells of the experimental area, the bottomhole pressure varied in the range of 2.7-8.5 MPa, respectively, the reduced reservoir pressure had values in the range of 2.9 - 8.9 MPa (Table). The average actual reduced pressure at the study site was 4.5 MPa. For many wells in the stimulation area, bottomhole pressure measurements have not been made at the current date. However, the proposed method offers the prospect of estimating both bottomhole and reduced reservoir pressure in the vicinity of these wells, knowing the productivity of the wells. The following information was used as initial data for carrying out calculations for the current date:

1. Consumption of production wells (volume of production recovered from the reservoir per unit of time);
2. Injectivity of injection wells (volume of injection of working agent into the formation);
3. Values of the length of well filters;
4. Conditional coordinates of the corresponding wells.

The collection of necessary data was carried out during the planning period for reservoir stimulation in order to ramp up oil recovery (August 2015). The calculation used field data for the periods before and after the stimulation (08.2015-10.2015). The obtained calculated values were compared with the values of measurements of bottomhole and reduced reservoir pressure in the wells of the experimental area for the period after the stimulation of the reservoir (11.2015-02.2016).

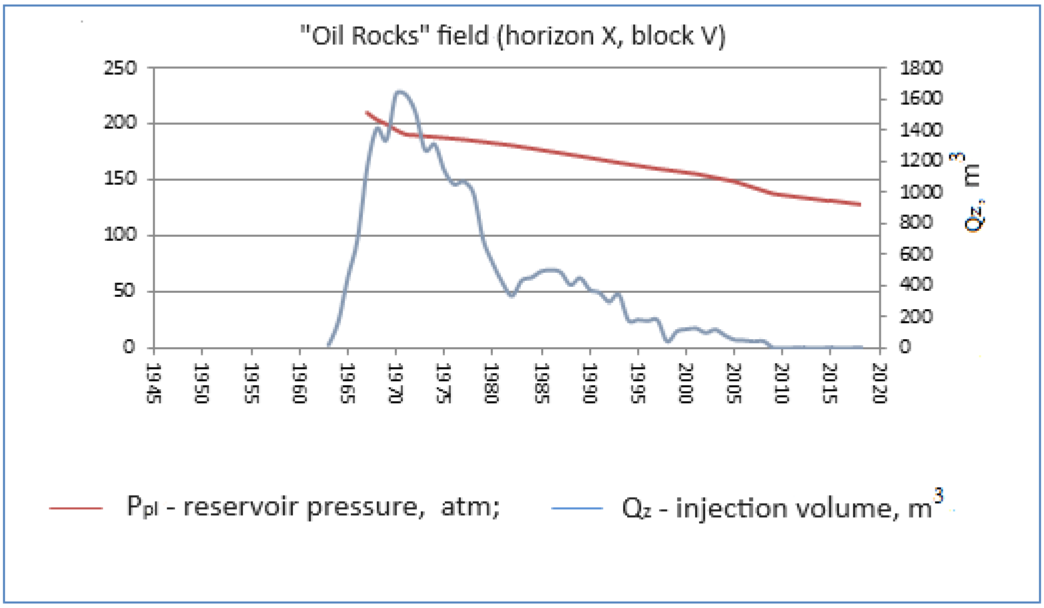

Fig. 1. Dynamics of the values of the reduced reservoir pressure and the volume of water injected into the reservoir along the horizon X on block V of "Oil Rocks" field.

Initial data and results of comparative analysis of calculated and actual values of reservoir pressure at the test site

№	Production for the period under review		Provisional coordinates		Filter	$P_{расч}$	$P_{заб}$	$P_{пл}$
	Oil $Q_н$, т	Water $Q_в$, м^3	*X*, м	*Y*, м	F, м	atm		
2361	5.0	0	156.19	107.12	8	**48.3**	40.5	42.7
2429	18.8	0	189.00	65.07	5	**50.8**	53.98	63.1
2423	22.0	0	191.86	78.52	10	**70.4**	70.14	76.2
2422	18.0	0	200.94	88.78	36	**53.1**	54.75	58.1
2444	23.0	0	194.55	97.53	14	**58.4**	56.67	61.7
2421	23.0	0	196.90	113.17	20	**51.7**	58.74	67.6
2414	2.0	0	152.82	86.77	8	**27.0**	27.12	29.5
2383	7.1	0	140.54	93.83	10	**34.6**	36.21	39.7

In line with the method of calculation and visualization of the distribution of filtration characteristics of formation fluid (Сулейманов и др., 2017; Лятифов 2021), the matrixes of distribution of hydrodynamic parameters were calculated and visualized at the time points of August-October 2015 (Fig. 2-8). Next, using the data obtained, the distribution of current reservoir pressure for December 2015 was calculated and visualized (Fig. 9). Digital visualization of isobar lines characterizing the current pressure distribution was obtained in the following way. The maximum and minimum values of the elements that make up the tensor of pressure values are highlighted. The resulting range of values is divided into equal intervals, each of which is assigned a specific color. Each color of the scale is associated with a specific pressure value. Cells with equal values are connected by a line. In accordance with the results obtained, a pressure distribution map is constructed in the area allocated for research (Fig. 9).

The results of a comparative analysis of calculated data with actual data from bottom-hole pressure measurements at wells are given in the table. At the same time, the average value of the relative error of the calculated values to the actual values is no more than 1%. The average calculated reservoir pressure for the area was 4.5 MPa, that is, the average calculated value of the reservoir pressure coincides with its actual reduced value.

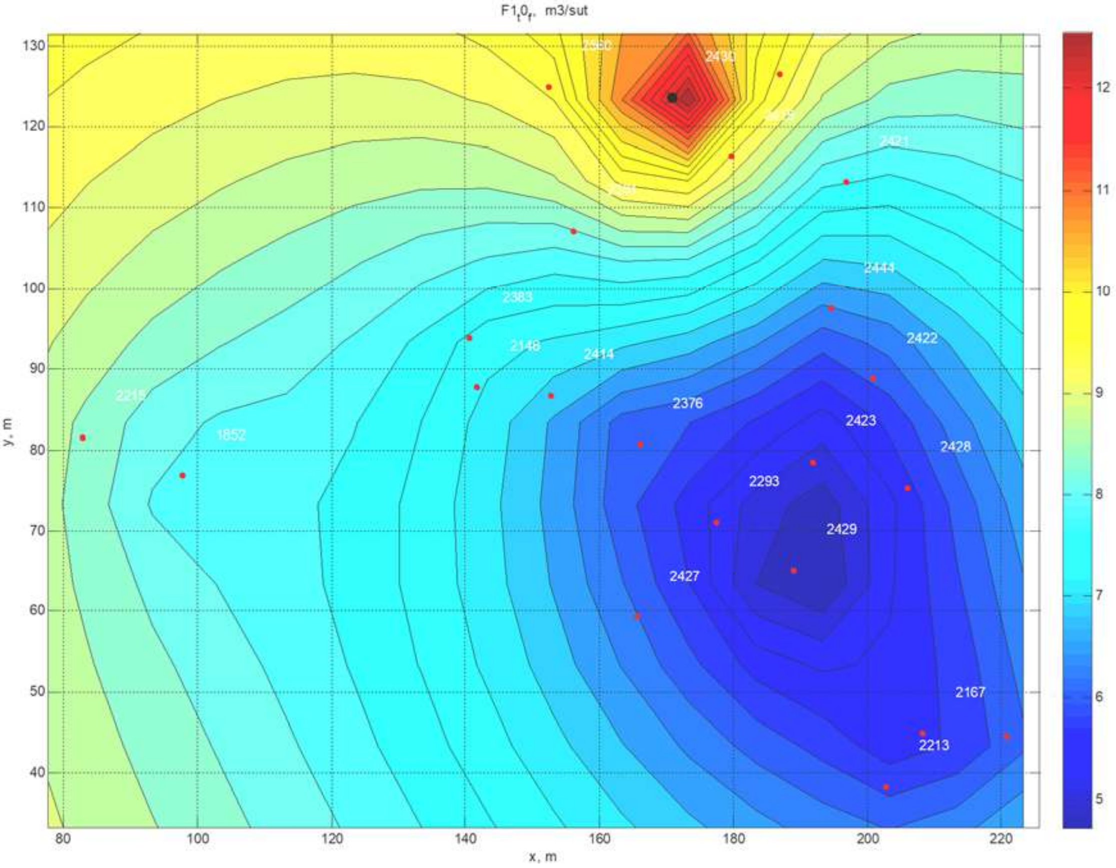

Fig. 2. Distribution of streamlines in the liquid $F_{1n}{}^{t}{}_{0}$ at time t_0

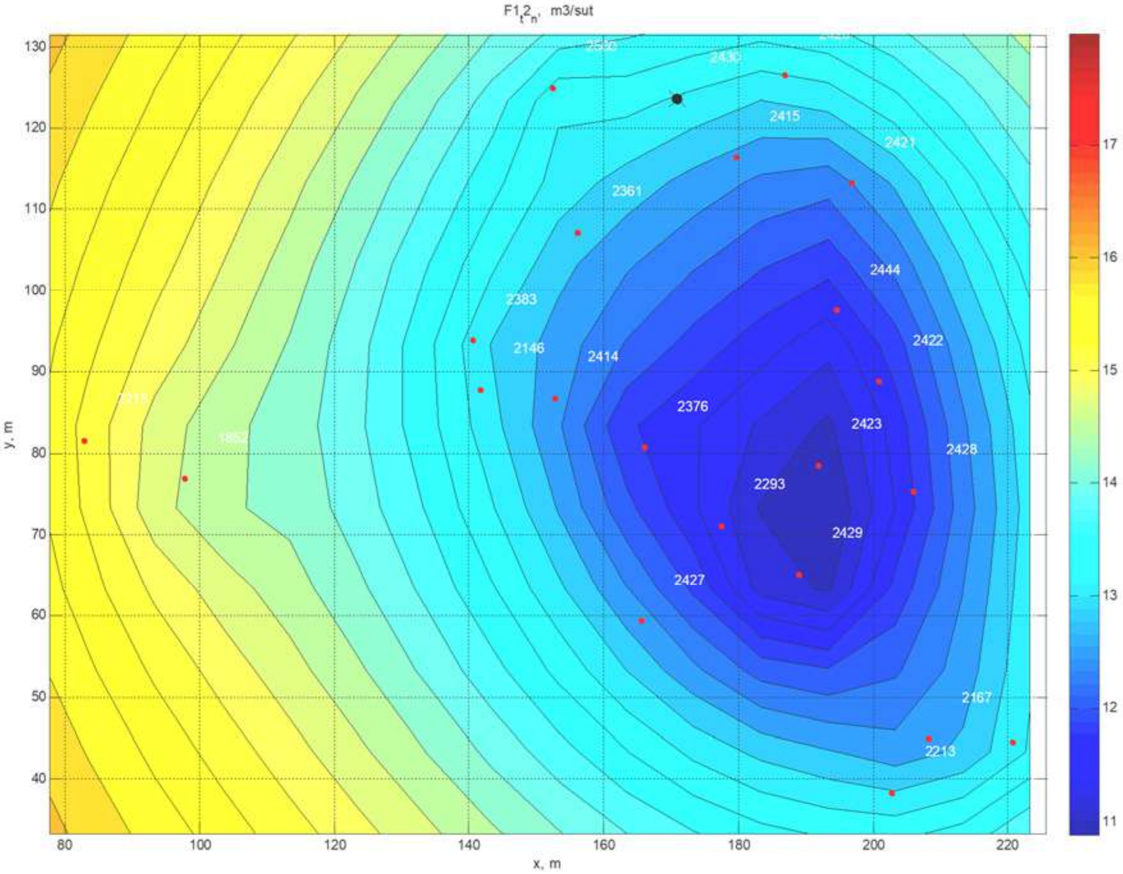

Fig. 3. Distribution of streamlines in oil $F_{1n}{}^{t}{}_{2}$ at time t_2.

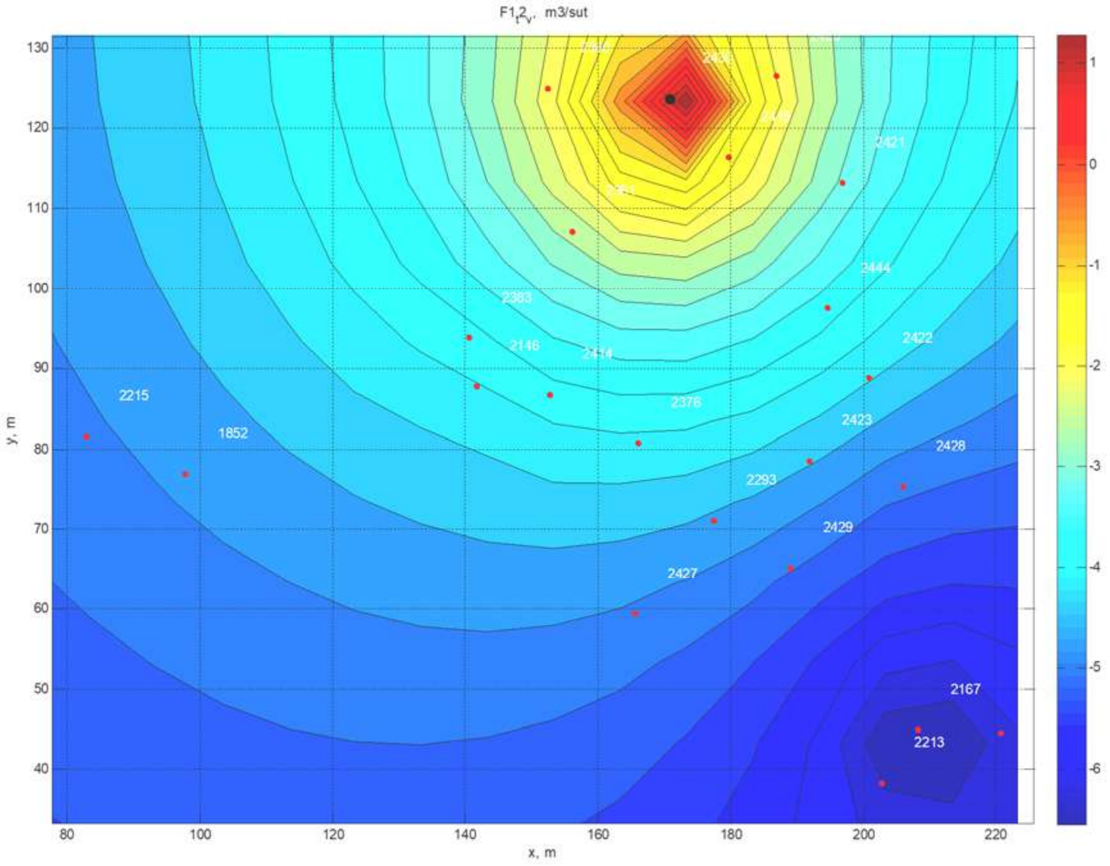

Fig. 4. Distribution of streamlines in water $F_{1v}^{t_2}$ at time t_2

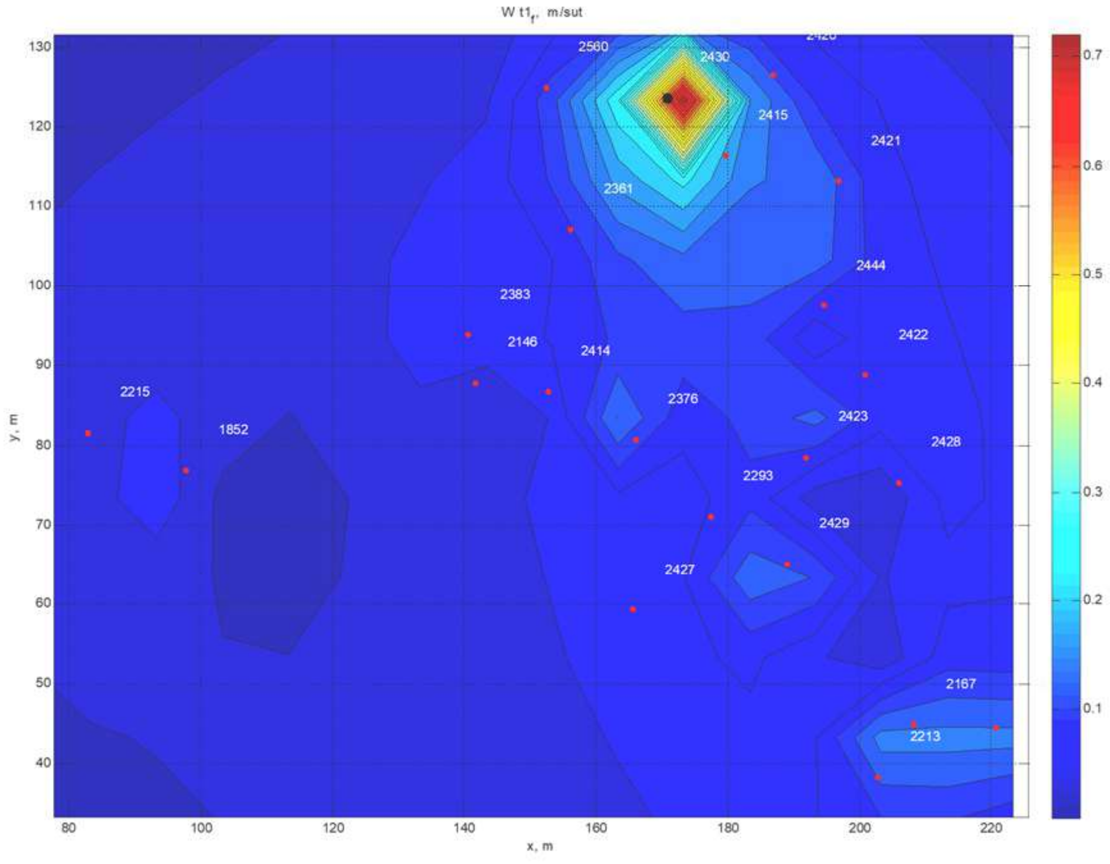

Fig. 5. Distribution of flow velocity $W_f^{t_1}$ of formation fluid at time t_1

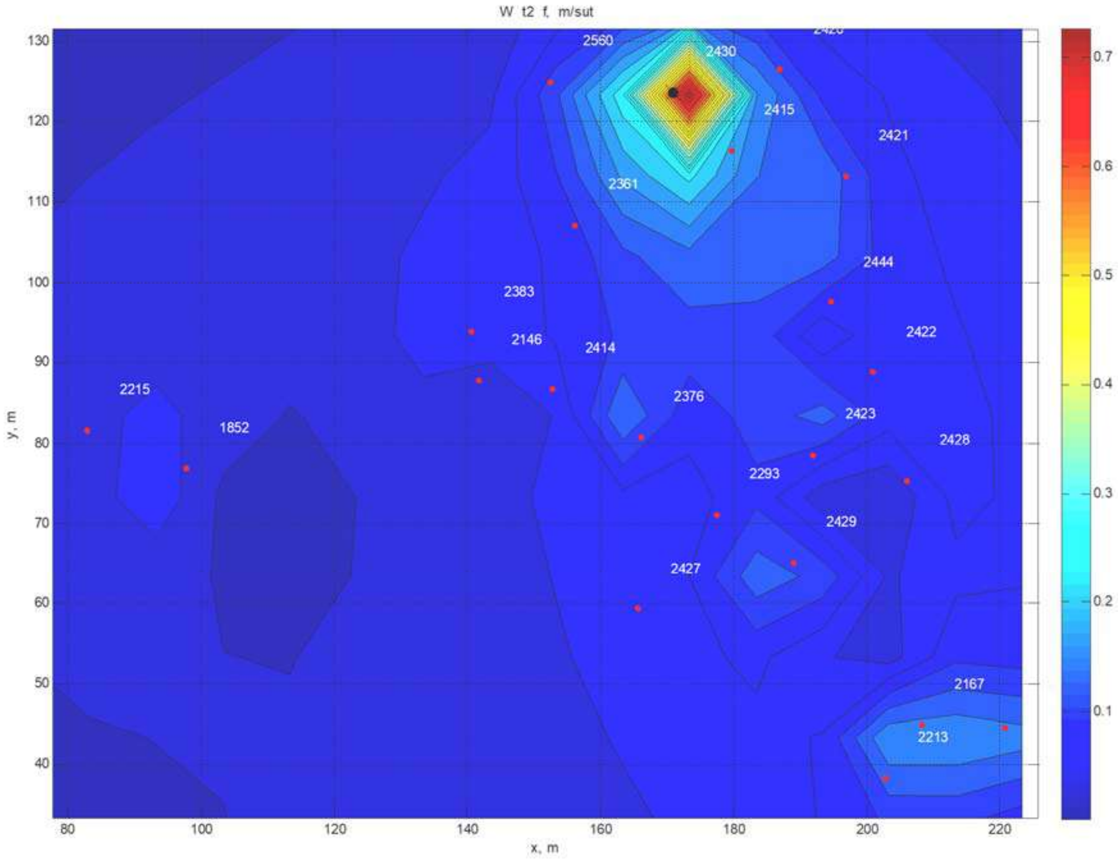

Fig. 6. Distribution of formation fluid flow velocity W^{τ}_{2} at time t_2

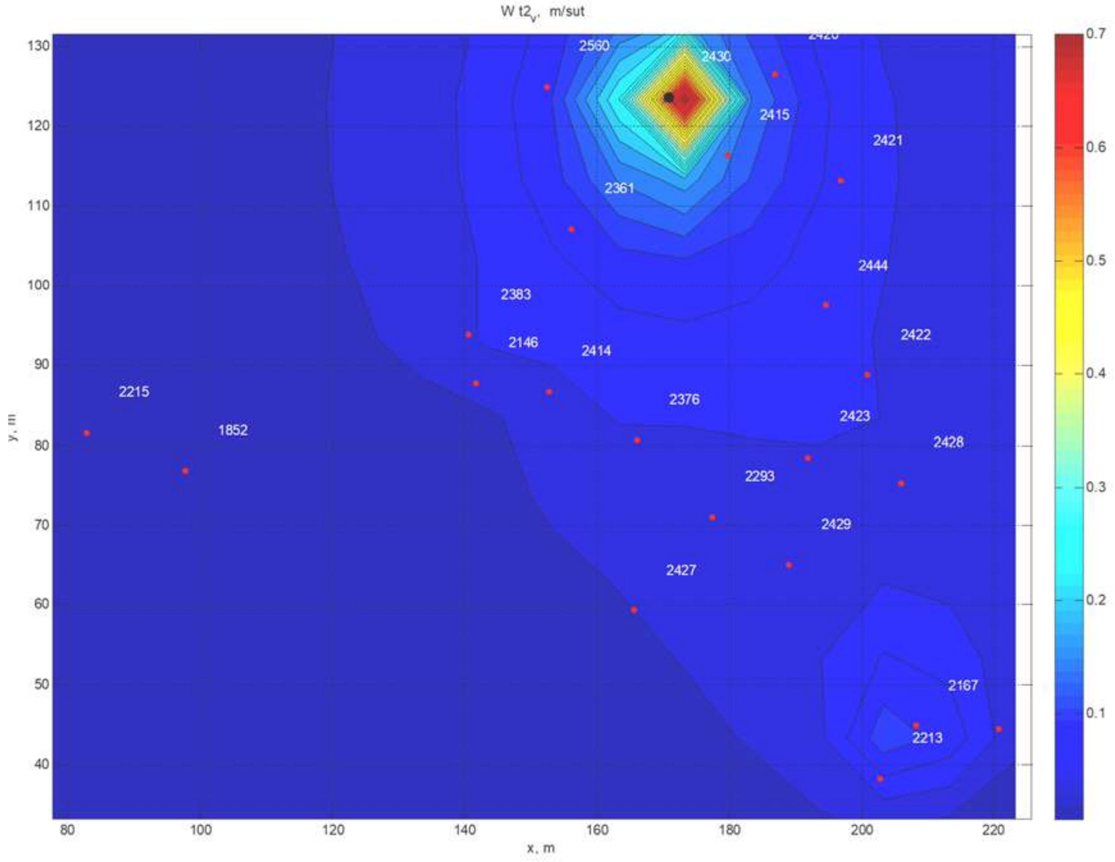

Fig. 7. Distribution of water flow velocity W^{τ}_{2} at time t_2

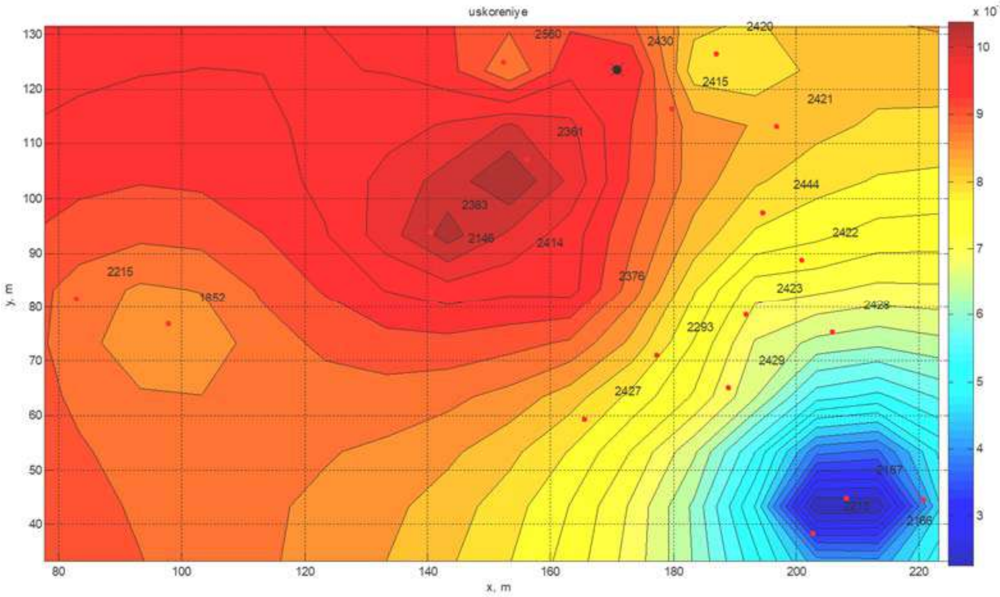

Fig. 8. Distribution of acceleration ***a*** in the reservoir fluid at time t_1

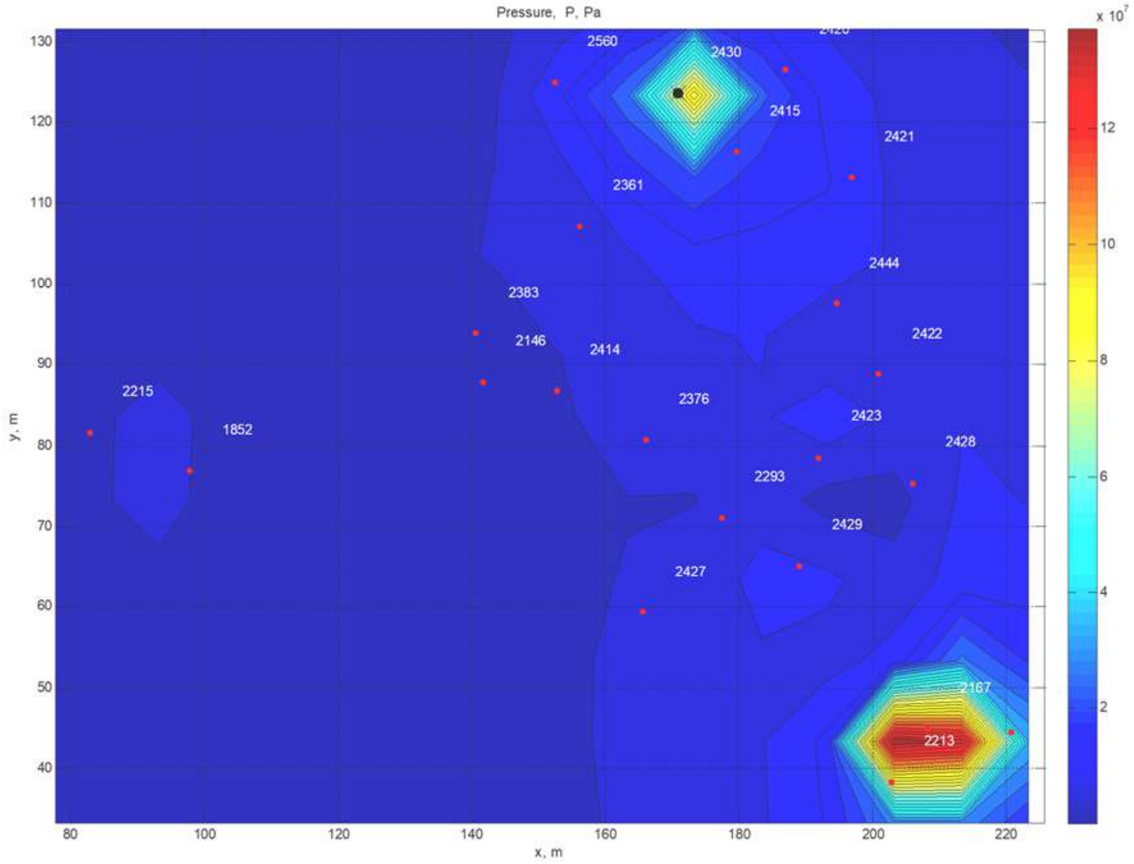

Fig. 9. Distribution of current reservoir pressure *P* at time t_2

Conclusion

1. An AI approach for rapid assessment of the distribution of current reservoir pressure based on oil production data is presented. The method is based on an algorithm that includes calculation of the current distribution of values of current functions, potentials, and flow velocity in a selected area;

2. In order to automate the calculations and visualize the obtained results, a special software module has been created on the basis of the “Matlab” engineering and scientific computing system package, which provides the facilities to calculate and visualize the pressure distribution in the area under study at the current time in accordance with the proposed algorithm;

3. The approach allows to monitor the current distribution of the current reservoir pressure of the productive reservoir in the area under consideration, as well as to evaluate the effectiveness of the impact on the reservoir to maintain the reservoir pressure;

4. The application of the proposed method to the data of the "Oil Rocks" field (horizon X, block V) as an example showed the high accuracy of the calculations. The average relative error of the calculated values of the reservoir pressure to the actual values of the bottomhole pressure measurements in the wells is not more than 1%, and the average calculated value of the reservoir pressure in the productive formation in the study area coincides with its actual reduced value.

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ОЦЕНКА РАСПРЕДЕЛЕНИЯ ТЕКУЩЕГО ПЛАСТОВОГО ДАВЛЕНИЯ ПО ДАННЫМ ДОБЫЧИ НЕФТИ С ПОМОЩЬЮ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА (ИИ)

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Резюме. На любом этапе разработки месторождений нефти и газа распределение пластового давления в продуктивных пластах является важной энергетической характеристикой пласта как в целом, так и на отдельных его участках. В данной статье рассматривается экспресс-метод оценки распределения текущего пластового давления на основе данных, полученных при разработке и эксплуатации нефтяных месторождений. Предлагаемая методика основана на алгоритме, включающем последовательный расчет и визуализацию текущего распределения значений таких гидродинамических показателей как функции тока, потенциалов, скорость потока, а также их градиентов на выделенном участке месторождения. Метод позволяет отслеживать фактическое распределение текущего пластового давления в продуктивном горизонте на рассматриваемой территории и оценивать эффективность воздействия на пласт, направленное на поддержание давления.

Разработанный подход также открывает широкие возможности для создания технологий искусственного интеллекта, для использования при анализе данных добычи нефти и газа, а также для машинного обучения при прогнозировании изменения пластового давления. Использование нейронных сетей при интеграции различных данных геологического, геофизического эксплуатационного характера и управлении операционными рисками позволяет создавать автоматические экспертные системы для оптимизации процессов разработки и эксплуатации месторождений нефти и газа.

Реализация предлагаемого подхода, проведенная на примере данных месторождения «Нефтяные Камни» (Горизонт X, Блок V), показала высокую точность расчетных значений пластового давления. Сравнительный анализ средней относительной погрешности расчетных значений пластового давления с фактическими значениями замеров забойного давления в скважинах составляет не более 1%, а среднее расчетное значение пластового давления в продуктивных пластах на исследуемой площади соответствует его фактическому значению.

Ключевые слова: *месторождение, пластовое давление, повышение нефтеотдачи пластов, зональное воздействие, продуктивный горизонт, продуктивность скважины, диагностика, фильтрация, мониторинг, линии тока*

SÜNİ İNTELLEKT VASİTƏSİLƏ NEFTİN ÇIXARILMASI MƏLUMATLARI ƏSASINDA CARİ LAY TƏZYİQİNİN PAYLANMASININ QİYMƏTLƏNDİRİLMƏSİ

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Xülasə. Neft və qaz yataqlarının işlənməsinin istismar mərhələsində məhsuldar layda və onun müəyyən hissəsində lay təzyiqinin paylanması neftvermənin artırılması məsələlərin həllində mühüm xarakteristikaların biridir. Bu məqalədə neft yataqlarının işlənməsi və istismarı zamanı əldə edilmiş məlumatlar əsasında layda cari təzyiqin paylanmasının qiymətləndirilməsinin ekspress metodu təklif edilir. İşlənmiş metodologiya, məhsuldar layın seçilmiş sahəsində axın və potensial funksiyaları, axın sürəti və onların qradiyentləri kimi hidrodinamik göstəricilərin lay üzrə cari paylanmasının hesablanması və vizuallaşdırılmasını aparmaq üçün işlənmiş alqoritmə əsaslanır. Metod cari lay təzyiqinin faktiki paylanmasını izləməyə və lay təzyiqin müəyyən səviyyədə saxlamaq üçün lazımı təsir tətbirlərin seçilməsi və bu təsirin effektivliyini qiymətləndirməyə imkan verir.

Təklif edilmiş yanaşma həmçinin neft və qaz hasilatı məlumatlarının təhlilində istifadə üçün, eləcə də lay təzyiqində dəyişikliklərin proqnozlaşdırılmasında, süni intellekt texnologiyalarının yaradılması üçün geniş imkanlar açır. Müxtəlif geoloji və geofiziki əməliyyat məlumatlarının inteqrasiyasında və əməliyyat risklərinin idarə edilməsində neyroşəbəkələrdən istifadə, neft və qaz yataqlarının işlənməsi və istismarı proseslərinin optimallaşdırılması üçün avtomatik ekspert sistemlərinin yaradılmasına imkan verir. Nümunə kimi, "Neft Daşları" yatağından (horizon X, blok V) məlumatlardan istifadə etməklə təklif olunan yanaşmanın həyata keçirilməsi lay təzyiqinin hesablanmış qiymətlərinin yüksək dəqiqliyini göstərdi. Quyularda lay təzyiqinin hesablanmış qiymətlərinin orta nisbi səhvinin quyudibi təzyiqinin ölçülmələrinin faktiki qiymətləri ilə müqayisəli təhlili 1%-dən çox deyil. Məhsuldar laylarda lay təzyiqinin orta hesablanmış qiyməti onun faktiki qiyməti ilə üst-üstə düşür.

Açar sözlər: *yataq, lay təzyiqi, neft veriminin artırılması, zonal təsir, məhsuldar lay, quyu məhsuldarlığı, diaqnostika, süzülmə, monitorinq, axin xətləri*