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IMPROVING THE EFFICIENCY OF HYDROCARBON DEVELOPMENT BY IMPROVING THE METHODS OF CONTROL AND REGULATION OF PROCESSES


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Identification of the regularity of pressure in the oil reservoir, considering the regularity of improving the method of control and reservoir development. The study used theoretical and experimental analyzes of the results with the use of software.

The results of the study will improve the accuracy of the design and development of oil and gas fields and can be used to improve the production technology of oil fields at their later stages of development. Taking into account the angle, the pressure distributions in the reservoir are changed in a circle, a new model is proposed in which the pressure dynamics is changed, it is solved by a two-dimensional problem taking known solutions. According to the known distribution of pressure in the reservoir, obtained experimentally, the characteristics of this parameter along the axis of the segment of the oil reservoir are fixed under changing boundary conditions. A mathematical model is proposed that considers the distribution of pressure along the angle of inclination of wells, will improve the prediction of pressure distribution in producing wells, which leads to the improvement of methods for monitoring and regulating development in oil fields.

KEY WORDS: *field, deposit, reservoir, regime, fluid, field development, control and regulation.*

ПРОЦЕСТЕРДІ БАҚЫЛАУ ЖӘНЕ РЕТТЕУ ӘДІСТЕРІН ЖЕТІЛДІРУ ЕСЕБІНЕН КӨМІРСУТЕКТЕРДІ ӘЗІРЛЕУ ТИІМДІЛІГІН АРТТЫРУ

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Мақала мұнай қабатындағы қысымның өзгеру заңдылығын бақылау әдісін жетілдіру және қабатты дамыту заңдылығын ескере отырып анықтауға арналған.

Зерттеу бағдарламалық жасақтаманы қолдана отырып, нәтижелерге теориялық және эксперименттік талдауды қолданды.

Қысымның таралу бұрышын ескере отырып, қабат шеңбер бойымен өзгереді, қысым динамикасы өзгеретін жаңа модель ұсынылады, ол белгілі шешімдерді қолдана отырып, *екі өлшемді мәселемен шешіледі. Эксперименталды түрде алынған қабаттағы қысымның белгілі таралуына сәйкес, мұнай қабаты сегментінің осі бойындағы осы параметрдің сипаттамалары өзгеретін шекаралық жағдайларда бекітіледі.*

Ұңғымалардың көлбеу бұрышы бойынша қысымның таралуын ескеретін математикалық модель ұсынылды, бұл өндіруші ұңғымалардағы қысымның таралуын болжауды жақсартуға мүмкіндік береді, бұл мұнай кен орындарын игеруді бақылау және реттеу әдістерін жетілдіруге әкеледі.

Зерттеу нәтижелері бойынша алынған деректер мұнай және газ кен орындарын жобалау мен игерудің дәлдігін арттырады және оларды игерудің кейінгі кезеңдерінде мұнай өндіру технологиясын жетілдіру үшін пайдаланылуы мүмкін.

ТҮЙІН СӨЗДЕР: *кен орны,кен орны, коллектор, режим, сұйықтық, кен орнын игеру, бақылау және реттеу*

ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ РАЗРАБОТКИ УГЛЕВОДОРОДОВ ЗА СЧЕТ СОВЕРШЕНСТВОВАНИЯ МЕТОДОВ КОНТРОЛЯ И РЕГУЛИРОВАНИЯ ПРОЦЕССОВ

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Статья посвящена выявлению закономерности изменения давления в нефтяном пласте с учетом закономерности совершенствования метода контроля и разработки пласта.

В исследовании использовался теоретический и экспериментальный анализ результатов с использованием программного обеспечения.

С учетом угла изменяются распределения давления в пласте по кругу, предлагается новая модель, в которой изменяется динамика давления, она решается двумерной задачей с использованием известных решений. Согласно известному распределению давления в пласте, полученному экспериментально, характеристики этого параметра вдоль оси сегмента нефтяного пласта фиксируются при изменяющихся граничных условиях.

Предложена математическая модель, учитывающая распределение давления по углу наклона скважин, которая позволит улучшить прогнозирование распределения давления в добывающих скважинах, что приводит к совершенствованию методов мониторинга и регулирования разработки на нефтяных месторождениях.

Полученные данные позволят повысить точность проектирования и разработки нефтяных и газовых месторождений и могут быть использованы для совершенствования технологии добычи нефтяных месторождений на более поздних стадиях их разработки.

КЛЮЧЕВЫЕ СЛОВА: *месторождение, залежь, коллектор, режим, флюид, разработка месторождения, контроль и регулирование.*

Introduction. To increase oil production at a late stage of operation, waterflooding technology is widely used, when reservoir pressure is increased with the help of water deposits. As a result, oil is squeezed out more efficiently from the pore space to production wells. Thus, the intensity of oil extraction from the reservoir increases. Such kind of situation often occurs when the injected water, moving through the most permeable areas, outruns the oil. Then a certain amount of the latter turns out to be closed in the "pillars", which makes it difficult to extract it. Hence the importance of managing the waterflooding process. Regulations for changing the injectivity of injection wells and the extraction of oil from producing wells require information about current changes in the reservoir. This, in turn, requires the relevance of research and improvement of field development technology as a solution to the most important and complex problem of hydrocarbon production in terms of flooding. We have developed a new technique for identifying patterns of pressure distribution in the reservoir and created new conditions for production control.

Formulation of the problem. The commissioning of a new field, as a rule, is complicated by insufficient knowledge of the structure of the deposit, the nature of the fluids saturating it by area, as well as the distribution of pressure in the reservoir.

Enhanced production of residual oil reserves at the final stages of development requires the use of other development methods, the economic unjustification of drilling new wells at this stage of operation. Under these conditions, the improvement of field development should follow the path of establishing patterns of pressure distribution during waterflooding based on the generalization of experience and experimental studies. The efficiency of oil field development during flooding largely depends on the viscosity of the oil that saturates the productive deposits. Establishing a relationship between oil recovery factor and oil viscosity has become especially relevant in connection with the production of large volumes of high-viscosity oil.

Several works are devoted to the management of production operations in order to increase oil recovery by maximizing the direction of fluids to the bottomholes of production wells [1, 2], in other works, an increase in oil recovery is solved by controlling and regulating development [3, 4].

Various development systems are used in accordance with the geological and physical conditions [5, 6], however, in the late stage of development, the oil reservoir turns out to be largely occupied by a displacing agent (for example, water or PGS). As is known, some zones with high oil saturation, close to the initial oil content in the reservoir, the so-called oil pillars, remain in the reservoir. To extract oil from pillars, the development system is changed [7, 8] or spot and selective waterflooding is used [9, 10].

Since the methods for maintaining reservoir pressure made it possible to significantly increase oil recovery compared to oil recovery of facilities developed in a natural regime, dispersed waterflooding systems, focal and by changing filtration flows, have been developed [11]. Other methods for maintaining reservoir pressure are also being created [12, 13].

It was shown in [3, 5] that flooding of high-permeability and water-saturated areas leads to partial or complete exclusion of medium and low-permeability layers from the mining process, while the problem of water inflow into wells is relevant not only for wells in operation, but also for newly created ones [2, 8].

In practice, the absence of new deposits, enhanced by fluctuations in oil prices, determines the search for new methods that will bring industrial enterprises into an economically viable zone. Therefore, various methods for improving the control and development of hydrocarbon deposits are rapidly developing.

At present, with the improvement of computer technology in the oil industry, a new applied direction has gradually emerged – geological and hydrodynamic modeling, which is aimed at obtaining new methods and improving existing ones for enhancing oil recovery. However, the fact stands out that, along with the noticeable improvements that the modeling has brought, "it was not possible to solve the main problem – to increase the accuracy of the results obtained" [1]. After some time, the permanent geological and hydrodynamic model of field development deviates the actual dynamics of the current oil production from the design, which is fraught with serious consequences. Therefore, the creation of a new methodology for managing production processes, excluding the identified shortcomings, remains very relevant.

Research methodology. To calculate the distribution of pressure at given points, the contour lines of the formation in the water-driven or elastic regime use known solutions to problems [8, 9]. Fluid inflow from an unrestricted circular reservoir to a runoff point or to the circular contour of an enlarged well is calculated using the well-known formulas of Carslow and Van Everdingen [9, 14].

To formulate the problem, let us take as an example an oil reduced circular deposit, which has the shape of a circle of radius R. It is surrounded by an infinitely stretching water-bearing area (*Fig. 1*).

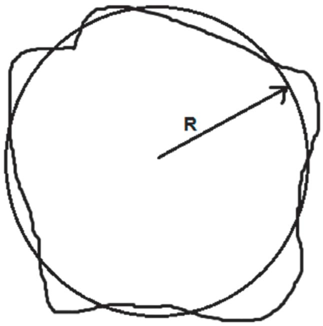

Figure 1 – **Scheme outline of the oil-bearing circle**

At t = 0, the oil deposit began to be developed with a flow rate q (m^3/day). All other reservoir parameters are assumed to be known.

From a technological point of view, it is of interest to determine the change in the pressure dynamics on the contour of the oil reservoir for ΔP compared to the initial reservoir pressure P0 after some time intervals, considering it to be a well with an enlarged radius [1, 5].

In the well-known calculations by Carslow and Yeger, Van Everdingen and Hurst [1, 2], the following solutions were obtained for the reduced radius of a production well

$$\Delta P_{кон} = \frac{q\mu}{2\pi kh} f(\tau)$$

$$f(\tau)=0,5[1-(1+\tau)^{-3,81}]+1,12\lg(1+\tau) \quad (1)$$

$$\tau - \aleph t/R^2$$

where q- is flow rate m is viscosity of liquid; t -is current time; k is permeability; R- is reduced well radius. In calculations, it is assumed that the pressure changes only along the radius vector R.

Since this calculation formula assumes pressure changes only along the radius vector of the influence of the angle of rotation, the problem here is one-dimensional.

Below we consider the flow diagram on the oil-bearing contour (along the circumference), the contour pressure is set, and it is possible to derive a calculation formula when the pressure changes, both along the radius vector and the change in the angle of rotation (*Fig. 2*).

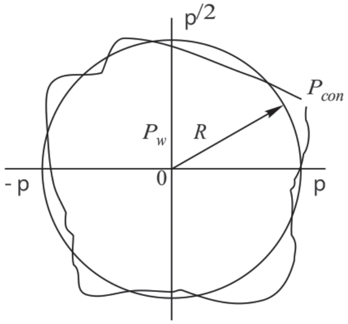

Figure 2 – **Scheme of the reduced contour of the oil reservoir**

For example, we take a contour, its model is given, where Pc is circuit pressure. Pw is pressure in the well, all parameters remain inside the circle (since we consider inside the circle). Move along the radius of the vector, enter R. Pc the highest pressure on the circuit. The task is set how the pressure to the well will change Pw, Pc → Pw.

We write all the coefficients a2, that is, the same process takes place over a certain period, the stability in time depends on

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} = 0 \text{ or } \Delta^2 P = 0 \quad (2)$$

solved in cylindrical coordinates

$$\begin{Bmatrix} x = r\cos\varphi \\ y = r\sin\varphi \end{Bmatrix}$$

Then the equation becomes

$$\frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial \varphi} + \frac{\partial^2 p}{\partial \varphi^2} = 0, \quad (3)$$

or $\Delta^2 P_{rt} = 0$.

To solve this problem, there are two types of mathematical approach. So, in the fundamental book by Zheltov, and in all his other works, the following is done: the pressure is distributed only along the contour, it does not change in the corners, that is j = const it is required to find a solution to the Laplace equation

$$\Delta P(x,y) = 0 \text{ or } \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} = 0 \quad (4)$$

inside the circle and satisfying the boundary condition P = f = Pc on the boundary (along the circumference) of the circle, where Pc is the pressure value at the boundary.

This corresponds to the interior Dirichlet problem for a circle, well developed in mathematical physics [10, 12].

It is possible to substantiate the possibility of applying the technique for solving the internal Dirichlet problem for the given problem. The value of the contour pressure at the boundary is constant, that is, the harmonic function reaches its maximum and minimum values only at the boundary at r = R in the near-wellbore zone, that is r = 0, P → ∞, which corresponds to the technological process-liquid selection.

Passing to the system of polar coordinates, we have the equation [14, 15]

$$\Delta P = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial P}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 P}{\partial \varphi^2} = 0 \quad (5)$$

and boundary conditions

$$P(r,\varphi) = Pk\ \sin\varphi$$

The solution to this equation is expressed by the Poisson integral [4]

$$P(r,\varphi) = \frac{1}{2\pi}\int_{-\pi}^{\pi} f(\psi)\frac{R^2-r^2}{r^2-2Rr\cos(\varphi-\psi)+R^2}d\psi, \quad (6)$$

where is the integral expression

$$K(r,\varphi,R,\psi) = \frac{R^2-r^2}{r^2-2Rr\cos(\varphi-\psi)+R^2};$$

called the Poisson kernel.

Note that K (r, φ, R, ψ) > 0 at r < R, because of 2Rr < R^2 + r^2, if r ≠ 0.

Solution is

$$\varphi - \psi = t;$$
$$\varphi = 0; \quad t = \varphi;$$
$$\varphi = \pi; \quad t = \varphi - \pi;$$
$$a = R^2 + r^2;$$
$$b = 2Rr;$$

$$P(r,\varphi) = \frac{P_k}{\pi}\int_{-\pi}^{\pi}\frac{(R^2-r^2)\sin(\varphi-\psi)}{R^2-2R\ r\cos(\varphi-\psi)+r^2}d\varphi =$$
$$= -\frac{P_k(R^2-r^2)}{\pi}\int_0^{\pi}\frac{\sin t}{R^2-2R\,r\cos t+r^2}dt = \frac{P_k(R^2-r^2)}{\pi}\int_0^{\pi}\frac{\sin t\,dt}{a-b\cos t} =$$

$$= -\frac{1}{b}\frac{R_k(R^2-r^2)}{\pi}\int_0^{\pi}\frac{\sin t\,dt}{\frac{a}{b}-\cos t} = -\frac{P_k(R^2-r^2)}{\pi b}\int_0^{\pi}\frac{d(\frac{a}{b}-\cos t)}{\frac{a}{b}-\cos t} = \frac{P_k(R^2-r^2)}{\pi Rr}\ln\left|\frac{a}{b}- -\cos t\right|\ \Big| =$$
$$\frac{P_k(R^2-r^2)}{\pi Rr}\left[\ln\left|\frac{a}{b}-\cos(\varphi-\pi)\right|\right]$$

$$= -\ln\left|\frac{a}{b}-\cos\varphi\right| =$$

$$= \frac{P_k(R^2-r^2)}{\pi Rr}\ln\left|\frac{\frac{R^2+r^2}{2Rr}-\cos(\varphi-\pi)}{\frac{R^2+r^2}{2Rr}-\cos\varphi}\right| = \frac{P_k(R^2-r^2)}{\pi Rr}\ln\left|\frac{R^2-2Rr\cos(\varphi-\pi)+r^2}{R^2-2Rr\cos\varphi+r^2}\right|;$$

The Puasson integral is derived under the assumption r < R, r = R representation (5) loses its meaning. However,

$$\lim_{r\to R} P(r,\varphi) = f(\varphi_0) = P_{k.}$$

Substituting boundary conditions into equation (5), we obtain solutions to the first boundary value problem inside the circle.

The solution is determined by the expression

$$P(r,\varphi) = \begin{Bmatrix} \frac{P_k(R^2-r^2)}{\pi R^2}\ln\left|\frac{R^2-2Rr\cos(\varphi-\pi)+r^2}{R^2-2Rr\cos\varphi+r^2}\right| at\ r < R \\ Pk \quad at\ r = R \end{Bmatrix}. \tag{7}$$

This solution shows for any value r < R and -p ≤ φ ≤ p it is possible to calculate the dynamics of the pressure distribution inside the circle and takes a given value at the boundary of the circle.

Considering the pressure distribution for an injection well, we make the following physical assumptions. The environment of the bottomhole zone is assumed to be homogeneous in terms of physical parameters and close enough to the injection well, and the pressure Pw is assumed to be given and constant. In this case, the problem reduces to the external Dirichlet problem for the circle of the Laplace equation.

Solution is,

$$\begin{Bmatrix} a = R^2 + r^2 \\ b = 2R\,r \end{Bmatrix}$$

$$t = \varphi - \psi;$$
$$\psi = \varphi - t;$$
$$d\psi = -dt;$$
$$\psi = -\pi;\ t = \varphi + \pi;$$
$$\psi = \pi;\ t = \varphi - \pi;$$
$$x = tg\frac{t}{2};$$

$$t = tg\,\frac{x}{2};$$

$$P(r,\varphi) = \int_{-\pi}^{\pi} P_c \frac{R^2-r^2}{r^2-2Rr\cos(\varphi-\psi)+R^2}d\psi = \frac{P_c}{2\pi}(r^2-R^2)\int_{-\pi}^{\pi}\frac{d\psi}{r^2-2Rrcos\,(\varphi-\psi)+R^2} =$$

$$= \frac{P_c}{2\pi}(r^2-R^2)\int_{-\pi}^{\pi}\frac{d\psi}{a-b\cos(\varphi-\psi)} = \frac{P_c}{2\pi}(r^2-R^2)\int_{\varphi-\pi}^{\varphi+\pi}\frac{dt}{a-b\cos t} =$$

$$= \int_{\varphi-\pi}^{\varphi+\pi}\frac{dt}{a-bcost} = \int_{\varphi-\pi}^{\varphi+\pi}\frac{\frac{2}{1+x^2}}{a-b\frac{1-x^2}{1+x^2}}dt = 2\int_{\varphi-\pi}^{\varphi+\pi}\frac{dx}{a+ax^2-b+bx^2} =$$

$$= 2\int_{\varphi-\pi}^{\varphi+\pi} \frac{dx}{(a-b)+(a+b)x^2} = \frac{2}{a+b}\int_{\varphi-\pi}^{\varphi+\pi} \frac{dx}{\frac{a-b}{a+b}+t^2} = \frac{2}{a+b}\sqrt{\frac{a+b}{a-b}}\, arctg\sqrt{\frac{a+b}{a-b}}\,x = \frac{2}{\sqrt{a^2-b^2}}\, arctg\sqrt{\frac{a+b}{a-b}}\,x =$$

$$= \frac{2}{R^2-r^2}\, arctg\, \frac{R+r}{R-r}x\ \Big| = \frac{2}{R^2-r^2}\, atctg\left[2\frac{R+r}{R-r}tg\, t\right]\Big| =$$

$$= -\frac{P_c}{\pi}(r^2-R^2)\frac{1}{R^2-r^2}\, atctg\left[\frac{R+r}{R-r}(tg(\varphi+\pi)-tg(\varphi-\pi)\right] = \frac{P_c}{\pi}\, atctg\left[2\frac{R+r}{R-r}tg\,\varphi\right];$$

From the Puasson integral we obtain the following solution

$$P(r,\varphi) = \begin{Bmatrix} \frac{P_c}{\pi}\ arctg(2\frac{R+r}{R-r}tg\varphi) & at\ r > R \\ Pc\quad at\ r = R \end{Bmatrix}. \qquad (8)$$

This solution continuously adjoins the boundary of the circle with the given values and remains valid not only for a constant value, but also for continuously or piecewise continuous variable values on the supply circuit.

To establish the pressure distribution in the reservoir, in the laboratory for research and production of oil and gas of the Atyrau University of Oil and Gas named after Safi Utebaev, experimental studies were carried out to characterize the pressure distribution along the axis of the oil-bearing reservoir segment under changing boundary conditions.

The experimental setup provides the ability to change the sequence of connection of reservoir models: serial, parallel and mixed connection.

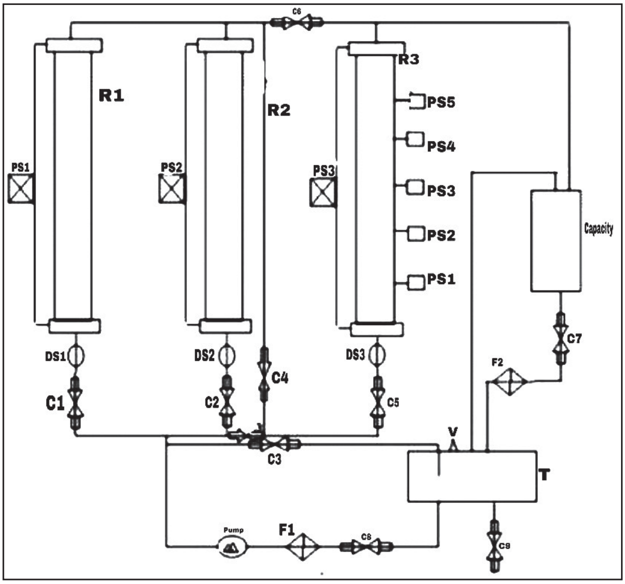

Figure 3 – **Hydraulic scheme of the installation for the experiment on segment No. 1–3**

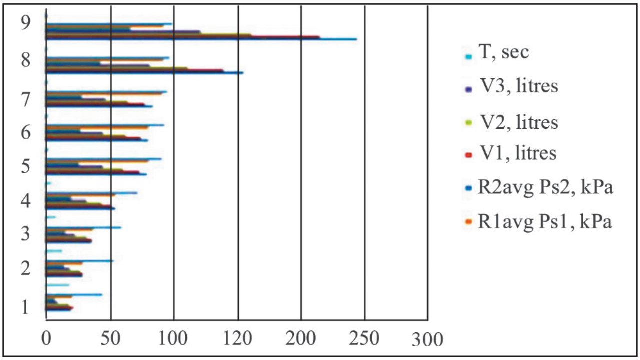

Figure 4 – **Pressure distribution in reservoir Nos. 1, 2, 3 P_{ps3} average, kPa**

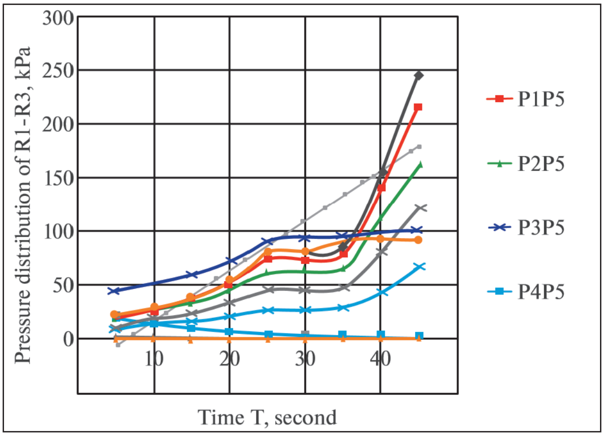

Figure 5 – **Pressure distributions in reservoir No. 3 P_{ps3} medium, kPa**

The core is pre-washed and cleaned of oil residues. The core was taken from the depths of 830–871.8 m from the Neokomsky II layer. Core samples are 1.0 m high (100 %), samples from the Neokom-I formation are 0.4–0.5 m high. The core is uniformly saturated with oil 0.0, 0.20, 0.40, 0.65, 1.0 m. Blu- ish-gray, silty-like, argillite-like, layered, thin-lamellar, uneven, roughly fractured, calcareous clays. On all spans, the seams are separated by coal residues within 1–2 mm.

Pressure sensors have been placed below. 3 sensors are placed along section F of the area. The sensor readings are presented in *Table 3*, according to which the graph is built, i. e., the purpose of the experiment is to determine the change in pressure by the angle of rotation of the radius vector. The experiment showed that the pressure changes to three different values at three points. This confirms the theoretical conclusion about the patterns of pressure distribution.

As an example, the parameters of the field were taken, and the deflection angle of 120° was calculated (*Fig. 7*).

Calculation of pressure distribution parameters in the injection well tained research results and calculated values confirm the established regularities of pressure distribution

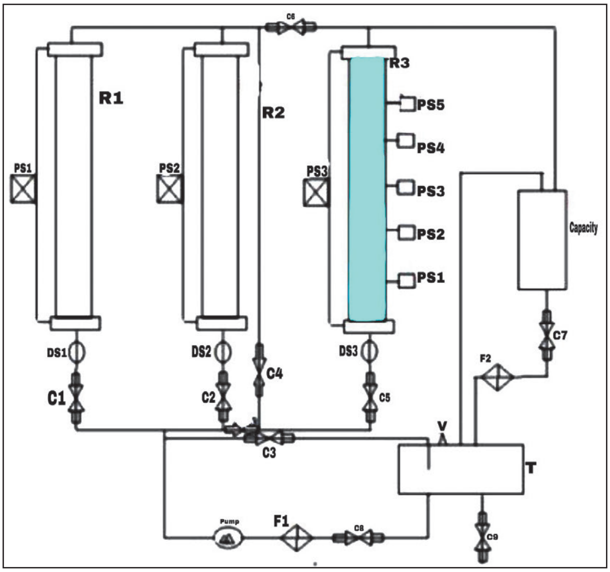

Figure 6 – **Hydraulic scheme of the experiment reservoir No. 3**

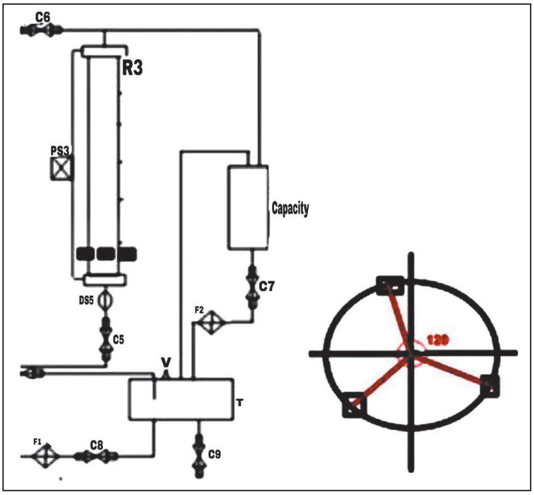

Figure 7 – **Scheme of the location of the sensors on the area of the reservoir**

in reservoir conditions, show the correspondence of the model to the field development processes, thereby allowing one to improve the field development methods.

Comparing the theoretical data and the results of experimental work, it was found that in addition to the physical properties of the reservoir, in which the regularity of pressure distribution in an inhomogeneous medium was revealed, the rate of its distribution also depends on the angle of change.

The results of experimental studies aimed at studying the pressure distribution in the reservoir make it possible to measure the pressure distribution parameters along the axis of the oilbearing reservoir segment under changing boundary conditions.

Thus, as a result of experimental work, the regularity of pressure distribution with the growth of a layer filled with quartz sand was established, and the experiment gave a positive result.

Conclusions. The critical analysis of literary sources and studies on the application of the tertiary method of enhanced oil recovery for the conditions of the fields of Western Kazakhstan shows the effectiveness of the polymer flooding technology, which is determined by the properties of the reagents used, the choice of which is carried out taking into account the individual characteristics of the physical and capacitive properties of productive formations and the state of development and operation of a particular Place of Birth.

A two-dimensional mathematical model of the dynamics of pressure distribution in a circular deposit has been built. Considering circular deposits as a source and sink, the calculation of the dynamics of pressure distribution inside the circle and outside the circle, taking a given value at the boundary of the circle, reduces to solving the internal and external Dirichlet problem and is shown for any value $r < R$ and $-p \leq \varphi \leq p$.

The conducted experimental studies aimed at studying the pressure distribution in the reservoir made it possible to measure the pressure distribution parameters along the axis of the oil-bearing reservoir segment under changing boundary conditions. To carry out the necessary studies, an experimental setup was designed, consisting of three reservoirs with different physical characteristics. The main formation was equipped with special pressure sensors, which made it possible to record pressures along the segment axis. In general, by selecting the necessary porous formation media, close parameters of the pressure distribution in the formation were obtained under changing boundary conditions.

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