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ENHANCED OIL RECOVERY OF DEPOSITS BY MAINTAINING A RATIONAL RESERVOIR PRESSURE

Purpose. Increasing oil recovery from deposits and reducing the water content of producing wells by providing conditions for uniform displacement of oil from the reservoir under the influence of high reservoir pressure.

Methodology. The purpose of the work is achieved by conducting theoretical and experimental studies of the process of creating high elastic energy in the formation by pumping water with injection well pumps to overcome the resistance of oil and water filtration through the pores of the rock and oil rise at the mouth of producing wells. The absence of pumps from producing wells and the acceptance of equal amounts of injection and production wells over the reservoir area significantly increases the reservoir pressure above the pressure of oil saturation with gas. Due to the significant elasticity of the rock and fluids under high reservoir pressure, the oil coverage with water increases and there is no premature breakthrough of water into producing wells. The possibility of creating high elastic energy in an oil reservoir by pumping water into injection wells has been experimentally studied.

Findings. It has been established that high reservoir energy in the field of elastic deformation of rock and fluids can be created mainly by pumps from injection wells, due to which oil is uniformly displaced from the reservoir along the entire front without breaking through the injected water into producing wells along the path of least resistance. The adoption of equal amounts of producing and injection wells and their sequential arrangement in rows contributes to the development of high potential energy in the reservoir and increase the pick-up rate of injection and production wells. As a result, the skeleton of the rock forming the pores expands, and the water injected into the reservoir and the displaced oil accumulate and increase reservoir energy.

Originality. The effectiveness of the proposed method for maintaining high reservoir pressure is achieved as a result of creating high energy of rock and fluids in the area of their elastic deflation and increasing the coverage coefficients of oil displaced by water over the area and profile of the productive formation without the use of additional capacities and pumping units from producing wells.

Practical value. The developed new technique for maintaining high elastic reservoir pressure not lower than the pressure of oil saturation with gas by pumping water into the reservoir can be carried out in oil fields using standard technological equipment and increase oil recovery to 60–70 % at its existing values of 40–45 % and reduce the water content of produced oil to 0–10 % at its existing values of 20–80 % and above.

Keywords: *oil deposit, formation, well, pressure, oil recovery, equipment*

Introduction. The efficiency of oil production is estimated by the volume of extracted oil from its geological reserve and the oil flow rate of producing wells. Moreover, both criteria are very important both from an economic point of view and on the principle of rational use of oil deposits. It is known that pumping water into a productive reservoir allows one not only to increase the rate of extraction, but also to significantly increase the volume of extracted oil [1]. This traditional method for maintaining reservoir pressure allows you to extract only two thirds of the initial geological oil reserves, since in the process of oil production, there is a gradual watering of producing wells to 80–90 % and above. The water injected into the reservoir, moving along the path of least resistance to movement, breaks into producing wells and a significant amount of oil is not extracted from the reservoir.

The use of well-known methods of secondary and tertiary oil recovery [2] does not allow one to fully increase the volume of initial technologically recoverable geological oil reserves. This is due to the insufficient knowledge of the processes of uniform displacement of oil from the productive reservoir by water and the rational choice of well parameters and operating modes. The methods for increasing oil recovery have not disclosed the possibility of creating high reservoir pressure within the elastic deformation of rock and fluids and the equality of the total throughput capacities of injection and production wells.

Literature review. In [3], it is noted that during normal flooding, an unfavorable condition is created for the displacement of oil from the reservoir and water tends to penetrate into the oil and move along the shortest path to the producing wells (Fig. 1, *a*). In the process of maintaining reservoir pressure by pumping water, oil is displaced from the reservoir unevenly over an area. This effect is enhanced by the geological heterogeneities of the reservoir. The authors of the above work believe that one of the applied technologies for maintaining reservoir pressure, providing a more complete and uniform displacement of oil from the productive reservoir by area, can be considered polymer flooding (surfactants and other types of chemical flooding), whose scheme is shown in Fig. 1, *b*.

A typical example is the use of a solution of partially hydrolyzed polyacrylamide in concentrations from several hundred to several hundred parts to displace oil (and associated water) from the reservoir. It is believed that polymer solutions move more evenly in the formation. Although the flow still tends to be greatest in areas with high permeability and along the shortest path between injection and production wells, the effect is weakened because the mobility of the polymer solution is less than the mobility of water.

At the same time, the authors believe that partially hydrolyzed polymers affect mobility in two ways. Firstly, polymer solutions have an apparent viscosity that is greater than that of water. They may exhibit significant shear sensitivity; i.e., the apparent viscosity may be a function of the shear rate to which the solution is subjected. Secondly, polymers are adsorbed on porous media and (or) mechanically trapped as a result of their large physical size. This retention of polymer molecules reduces the amount of polymer in solution, but also causes a decrease in the effective permeability of the porous medium (oil reservoir).

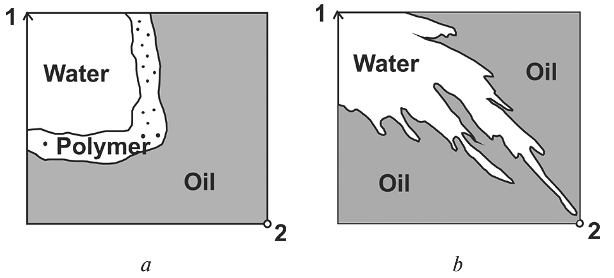


Fig. 1. The process of water breakthrough in the reservoir (a) along the path of least resistance to producing wells and the traditional representation of the process of oil displacement from the reservoir (b) with an aqueous polymer solution:
1 and 2 – injection and production wells, respectively

Research on enhanced oil recovery is very encouraging with chemical methods that significantly improve wettability properties and improve recovery rates compared to traditional methods. In order to optimize the compositions of surfactants and polymers in the presence of salts, many experiments have been conducted to measure additional extractions. In typical experiments [4, 5] conducted with partially hydrolyzed polyacrylamide, enhanced extraction was observed at a concentration of sodium hydroxide from 0.7 to 1 wt.%, and a surfactant concentration of 0.2 wt.%.

It is also well known that too much residual oil remains stagnant in the porous structure of the rock, which can be extracted by reducing the interfacial tension between water and oil using certain surfactants [6, 7].

The key mechanism of alkaline flooding is the penetration of alkaline solutions into viscous oil, followed by the formation of water droplets inside the oil phase [8, 9]. This changes the interfacial properties of oil and water with the formation of water channels, thereby increasing the efficiency of displacement in the chemical method for increasing oil recovery using an alkaline solution.

In [10], a graphical method was proposed to assess the effect of the grid scheme of the location of wells on the possibility of expanding the coverage areas of oil by reservoir flooding. The authors point out that visualization of oil extraction contours and temporary flooding contours makes it possible to determine the drainage trajectory for any group of producing and injection wells, taking into account reservoir productivity.

The use of nanoparticles is considered promising for increasing oil recovery, especially when they are combined with surfactants. In [11], the advantages of mixing Al_2O_3 nanoparticles with SAIL 1-dodecylpyridinium chloride were investigated. It was found that the addition of nanoparticles to the surfactant helped: slightly increase its viscosity, increase the ability to reduce the water-oil interfacial tension and reduce adsorption on carbonate rocks (adsorption on sandstone turned out to be excessive).

However, practice shows [12, 13] that traditional methods for increasing oil recovery by maintaining reservoir pressure by injecting aqueous solutions of polymer, surfactants and other reagents into the productive reservoir have not yet yielded tangible positive results. This is evidenced by the current problems of high water content (up to 80–90 % and above) and low flow rate (below 5 tons/day) of producing wells (including those using polymer flooding) in many oil fields, especially at the middle and late stages of their development.

Thus, the available methods for maintaining reservoir pressure by injecting aqueous solutions of polymer, surfactants and other reagents into the formation do not fully allow achieving high oil recovery and reducing the water content of producing wells. This can be explained by the fact that the slowing down of the displacement agent, an aqueous solution of polymers, occurs not only along the path of least resistance, but also even more slowly along the lateral sections of the displaced oil. In any case, the viscous water pumped thickened with polymers will again primarily displace oil along the path of least resistance to its movement and the injected water breaks through the oil flow into the producing wells and premature flooding of the extracted oil.

One of the ways to increase the efficiency of oil recovery methods is the creation of water isolation zones below and above the productive formation [14], purification of water injected into the formation from suspended clay particles and intensification of oil inflow to the well faces [15]. At these intervals, the production column is perforated and gel-forming reagents and expanding grouting materials are pumped into the formed channels. The purification of reservoir water from suspended clay particles is carried out in granular filters with variable particle sizes. The treatment of the bottom-hole zone of producing wells is carried out using low-boiling oil components with a content of carbon atoms C_6-C_9 in molecules.

One of the effective methods for reducing the filtration resistance of oil injected into the formation and displaced while maintaining high reservoir pressure is to restore the natural permeability of the bottomhole formation zone by removing colmatation products formed during well drilling. For this purpose, an original method of implosive impact on productive horizons during well development was proposed in [16].

Unsolved aspects of the problem. The reason for the low efficiency of traditional methods for increasing oil recovery can be explained as follows. Uniform displacement of oil from the reservoir by water or an aqueous polymer solution over an area can be achieved only at high pressures in the reservoir within its elastic deformation not lower than the saturation pressure of oil with hydrocarbon gases. However, the existing oil production technology, which includes pumps from both injection and production wells, does not allow creating high reservoir pressure. Fig. 2 shows the traditional layout of pumping units and a plot of pressure changes in the oil reservoir between the injection and production wells.

It can be seen from the pressure change diagram that the pumping unit from the injection wells creates pressure p_1, including pressure to overcome the resistance to water movement p_{11} inside the tubing and the pressure of the water column p_{12} inside the tubing of the injection well with a negative sign, and pressure to overcome the oil filtration resistance p_{13} in the reservoir. The pumping unit from the side of the producing well creates pressure p_2, including pressure to overcome the resistance to the movement of oil p_{21} inside the tubing and the pressure of the oil column p_{22} inside the tubing of the producing well.

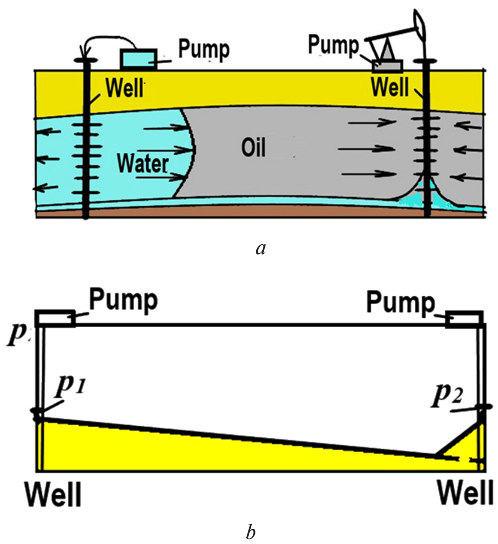


Fig. 2. Pump layout (*a*) *and pressure change diagram* (*b*) *in the oil reservoir between injection and production wells with traditional oil production technology*

The pressure values p_1 and p_2 can be determined using generally accepted formulas

$$p_1 = p_{11} + p_{12} + p_{13} = \frac{\lambda}{2d} H v_1^2 g - \rho_1 g H + vL\mu \frac{\mu}{k}; \qquad (1)$$

$$p_2 = p_{21} + p_{22} = \rho_2 g H + \frac{\lambda}{2d} H v_2^2 g, \qquad (2)$$

where p_1 and p_2 are the densities of water and oil; respectively, H is the depth of oil; λ is the coefficient of resistance inside the tubing; v_1 and v_2 are the displacement velocities of water and oil, respectively; g is the acceleration of gravity of the body; d is the diameter of the tubing; L is the power circuit; μ is the viscosity of the oil; k is the permeability coefficient of the reservoir.

The pressure change diagram shows that the pressure created in the formation is very low and its value will always be less than the pressure within the elastic deformation of the rock and fluids and the pressure of oil saturation with gas. The downhole pump from the side of the producing well, by creating a vacuum in the bottomhole zone, reduces the reservoir pressure created by the pump from the injection well. Under low-pressure conditions, water displaces oil from the reservoir over a small area with small coverage and, moving along the path of least resistance to filtration, breaks into the producing well. At the same time, a significant amount of unrecovered oil remains in the reservoir on both sides of the water flow.

The next important factor reducing oil recovery is the discrepancy between the number and throughput capacities of injection and production wells from the point of view of the material balance of oil injected into the formation and extracted from the formation. For example, in four, five, seven and nine point reversed and non-reversed well grids, the ratio of quantities and throughput capacities of producing and injection wells varies within large limits and ranges from 3 to 8 (Fig. 3).

Fig. 3 shows that as a result of low reservoir pressure in all traditional schemes for the arrangement of wells in triangular and rectangular grids and the predominance of the number of producing wells over the number of injection wells, oil coverage with water is insignificant and water breakthrough into producing wells occurs faster.

Purpose. The objectives of this work are to increase oil recovery from deposits and reduce the water content of producing wells by providing conditions for uniform and complete displacement of oil from the reservoir by water. It is necessary to study the factors influencing the processes of oil field development by maintaining high reservoir pressure and premature water breakthrough into producing wells. One of the most important tasks in increasing oil recovery is the choice of a rational well grid and the ratio of the quantities of injection and production wells.

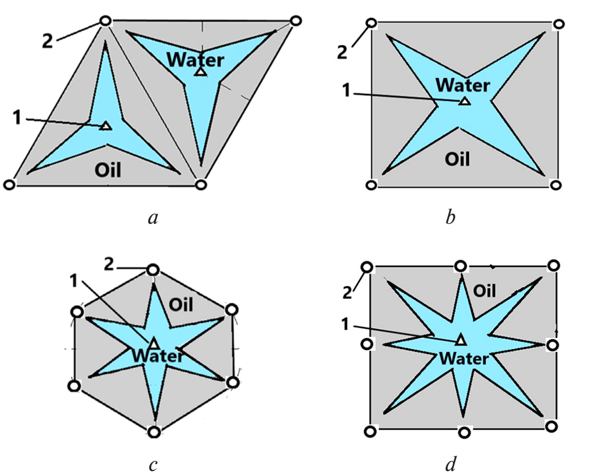


Fig. 3. Traditional well layouts in four (a), five (b), seven-point (c) triangular grids and in a nine-point (d) rectangular grid: 1 and 2 wells, respectively, injection and production

Methods. The processes of uniform displacement of oil from the reservoir along the entire front and the factors influencing the increase in the flow rate of wells and the decrease in the water content of the extracted oil have been studied. We have obtained a patent for a method for increasing oil recovery [17] by creating a high reservoir pressure above the saturation pressure of oil with hydrocarbon gases. This method consists in the fact that during the injection of the agent of water into the oil reservoir by injection well pumps, a high reservoir pressure is created in the area of elastic deformation of rock and fluids, exceeding the pressure of oil filtration through the pores of the rock and lifting oil to the surface through producing wells. At the same time, there are no pumps from the producing wells, and reservoir energy for displacing oil with water is carried out only by pumping units from the injection wells. A diagram of the pressure change in the oil reservoir between the injection and production wells when installing pumps only from the injection wells is shown in Fig. 4.

The reservoir pressure p, developed by pumps from injection wells, is the sum of the pressures to overcome: resistance to the movement of water inside the tubing, gravity of the column of water inside the injection well (with a negative sign), resistance to oil filtration in the formation and resistance to the movement of oil inside the tubing and gravity of the column of oil inside the producing well.

Then this total pressure p is expressed by the equation

$$p = \frac{\lambda}{2d} H v_1^2 g - \rho_1 g H + vL\mu \frac{\mu}{k} + \rho_2 g H + \frac{\lambda}{2d} H v_2^2 g. \qquad (3)$$

From this equation and the pressure change diagram, it can be seen that the reservoir pressure between wells increases significantly throughout the entire volume of the productive formation, carrying out high elastic energy of the rock and its value will always be higher than the oil saturation pressure with gas.

From the point of view of the material balance of the injected water into the reservoir and the extracted oil, it is more advisable to take the ratio of the quantities of producing and injection wells equal to or close to 1. Fig. 5 shows the schemes of sequential in-line (Fig. 5, *a*) and offset (Fig. 5, *b*) placement of producing and injection wells with equal amounts over the entire area of the reservoir.

From this well placement, it can be seen that the adoption of equal amounts of producing and injection wells allows for the creation of high potential energy in the formation within its

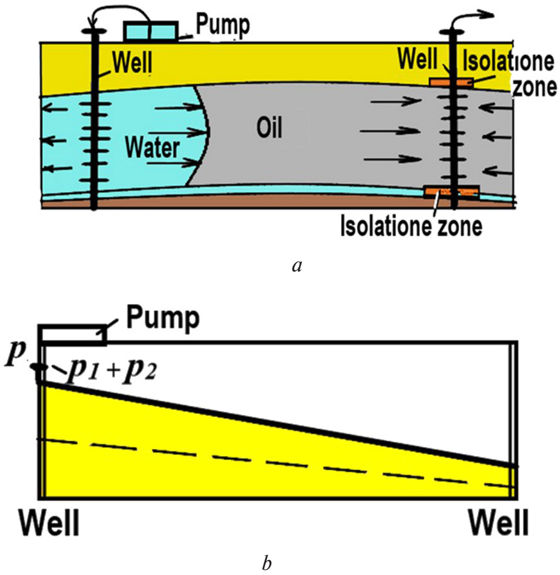


Fig. 4. A diagram of the pump installation only from the injection wells (a) and a diagram of pressure changes (b) in the oil reservoir between the injection and production wells

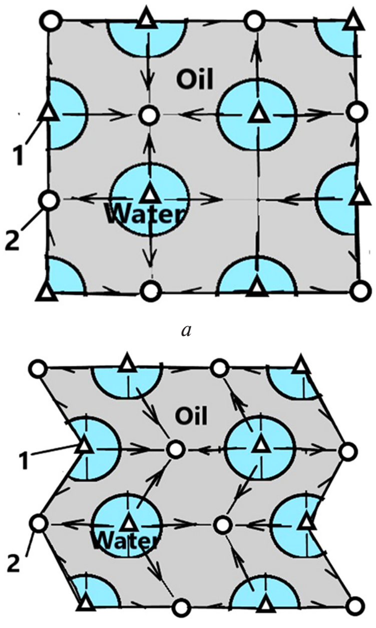


Fig. 5. Recommended schemes of sequential in-line (a) and offset (b) placement of production and injection wells with equal amounts over the entire reservoir area:

1 and 2 wells are injection and production wells, respectively

elastic deformation of rock, water, and oil. As a result, the skeleton of the rock forming the pores expands, and the water injected into the reservoir and the displaced oil are compressed, accumulating and increasing reservoir energy. In conditions of comprehensive compression, under the influence of high pressure in the reservoir, water moves along the entire front with a large coverage of oil in the direction of producing wells.

To determine the flow rate of wells with steady radial filtration of oil under high reservoir pressure, the Darcy formula can be used.

$$v = \frac{k}{dL \cdot \mu} dp; \quad \frac{Q}{F} = \frac{k}{dL \cdot \mu} dp. \qquad (4)$$

After integrating the variable values of the power circuit dL from zero to

$$Q \int_0^L dL = \frac{\pi Dhk}{\mu} \int_{p_0}^{p} dp; \quad Q = \frac{\pi Dhk}{L\mu}(p - p_0), \qquad (5)$$

where v is the oil filtration rate; k is the permeability coefficient; dp is the change in reservoir pressure; L is the supply circuit; μ is the viscosity of oil; Q is the flow rate of the well; F is the area of the perforated face of the well; D is the diameter of the well; h is the thickness of the formation.

It can be seen from this formula that during the operation of wells, the oil flow rate largely depends on the reservoir pressure and permeability of the bottom-hole formation zone. According to the proposed method of location of wells and pumping units, the reservoir pressure and flow rate of oil wells will be much higher than with the traditional method.

It is known that under conditions of comprehensive compression, the tensile strength of rocks increases significantly [18]. In conditions of uneven all-round compression (preliminary all-round load of 95 MPa), the strength limits of sandstones and dolomites, respectively, increase to 224 and 345 MPa. With existing oil depths of up to 5,000 m, the rock pressure is within the elastic range of 150–160 MPa. Then, in the formation conditions of comprehensive compression, it is possible to create a high pressure in the formation exceeding the pressure of oil saturation with gas by applying the recommended method for maintaining high reservoir pressure.

Thus, the acceptance of the number of injection wells equal to the number of producing wells with their sequential arrangement in rows and the creation of high reservoir pressure by injection well pumps to overcome the resistance of oil filtration through the pores of the rock and the rise of oil through the producing wells do not lead to a phase change in oil in the reservoir and a decrease in pressure below the pressure of oil saturation with gas. This makes it possible to significantly increase oil recovery and prevent flooding of producing wells.

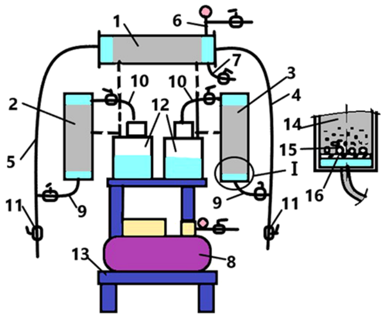
Results. The purpose of the experiment was to compare the developed and traditional methods for maintaining reservoir pressure. The processes of water filtration in two reservoir conditions were studied in a laboratory installation (Fig. 6): without elastic and with elastic medium in the pores of the rock.

The laboratory installation (Fig. 6, *b*) is a reservoir model and consists of one horizontal 1 and two vertical cylindrical working chambers *2* and *3*, which are filled with rock samples – quartz sand with particle sizes of 0.6–0.8 mm.

The working chambers are connected in series with each other by flexible pipelines *4* and *5*. The horizontal working chamber has a branch pipe *6* with a pressure gauge and a tap for water supply and a branch pipe *7* with a pressure gauge and a tap for gas (air) supply from the compressor *8* with a pressure gauge and a tap. Vertical working chambers are equipped with an inlet pipe *9* from below, and an outlet pipe *10* from above with pressure gauges and taps, as well as taps *11* for draining water. There are receiving tanks *12* under the outlet pipes *10*. The working chambers, compressor and receiving tanks are mounted on the frame *13*.

The main dimensions of the working chambers are: the inner diameter of the pipe is 80 mm and the length is 550 mm. Rock – sand *14* (Fig. 4, node I), located inside in the working chambers, is pressed between thin layers of *15* solid granular materials with variable particle sizes of 1.0–2.0 mm and a round plate mesh *16* with a hole diameter of 1.5 mm. This design of the working chamber allows the rock – sand sample to steadily filter the agent water.

a



b

Fig. 6. General view (a) and schematic diagram (b) a laboratory experimental installation

In the pores of a rock of a horizontal chamber without an elastic medium, the medium is created by pumping water into it, and an elastic medium is created by pumping gas (air) into it. At the beginning, the regularities of the process of oil displacement from the reservoir by water are considered, provided that an elastic medium is not created in the pores of the rock. Water at a pressure of 0.65 MPa is supplied through the inlet pipe *6* to the horizontal working chamber *1* (Fig. 6, *b*). Here the water is divided into two streams: left and right.

The left stream of water passes through the pores of the rock sample of the horizontal *1,* and the left vertical *2* working chambers, and then enters through the inlet pipe *10* into the left receiving tank *12.* And the right water flow passes through the pipeline *4* and the pores of the rock sample of the right vertical working chamber *3* and enters through the inlet pipe *10* into the right receiving tank *12.* At the same time, the volume of water in the tanks is measured after a certain time.

It should be noted here that the source water moves from the intake pipe *6* in two directions having different filtration resistances. Moreover, the right stream experiences less filtration resistance than the left stream, passing only through the rock of the vertical working chamber *3.* Therefore, the right water flow in the experimental installation simulates the process of water movement in the reservoir towards the producing wells along the path of least resistance, i. e. along the shortest path between the injection and production wells.

And the left stream experiences greater filtration resistance than the right stream, passing through the rocks of two working chambers – horizontal *1* and vertical *2.* The left water flow in the installation simulates the process of oil displacement by water in the formation towards producing wells along the edges of the oil displacement front by water from the formation. Therefore, the volume of water per unit of time in the left receiving tank will be less than in the right receiving tank due to the large difference in the created resistance to movement (filtration) of the left and right water flows through the pores of the rock. This is evidenced by the results of the experiments, which are presented in Table 1 and the graph (Fig. 7).

It can be seen from Table 1 and the graph (Fig. 7) that with an increase in the resistance to water filtration in the rock, its displaced volume V_1 significantly decreases, and with a decrease in the resistance to water filtration, its displaced volume V_2 increases.

This suggests that in an oil reservoir, a significant part of the water will move along the path of least resistance and a smaller part along the flanks. There will be premature flooding of producing wells. Premature watering will also be significantly facilitated by the suction pumps of producing wells.

Then, the regularities of the process of oil displacement from the reservoir by water are considered, provided that an elastic medium is created in the pores of the rock. To do this, we fill two vertical working chambers *2* (Fig. 6, *b*) and *3* with water and close the tap of the inlet pipe *6* of the horizontal working chamber and the taps of the inlet pipes *9* of the vertical working chambers. Then the water is drained from the horizontal working chamber through the taps of the nozzles *11* and *7.* The taps of the nozzles *10* are opened. The flexible pipeline of the compressor *8* is connected to the nozzle *7* of the horizontal working chamber.

The compressor electric motor is switched on. Gas (air) from the compressor cylinder at a pressure of 0.60 MPa moves through the nozzle *7* into the pores of the rock of the horizontal working chamber *1*, then through pipelines *4* and *5* begins to displace water from the pores of the rock of two vertical working chambers *2* and *3.* Water, moving through two nozzles *10*, enters the receiving tanks *12.* At the same time, the time of water outflow and the volume of its receiving tanks are measured. Next, a higher pressure is created in the compressor cylinder and the experiment is repeated. The results of the experiments are shown in Table 2 and Fig. 8. It should be noted here that filling the pores of a horizontal working chamber with a gas (air) easily compressed under pressure simulates the process of creating high pressure in an oil reservoir in the area of elastic deformation of rock and fluids, which ensures a more complete displacement of oil from the reservoir with water.

It should be noted here that filling the pores of a rock with a horizontal working chamber with a gas (air) that is easily com-

Table 1

The results of measurements of the time of water outflow and the volumes of its receiving tanks and calculations of water consumption during experiments without creating an elastic medium in the pores of the rock

No.	Time *t*, s	Pressure *p*, MPa	Water volume, 10^{-3} m^3		Water consumption, 10^{-6} m^3/s	
			V_1	V_2	Q_1	Q_2
1	60	0.65	3.0	5.1	50.0	85.0
2	90	0.65	4.5	7.7	50.0	85.5
3	120	0.65	5.9	10.2	49.2	85.0

Table 2

The results of measurements of the time of water outflow and the volumes of its receiving tanks and calculations of water consumption during experiments with the creation of an elastic medium in the pores of a rock

No.	Time *t*, s	Pressure *p*, MPa	Water volume, 10^{-3} m^3		Water consumption, *Q*, 10^{-6} m^3/s	
			V_1	V_2	Q_1	Q_2
1	12	0.60	0.60	0.60	50	50
2	10	0.80	0.60	0.60	60	60
3	8	1.00	0.60	0.60	75	75

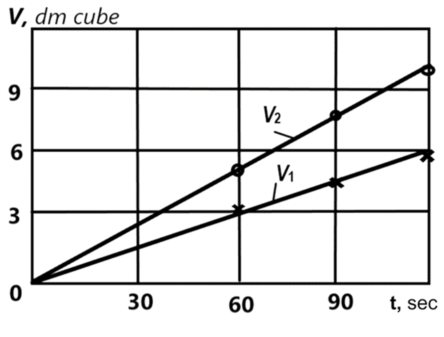


Fig. 7. The dependence of the volumes of the left V_1 and right V_2 of the water flows passing through the rocks of the working chambers on time t

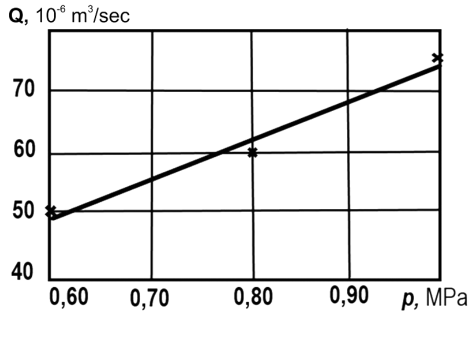


Fig. 8. Dependence of water consumption ($Q_1 = Q_2 = Q$ for each working chamber on pressure p, created by the compressor)

pressed under pressure simulates the process of creating high pressure in an oil reservoir in the area of elastic deformation of rock and fluids, which ensures a more complete displacement of oil from the reservoir with water. It can be seen from Table 2 and the graph (Fig. 8) that in the process of creating an elastic medium in a horizontal working chamber by pumping gas under pressure, the volumes of water passing through the left and right vertical working chambers are the same. This indicates the advantage of creating an elastic high pressure in the oil reservoir, which allows the oil to be evenly displaced from the reservoir by water.

Thus, theoretical prerequisites and laboratory experiments showed the possibility of significantly increasing oil recovery and reducing well waterlogging by creating elastic high reservoir pressure in the area of elastic deformation of rock and fluids, exceeding the pressure of oil filtration through the pores of the rock and lifting oil to the surface through producing wells, but not less than the pressure saturation of oil with hydrocarbon gases. At the same time, the producing wells are not supplied with pumps and, as the water is flooded, the producing wells are transferred to injection wells.

In order to prevent the inflow of water from the aquifers, it is advisable to create water isolation zones below and above the productive formation by perforating the expansion column and cement stone and pumping gel-forming nanofluid and micro-cement solution into the formed channels. Periodic cleaning of the bottomhole zone of the formation from asphalt-tar and paraffin deposits using low-boiling oil components with a content of carbon atoms C_6-C_{10} in molecules allows maintaining a high value of production well flow rates.

Conclusions. The following conclusions are drawn.

1. The available methods for maintaining reservoir pressure by pumping aqueous solutions of polymer, surfactants and other reagents into the formation do not fully allow achieving high oil recovery and reducing the water content of producing wells. This is evidenced by the currently existing problems of low flow rate (below 5 tons/day) of producing wells and high water content (up to 80–90 % and above) of produced oil.

2. The main reason for the low efficiency of secondary and tertiary oil recovery methods can be explained by the fact that the slowing down of the displacement agent – an aqueous solution of polymers occurs not only along the shortest path, but also even more slowly along the lateral sections of the displaced oil. In any case, viscous water or ordinary water pumped thickened with polymers will primarily displace oil in the direction of least resistance to its movement and there is a breakthrough of the injected water through the flow of oil into the producing wells.

3. The existing oil production technology, which includes pumps from both injection and production wells, creates a low reservoir pressure. Downhole pumps of producing wells create a vacuum in bottom-hole zones and significantly reduce the reservoir pressure developed by the injection well pump. Under these conditions, water displaces oil from the reservoir over a small area with a small coverage and, moving along the path of least resistance to filtration, breaks into the producing well. At the same time, a significant amount of unrecovered oil remains in the reservoir on both sides of the water flow.

4. An important factor reducing oil recovery from the point of view of the material balance of extracted oil from the reservoir and water injected into the reservoir is the lack of correlation between the quantities and throughput capacities of injection and production wells. For example, in four, five, seven and nine point reversed and non-reversed well grids, the ratio of quantities and throughput capacities of producing and injection wells varies widely and ranges from 3 to 8.

5. A new method is proposed, which consists in the process of pumping water agent into the oil reservoir by injection well pumps to create an elastic high reservoir pressure in the area of elastic deformation of rock and fluids, exceeding the pressure of oil filtration through the pores of the rock and lifting oil to the surface through producing wells. At the same time, there are no pumps from the producing wells, and reservoir energy for displacing oil with water is carried out only by pumping units from the injection wells. The reservoir pressure between wells increases significantly throughout the entire volume of the productive formation realizing the high elastic energy of the rock and its value will always be higher than the pressure of saturation of oil with gas.

6. The acceptance of equal amounts of producing and injection wells and their sequential arrangement in rows also allow for the creation of high potential energy in the reservoir within its elastic deformation of rock, water and oil. As a result, the skeleton of the rock forming the pores expands, and the water injected into the reservoir and the displaced oil are compressed, accumulating and increasing reservoir energy. In conditions of comprehensive compression, under the influence of high pressure in the reservoir, water moves along the entire front with a large coverage of oil in the direction of producing wells.

7. The regularities of the process of uniform filtration of water in the pores of a rock under the action of an elastic medium have been experimentally established. By filling the pores of a rock with an easily compressible gas (air) under pressure, the process of creating elastic energy in the formation is simulated, which ensures uniform water movement along the entire front of the formation model.

8. The conducted studies of the fluid filtration process in an elastic medium showed the possibility of a significant increase in oil recovery and reduction of well waterlogging by creating an elastic high reservoir pressure in the area of elastic deformation of rock and fluids from injection wells exceeding the pressure of oil filtration through the pores of the rock and oil rise to the surface. In order to increase the flow rate of producing wells, it is advisable to build water isolation zones below and above the productive formation and periodic treatment of the bottom-hole zone of the formation of low-boiling oil components with carbon atoms C_6-C_{10} in molecules.

The developed new technique for maintaining high elastic reservoir pressure not lower than the pressure of oil saturation with gas by pumping water into the reservoir can be carried out in oil fields using standard technological equipment and increase oil recovery to 60–70 % at its existing values of 40–45 % and reduce the water content of produced oil to 0–10 % at its existing values of 20–80 % and above.

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Підвищення нафтовіддачі покладів підтриманням раціонального пластового тиску

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Мета. Збільшення вилучення нафти з покладів і зниження обводненості видобувних свердловин шляхом забезпечення умов рівномірного витіснення нафти із пласта під впливом високого пластового тиску.

Методика. Мета роботи досягається проведенням теоретичного та експериментального дослідження процесу створення високої пружної енергії у пласті закачуванням води насосами нагнітальних свердловин на подолання опору фільтрації нафти й води через пори гірської породи та підйому нафти на гирлі свердловин. Відсутність насосів з боку видобувних свердловин і прийняття рівної кількості нагнітальних і видобувних свердловин по площі пласта істотно підвищує тиск вище тиску насичення нафти газом. Завдяки значній пружності гірської породи та флюїдів під високим пластовим тиском збільшується охоплення нафти водою й не відбувається передчасний прорив води у видобувні свердловини. Експериментально вивчено можливість створення в нафтовому пласті високої пружної енергії закачуванням води насосами нагнітальних свердловин.

Результати. Встановлено, що високу пластову енергію в області пружної деформації гірської породи та флюїдів можна створити переважно насосами з боку нагнітальних свердловин, завдяки чому відбувається рівномірне витіснення нафти із пласта по всьому фронту без прориву води, що закачується, у видобувні свердловини на шляху найменшого опору. Прийняття рівної кількості видобувних і нагнітальних свердловин і послідовне розташування їх у рядах сприяє розвитку високої потенційної енергії у пласті та дозволяє підвищити прийомистість нагнітальних і дебіти видобувних свердловин. У результаті цього скелет гірської породи, що утворює пори, розширюється, а закачена у пласт вода і нафта, що витісняється, накопичують і збільшують пластову енергію.

Наукова новизна. Ефективність запропонованого методу підтримки високого пластового тиску досягається в результаті створення високої енергії гірської породи та флюїдів в області їх пружної деформації та збільшення коефіцієнтів охоплення нафти, що витісняється водою, за площею й за профілем продуктивного пласта без застосування додаткових потужностей і насосних установок з боку видобувних свердловин.

Практична значимість. Розроблену нову методику підтримки високого пружного пластового тиску не нижче тиску насичення нафти газом закачуванням води у пласт можна здійснити на нафтових родовищах застосуванням стандартного технологічного обладнання й підвищити нафтовіддачу пластів до 60–70 % за існуючих значень 40–45 % і знизити обводненість до 0–10 % за існуючих значень 20–80 % і вище.

Ключові слова: *поклад нафти, пласт, свердловина, тиск, нафтовіддача, обладнання*

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