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Horizontal wells as a means of intensification of oil production

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ABSTRACT
Numerous experimental and field studies have established that during the development of oil and gas fields, there are deformations of rocks that occur due to changes in reservoir pressure. It is established that with a drop in reservoir pressure, the volume of the pore space of the formation decreases due to the elastic expansion of the rock grains and an increase in compressive forces transmitted to the skeleton from the masses of the overlying rocks. As a result, there is a change in the deformation processes in the porous medium, accompanied by a decrease in its porosity and permeability, and a more significant change, compared with the porosity of the formation, is the permeability under one and the same pressure change. The manifestation of these anomalies in reservoir conditions, which cause nonlinear effects, can significantly affect the entire process of reservoir development and lead to various qualitative and quantitative discrepancies between the observed facts and the indicators that were calculated.
Keywords: horizontal wells, productive formation, drilling, horizontal trunk.

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Introduction

The search for ways to solve the problem of meeting the public's need to increase the productivity of each of the drilled wells has always been in many directions, starting from the correct choice of the well laying point, preserving and improving the permeability of rocks in the bottom-hole zone of the wellbore, developing methods of influencing the productive reservoir itself, creating effective oil-displacing agents and methods for regulating their movement through productive reservoirs, etc.

Each direction, as well as their rational combination, gave a technical effect in the form of an increase in well productivity, but in many cases this increase was insufficient to ensure an economically acceptable profitability of the methods used.

As is known, the main directions of intensification of the development of oil and gas fields are to increase the pressure gradient in the reservoir using the most intensive methods of maintaining reservoir pressure, as well as to reduce filtration resistances in the bottom-hole zones of production and injection wells.

Along with such methods as "hydraulic fracturing" and various physico-chemical methods of processing bottom-hole zones of wells, the "method of reducing filtration resistances" in bottom-hole zones of wells by drilling with an increased surface of opening the productive reservoir has great opportunities. Such wells include inclined-directional (NNS), horizontal (GS) and branched-horizontal wells (CSG).

For a long time, the idea of increasing the productivity of wells by significantly increasing the contact area of the borehole with the rocks of the productive formation did not receive its development. The first attempts to implement it were made in the former USSR back in 1937 at the Yarega field [1]. However, the pre-war situation and the lack of appropriate technical means and technologies, which caused the high cost of drilling horizontal wells, led to the suspension of work in this direction. The discovery of highly productive fields in Western Siberia has again reduced interest in the development of deposits by horizontal wells, which was resumed in the 50s of the last century.

However, the global trend observed in recent decades of a significant increase in the share of proven oil reserves in low-yield reservoirs, the development of which by vertical wells is obviously unprofitable, has again brought to the fore the need for practical implementation of ensuring a large area of contact between the wellbore and the productive reservoir.

Currently, the development of oil and gas fields using inclined and horizontal wells is relevant and is considered one of the most important recent achievements in the oil and gas industry. Horizontal drilling, in the world practice of oil and gas production, has become a standard technology and is considered an important method of increasing oil and gas production. In this regard, there is an increased interest in the study of issues related to the use of horizontal and branched-horizontal wells in the development of natural hydrocarbon deposits all over the world.

Horizontal wells are used in depleted productive formations, as well as in fields with difficult-to-recover oil reserves, when widespread methods of developing oil and gas fields do not allow achieving a high level of oil production. The development of oil fields by horizontal wells is a new version of the technology for increasing productivity, as well as a new method of development, gradually replacing the methods of operation by vertical wells. However, at present, methods for predicting production, designing and optimizing systems for developing deposits opened by horizontal and branched-horizontal wells are not sufficiently developed.

Currently, horizontal well drilling is successfully used in most oil-producing countries of the world. It has received special development in the USA, Canada, France, Denmark, Norway and other countries.

A horizontal shaft running along the productive horizon for tens and hundreds of meters connects with each other the areas of heterogeneous, low-permeable, poorly drained, cavernous and fractured sections of the formation that were not previously involved in development. This technique not only increases the filtration rate in the inter-well space, but also increases the degree of reservoir coverage, increasing the final oil recovery. Most often, horizontal trunks are used when cutting the side trunk. The cutting of the side trunk is this new life of a low-yield well.

Currently, production workers and scientists have accumulated a huge statistical material based on the experience of working horizontal wells at various fields. The length of the horizontal section of wells varies from 100-200 m to 1.4 km and depends on the skill of the drilling company and the equipment used. The practice of directional drilling of horizontal wells is currently owned by several drilling foreign companies (Gorvel, Exxon, Amoko, Philips, etc.) and enterprises in the former USSR.

Therefore, the process of creating and rapidly improving the technique and technology of drilling horizontal wells, which led to a sharp decrease in their cost, cannot be considered spontaneous, but should be considered as a natural consequence of the need that has arisen. Demand, as always, caused supply and, in turn, stimulated the development of research on the quantitative refinement of known and identification of new opportunities for using wells with horizontal sections of the trunk of various lengths and shapes.

A huge number of publications devoted to the study of various operational parameters of horizontal wells have appeared. To date, a significantly higher productivity of horizontal wells compared to vertical wells, with other equal conditions, is a fact proven theoretically and confirmed by practice.

Based on the conducted research and accumulated practical experience, it is now generally accepted that the greatest effect from using the capabilities of horizontal wells can be useful at operational facilities with the following characteristics [2]:

- sub-gas objects and objects with plantar water; - collectors with vertical fracturing;
- deposits of high-viscosity oils and bitumen;
- offshore and hard-to-reach productive zones;
- during the operation of gas deposits;
- when using methods to increase oil recovery, especially thermal methods;
- at the viscosity of oil (μ>10 MPa.c);
- low-efficiency mode of reservoir development; - the effective thickness of the formation is at least 3m;
- low permeability of collectors (k < 0.1 mm2);
- large residual recoverable reserves.

Experimental part and discussion of results

In accordance with the chronology of the study of this issue, we will first review the works published in the former USSR on the topic related to horizontal wells.

A wide range of studies is devoted to the study of various operational parameters of HS. A number of theoretical and experimental works are devoted to the issues of steady and unsteady fluid inflow to horizontal wells. Let's focus on some of the results of the main studies.

One of the first works on determining the productivity of horizontal oil wells is the work of I. A. Charny on the inflow of incompressible fluid to a horizontal trunk, asymmetrically located relative to the supply circuits with distances Rk1, Rk2 and contour pressures Pk1, Pk2, respectively. Under the conditions that the distance from the well to the reservoir boundary H is greater than or equal to the thickness h, i.e. H ≥ h. For the case when the horizontal trunk is located symmetrically to the power supply circuit, I. A. Charny obtained the following expression for determining the flow rate of the HS:

$$Q = \frac{2\pi k(P_k - P_c)}{\mu\left[\frac{2\pi H}{h} + ln\frac{h}{2\pi R_c}\right]}, \qquad (1)$$

Where k is the reservoir permeability, Pk, Pc is the pressure on the supply circuit and at the bottom of the well; μ is the oil viscosity; H is the distance from the well to the reservoir boundary; h is the thickness of the reservoir; Rc is the radius of the well.

Later, A.M. Pirverdyan studied a similar problem for the case when one of the boundaries is closec (impenetrable), for example, at Rk = Rk1, and the pressure Pk2 is set at the second boundary Rk = Rk2. Taking into account this condition, the oil inflow to the horizontal trunk is presented in the form:

$$Q = \frac{2\pi k(P_k - P_c)}{\mu\left[\frac{2\pi k}{h} + ln\frac{h}{2\pi R_c} + \frac{1}{2}ln\frac{2}{1-cos\frac{\pi(2a-R_c)}{h}}\right]}, \qquad (2)$$

Where a is the distance from the axis of the horizontal trunk to the roof or the sole of the formation. With a symmetrical arrangement of the horizontal trunk in thickness a=h/2.

The theoretical studies of I. A. Charny anc A.M. Pirverdyan are devoted to the issues of fluic inflow to horizontal wells of infinite length in layers of finite thickness. If we use these formulas to determine the flow rate of horizontal wells of finite length, the result will be underestimated, and the error at different well lengths and reservoir thicknesses cannot be strictly determined. In addition, the obtained formulas are suitable only for a band-shaped deposit.

The possibility of obtaining a solution to the oil inflow by dividing the flow into two zones in the horizontal and vertical planes is also used in the work of S. D. Joshi. With a symmetrical arrangement of the horizontal barrel in thickness, the formula for determining the flow rate is proposed as:

$$Q = \frac{2\pi kh\Delta P}{\mu B\left[ln\left(A + \frac{\sqrt{A^2 - (L_r/2)^2)}}{L_r/2}\right) + \frac{h}{L_r}ln\frac{h}{2R_c}\right]}, \qquad (3)$$

Where B is the volume coefficient of oil; Lr is the length of the horizontal section of the trunk; Lr h and Lr /20.9 R. A is the half of the major axis of the ellipse taken as the shape of the drainage zone by a horizontal well determined by the formula:

$$A = \frac{L_r}{2}\left[\frac{1}{2} + \sqrt{\frac{1}{4} + \left(\frac{2R_k}{L_r}\right)^4}\right]^{0,5}, \qquad (4)$$

For Lrh, the formula of G. I. Renald and J. M. Dupug, which has the form, is more accurate for determining the oil flow rate:

$$Q = \frac{2\pi kh\Delta P}{\mu B\left[\cos h^{-1}(X) + \frac{h}{L_r}ln\frac{h}{2\pi R_c}\right]}, \qquad (5)$$

where X=24A/Lr

In the works of 3.S. Aliev et al., formulas for determining the flow rate of an oil horizontal well that has completely opened up strip-shaped homogeneous isotropic and anisotropic formations are proposed. According to this method, it is assumed that the filtration region consists of two zones, in the first of which the layer thickness is considered a function of the radius, i.e. h=h(r) and varies according to the parabola. Under the accepted conditions, the oil flow rate of a horizontal well that has opened an isotropic reservoir is proposed to be determined by the formula [4-6]:

$$Q = \frac{kL_r\Delta P}{\mu B}\frac{1}{\left[1 + \frac{2R_c}{h-2R_c}ln\frac{2R_c}{h}\right] + \frac{R_k - (h-2R_c)}{2h}}, \qquad (6)$$

If the horizontal borehole is located asymmetrically in thickness, the well flow rate will be determined by the sum of the flow rates from the upper and lower zones, according to the formula:

$$Q = \frac{kL_r\Delta P}{\mu B}\frac{1}{\frac{2}{h_1}\left[h_1+R_c\ln\frac{R_c}{h_1+R_c}\right]+\frac{R_k\cdot h_1}{(h_1+R_c)}+\frac{2}{h_2}\left[h_2+R_c\ln\frac{R_c}{h_2+R_c}\right]+\frac{R_k\cdot h_2}{(h_2+R_c)}} \quad , (7)$$

where h1 = (h-h2) is Rc-the thickness of the formation of the i – th zone minus the radius of the well. Accordingly, for an anisotropic reservoir, taking into account the anisotropy parameter, the oil flow rate is determined by the formula:

$$Q = \frac{2kL_r\Delta P}{\mu B}\frac{1}{\left[\frac{1}{\vartheta h_i}\left(\vartheta h_i+R_c ln\frac{R_c}{R_c+\vartheta h_i}\right)\right]+\frac{R_k-\vartheta h_i}{R_c+\vartheta h_i}} \quad , \quad (8)$$

where ʋ is the anisatropy parameter determined from the equality: ϑ=√(k_ver/k_pore).

The problem of fluid flow to a well of finite length in an unlimited space and to a well arbitrarily located in a half-space, as well as to a system of similar wells, was solved by P. Ya. Polubarinova-Kochina. The results of these studies are valid only for the case when the reservoir capacity is many times greater than the length of the borehole, otherwise the obtained formulas cannot be used.

The problem of the steady flow of liquid to horizontal and inclined wells was also solved experimentally. The greatest interest in this direction is the work of V. I. Shurov, which was carried out on an electrolytic model [3]. The processing of the experimental results is based on the Dupuy formula, in the denominator of which the term is introduced in the form of an additional parameter “C”, which characterizes the value of the hydrodynamic perfection of the well. The value of the parameter " C " is determined by comparing the flow rates of horizontal and inclined wells with the flow rates of vertical wells for different values of lengths, diameters of wells, reservoir capacities and angles of inclination of trunks in the formation. The value of the parameter " C " has a negative value. This indicates that the flow rate of inclined and horizontal wells, all other things being equal, is higher than the flow rate of vertical wells. The results are summarized in tables, on the basis of which graphs are constructed. However, a strict analytical dependence was not obtained. Each specific case requires its own table or series of graphs, on the basis of which calculations can be made. This is the main drawback of V. I. Shurov's work.

The formulas obtained by V. P. Merkulov are semi-empirical. They do not require the use of any graphs or tables to calculate the debits [4]. However, there are certain limits of applicability found on the basis of experimental data. It is impossible to judge the errors of calculations carried out according to the proposed formulas within unspecified limits.

In the works of American researchers, results similar to the results of the works of V. I. Shurov and V. P. Merkulov were obtained, although they were carried out much later. In the work of Yu. P. Borisov et al. [5, 6] for homogeneous and layered formations, when the permeability in the vertical direction is zero, and in the horizontal direction K=const, under a rigid water pressure regime, analytical dependences are obtained for determining the flow of liquid to single horizontal wells of finite length, to inclined and multi-hole wells and to their systems in circular and strip deposits.

When solving these problems, the method of filtration resistances is used. A comparison of the calculation results with the results of electrolytic modeling showed a satisfactory coincidence. In addition, [7] a general hydrodynamic theory of the inflow of a homogeneous liquid in a horizontal infinite reservoir of constant thickness is proposed. In the solution, the method of constructing the Newtonian potential of a point source acting in a reservoir of limited thickness was used. However, the solutions obtained in a strict analytical formulation are very complex and difficult to use even taking into account the capabilities of computer technology. The lack of numerical results for exact formulas did not allow us to assess the reliability of the proposed approximate solutions.

In the work of G. A. Razumov, a study of horizontal wells of finite length and their radial systems in the conditions of an aquifer pressure reservoir of limited capacity with a rectilinear supply circuit is presented [8]. When the approximate calculation formulas are derived, the theoretical linear flow with a constant intensity along the length q is replaced by a “filter” having the shape of the equipotential closest to the well in the form of an ellipsoid of rotation. This method is used for horizontal wells by P. Ya. Polubarinova-Kochina, and before it was used by N. K. Girinsky – for vertical well [9]. The transition from an imaginary equapotential filter to a real tubular well with a radius r=rc can be performed by equating the areas of the water intake surface of an ellipsoid with a small semi-axis "b" and a cylinder of equal length b=1.415 rc.

The issues of fluid inflow to a horizontal perfect well, taking into account the influence of the supply circuit, the permeability of the reservoir sole, the location of the filter relative to its roof and the non-stationary filtration, are studied in the works of M. A. Huseynzade. In the work it is indicated that, in relation to horizontal wells, the anisotropy of the formation should be taken into account [10]. The fact is that, as a rule, the vertical permeability is less than the horizontal one. And if for vertical perfect wells the anisotropy of the reservoir has absolutely no effect on the inflow, then for horizontal wells the influence of anisotropy becomes very significant. It is qualitatively clear that the anisotropy of the formation reduces the efficiency of its longitudinal opening. On the basis of what has been said in this work, studies of the flow of liquid to longitudinal (inclined, horizontal) wells along the reservoir under various filtration modes have been carried out.

The lack of accurate analytical solutions significantly complicates the task of establishing the applicability of existing approximate solutions in various conditions.

With this in mind, the paper [11] offers an exact analytical solution to the equation of three-dimensional fluid filtration for determining the productivity of horizontal wells. It is assumed that a limited band-shaped reservoir with an arbitrary thickness, homogeneous in permeability, is opened by a horizontal well with a filter length n and is operated with a constant flow rate q evenly distributed along this length. The roof and the sole of the formation are considered impenetrable. The reservoir under study has a power supply circuit, on which a constant pressure is maintained. In addition, it is assumed that the well can be replaced by a linear source located along its axis. A finite integral Fourier transform is applied to solve the problem. According to the obtained formulas, multivariate calculations were performed for the symmetrical and asymmetric placement of a horizontal well. At the same time, the influence on the filtration resistance of the place, degree and symmetry of the opening by a horizontal well of a homogeneous reservoir, according to reservoir properties, was studied. Further, the same problem is generalized to take into account the anisotropy of the reservoir in terms of permeability [12].

The issues of operation of horizontal wells with gas inflow are investigated in [13]. In this work, it is indicated that with the same depression on the reservoir, the flow rates of horizontal wells are several times higher than the productivity of vertical ones due to the increased interval of gas inflow. Therefore, for the most accurate justification of the technological mode of operation of horizontal wells, it is necessary to take into account the quadratic law of gas filtration, otherwise significant errors may occur in determining their performance indicators.

Next, an approximate method for schematizing the process of gas inflow to wells is considered. At the same time, in the bottom-hole zone of a horizontal well, a hyperbolic or parabolic dependence between the thickness of the formation and the distance from the well is taken and the equation of one-dimensional nonlinear gas filtration in a reservoir with a variable thickness is used, and plane-parallel filtration is considered outside this zone. This method of schematization of the gas inflow to the horizontal shaft under the conditions of the quadratic filtration law allows us to obtain simple analytical solutions to problems related to the determination of well performance indicators. Comparison of the results of calculations using the proposed method with the results of numerical modeling of three-dimensional non-stationary gas filtration showed their fairly good convergence. It was shown, in particular, that the determination of the well flow rate using the proposed approach can be carried out with an error not exceeding 4%.

Recently, a significant number of works related to the exploitation of fields, mainly oil, by horizontal wells have been published abroad.

In these publications, most of the authors used the results and conclusions obtained by Soviet scientists Yu. P. Borisov, V. P. Pilatovsky, etc. Among such works are the studies of D. K. Bodu, S. D. Dojoshi, J. Comba, A. S. Ode, D. Sparmin, R. Hagen, F. E. Kuchuk, A. E. Roza, R. Ragavan, D. E. Wilkinson, E. Ozkan, etc., [14, 15, 16] who proposed various methods of analytical and numerical solutions to problems of two - and three-dimensional unsteady filtration of compressible fluid to determine the productivity and interpretation of the results of the study of horizontal wells.

The paper [14] presents an analytical solution to the problems of pressure drop and recovery in a horizontal well. The three-dimensional equation of motion is solved by the method of integral transformations. For small, intermediate and large time values, where there are rectilinear sections on the pressure change curves, simplified formulas for pressure are given. The validity of the method is demonstrated by comparing the results of numerical modeling with a similar analytical solution. The method recommended for the analysis of pressure drop and recovery is illustrated by practical examples. The method allows you to determine the characteristics of the reservoir, including permeability, skin factor and distance to the boundaries.

The study of special flow regimes in the process of an unsteady inflow to a horizontal well has been the object of a significant number of works in the modern literature. For example, this was done in for the Bombay field [17], where simultaneously measuring the pressure drop and flow rate made it possible to identify the modes of pseudo-radial flow at an early and late time, as well as linear flow during the transition period [18].

The analysis of these successive flow modes allows us to estimate the permeability of the anisotropic reservoir and the skin factor. The refined parameters obtained for the field example are compared with the results of extensive conventional studies for the same horizontal well [19].

The detected good agreement for horizontal permeability increases the confidence level for parameters such as vertical permeability and the actual skin factor.

In a mathematical model is given for calculating the pressure in an infinitely conducting horizontal well. At the same time, the following assumptions are made: the reservoir is horizontal, homogeneous and has a constant horizontal and vertical permeability, the product enters through a well represented by an I-linear source, the filtration mode is unsteady, the reservoir is limited by upper and lower impermeable boundaries, the pressure at an infinitely remote distance from the well remains constant and equal to the initial value. The analytical solution is found using the "instantaneous source theory" and the green function.

The work is devoted to the analysis of pressure recovery for horizontal wells in a real fractured formation [20]. A combination of analytical and numerical methods was used to conduct a consistent interpretation of the results of the well analysis, taking into account the possible double porosity of the reservoir [21].

In a method is given for interpreting the results of a study of horizontal wells in an unsteady mode (using the example of the Prudhoe Bay field in the USA). The complex geometry of the flow in a horizontal well makes it difficult to analyze pressure recovery curves (KVD). The peculiarity lies in the fact that it is impossible to determine the parameters based on pressure and flow rate data for a short study time. It is necessary to get an inflow to the face and achieve an inflow under pressure, and then remove the KVD, which will allow you to determine the parameters accurately.

The work presents the results and a representative data set of a non-stationary study of a horizontal well on the area of the Austin Chalk field (USA). The data set shows the possibility of radial flow in an early period of time, strongly distorted by the storage effect (accumulation of fluid in the wellbore). This is followed by a well-developed period of linear inflow. The data are interpreted in terms of a pseudo-stationary model with double porosity and the range of changes in the permeability of cracks, the volume of pores and the value of the flow coefficient are determined [22, 23].

The partial differential equation describing the filtration of a liquid in a porous medium to a horizontal well is very complex. In its solution for the deposit is proposed. The solution is obtained by the method of separating variables. The slow convergence of the obtained solution is overcome by using certain simplifying formulas. A complex solution is reduced to a form that is convenient for calculating productivity. The form of the expression obtained for it is identical to the well-known expression for a vertical well.

Simple formulas are proposed for determining two parameters:

1) a geometric factor associated with anisotropy in permeability, the location of the well and the relative size of the drained volume;
2) the skin factor caused by the incompleteness of the opening and related to the length of the well.

A fairly general solution is obtained, which is still not accurate, for the most common cases the error does not exceed 3%.

Provides an analysis of pressure changes in a horizontal well or a branch of a vertical well in comparison with a vertical crack that completely opens the deposit. Two types of boundary conditions at the well are considered: constant inflow and infinite conductivity. Analytical expressions and dependencies for the pseudo-skinfactor are obtained.

It is indicated in that the analysis of pressure recovery curves in a well with a horizontal trunk in an unsteady mode should be carried out taking into account the measured inflow profiles, which makes it possible to estimate the effective length of the horizontal trunk and specify the parameters characterizing the reservoir properties. A specific field example demonstrates the difficulties that arise when interpreting data on pressure recovery in an unsteady mode in a well with a horizontal trunk under constant boundary conditions.

It should be noted that in addition to the above-mentioned articles by foreign authors, the• are still many works in Western oil journals devot to solving both direct and inverse problems relat to horizontal wells [24].

Later, various researchers (V. G. Griguletsky, • A. Nikitin, A. P. Telkov, V. D. Lysenko, S. D. Joshi, M. Giger, etc.), based on various inflow mode obtained and proposed fairly simple analytic expressions for estimating the flow rates of sing• HS located in the center of homogeneous laye with elliptical, circular and semi-distinct supp circuits.

In the works [25] of M. N. Veliyev, the issues • fluid inflow to the GS battery in the thre dimensional region are considered. For the ca when the number of wells in the battery arbitrary, the problem is solved in an exa formulation and analytical dependencies a obtained in a very convenient form for conducti hydrodynamic calculations. The interference • vertical and horizontal wells was studied. Tl problem is solved: when vertical and horizont wells are operated simultaneously in the reservo The influence of the distance between wells on tl productivity of wells has been studied.

In our review, we touched only on the mc• important, in our opinion, studies.

Summing up the review done, we can note tl following:

- horizontal wells are the most interesting to discussed in the oil industry these days and ha certain advantages over vertical wells, in terms • such parameters as crossing with a large number faults, the efficiency of reservoir coverage a accelerating the increase in oil production;

- the productivity of a horizontal well homogeneous non-fractured formations with single-phase filtration is higher than the productivity of a vertical well that has completely opened this formation, if the length of the horizontal trunk is greater than

$$h = \sqrt{\frac{K_{\text{г}}}{K_{\text{в}}}}, \quad (9)$$

where h is the thickness of the formation, m; and, respectively, the horizontal and vertical permeability of the formation, microns;

- horizontal wells drilled in a homogeneous naturally fractured formation with a fairly high conductivity of the crack system do not provide increased oil recovery and even accelerated reserve extraction;

- horizontal wells are able to provide increased final oil recovery when implementing a linear flooding mode, as well as in the case of a ring-shaped flooding;

-in the conditions of the manifestation of the effect of the formation of water or gas cones, horizontal wells provide much higher accumulated production (at least 3-4 times).

- in multiphase systems, the equations for the productivity coefficients of horizontal and vertical wells can only be used to estimate the ratio of these coefficients;

- in homogeneous reservoirs operating at depletion, horizontal wells in low-permeable reservoirs provide both higher flow rates and a significant increase in oil recovery, and in high-permeable wells, a significant increase in oil extraction with a moderate increase in final oil recovery;

- increased productivity at the same rate of selection allows one to maintain a reduced depression on the reservoir, contributing to a decrease in water or gas production, as well as significantly reduce the loss of gas condensate from gas in the near-water zone at gas condensate fields;

- in reservoirs with natural vertical fracturing, the recoverable volume of oil increases with the increase in the length of the horizontal trunk in the direction perpendicular to the orientation of the crack system, while reducing the duration of operation;

- reducing the length of the horizontal trunk or its location parallel to the crack system leads to a more significant reduction in oil recovery with a decrease in the permeability of the fractured rock skeleton;

- when developing homogeneous reservoirs by flooding with horizontal production and injection wells, oil production is noticeably accelerated. Throughout the entire period of operation, the accumulated oil production is always greater than during the development of vertical wells, but the water content of the products is higher. Therefore, the profitability of using this method of development may depend on additional costs.

Even this far from complete list of the results of hydrodynamic studies of fluid inflow to horizontal wells indicates that the use of horizontal wells is not only a means of increasing well productivity, but can be an important component of new field development systems (especially low-productivity ones), which allows significantly increasing the final oil recovery coefficients and reducing the time of field development.

Therefore, it is no accident that in recent years dozens of patents have been protected in the USA, Russia, Canada and other countries for systems for the development of hydrocarbon-containing deposits using both their own capabilities of horizontal wells and in combination with traditional methods of influencing formations (flooding, thermal methods, wave action, etc. physical and chemical methods). A comparative analysis, on average, of the economic indicators of the construction and operation of horizontal and vertical wells revealed that:

- GP debits increased from 2.5 (Russia) to 3-4 times (USA, Canada);
- the cost of construction is from 1.1-1.3 (USA, Canada) to 2 times (Russia) and higher;
- technological efficiency ranges from 5O% (Russia) to 90% (USA, Canada);
- the profit rate from the introduction of HS was 5O% (Russia), 160% (USA), 186% (Canada).

To date, more than 26,000 GS have been drilled in the world, more than 1300 in Russia, including half of them in Tatarstan and Bashkortostan. In Kazakhstan, drilling and development of GS is a promising direction and there are several fields where GS have been drilled.

More than 30 deposits containing industrial oil reserves have been identified on the Mangyshlak Peninsula [26]. The largest of them-Uzen contains 75% of all oil reserves of the peninsula. The field was discovered in December 1961, and has been in industrial development since 1965. 25 productive horizons (I-XXV) have been identified in the field section. Productive horizons are represented by frequent interbedding of sand-siltstone and clay layers.

The horizons of the I-XII Cretaceous age are gas-bearing, the XIII-XVIII horizons of the Upper and Middle Jurassic age represent the main (>90%) floor of the oil and gas potential of the field. In some areas, the XIX-XXV horizons of the Lower Jurassic age are oil and gas-bearing.

The effective oil-saturated thickness of the horizons (layers) varies within 7-22m. The viscosity of oil is <10 MPa s, the values of permeability vary widely from 0.01-2 mm2. Collectors are of the pore type. Oil reserves are 1.054 billion tons [27]. More than 60% of the initial balance oil reserves are concentrated in low-permeable reservoirs and belong to the category of hard-to-recover (table 1). The accumulated production is more than 300 million tons. Despite the long development time of the field, the degree of use of reserves does not exceed the value of 0.32.

Thus, it is established that the fields of the Atyrau region and the low-permeable oil zones of the Uzen field are promising objects for drilling horizontal wells [28, 29].

It should be noted that in the conditions of modern scientific and technological progress, when the technical possibility of drilling deep and ultra-deep wells has increased, there is a real possibility of involving deposits lying at great depths in the development. This leads to the urgent need for a comprehensive study of the flow processes of reservoir fluids and the construction of

Table 1 - The list of operational objects of deposits recommended for the introduction of horizontal wells

Deposit	**Effective thickness, m**		**Dismemberment Kr**		**Permeability, mkm²**		**Initial balance sheet reserves, thousand tons**
	h	Gran.	Kp	wounds.	K	Gran.	wounds.
XIII	7,8	hmin >3 m	6,3	Kb>3	0,194	More than 60% of the initial balance oil reserves are concentrated in low-permeability (K ≤ 0.1 mkm2) reservoirs	225,5
XIV	18		9,1		0,247		426,5

computational schemes for the development of deep-lying reservoirs (characterized by high reservoir pressures, fracturing and deformability), taking into account changes in physical properties. However, in deep-lying reservoirs, a change in the intra-pore pressure during operation often leads to the fact that the difference between the mountain and non-pore pressures reaches values sufficient to deform the skeleton of many rocks, reduce the number and diameter of open pores, which leads to a significant change in the capacitance and filtration characteristics of reservoir rocks [30].

Naturally, it should be expected that under these conditions, the nature of the flow of fluids to horizontal wells will differ for such in reservoirs lying at shallow depths. In this regard, there is a need to develop modeling of filtration processes in the conditions of development by horizontal wells of deep-lying deposits composed of fractured and deformable rocks.

A list of works devoted to the use of horizontal wells in the development of oil and gas fields can be found in [31].

Conclusions

Thus, it is established that the fields of the Atyrau region and the low-permeable oil zones of the Uzen field are promising objects for drilling horizontal wells.

A mathematical model and its solution for steady-state liquid filtration to CSG in a deformable porous medium are proposed, scientifically substantiated and implemented. The analysis of the derived dependence showed that the flow rate of a well in a deformable formation is less, respectively, than the flow rate of a well draining a non deformable formation (α=0) with the same pressure drops and other equal characteristics of the formation. The rate of growth of the well flow rate slows down for multi-barrel horizontal wells, with an increase in the number of trunks.

Conflict of interests. On behalf of all authors, the correspondent author declares that there is no conflict of interests.

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Көлденең ұңғымалар - мұнай өндіруді қарқындатудың құралы ретінде

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ТҮЙІНДЕМЕ
Көптеген эксперименттік және коммерциялық зерттеулер мұнай және газ кен орындарын игеру кезінде тау жыныстарының деформациясы бар екенін анықтады. Қойнауқаттық қысымның төмендеуімен қойнауқаттың кеуек кеңістігінің көлемі жыныс түйірлерінің серпімді кеңеюі және қаңқаға жоғары жатқан жыныстардың массасынан берілетін қысатын күштердің артуы салдарынан азаятыны анықталды. Нәтижесінде кеуекті ортадағы деформациялық процестердің өзгеруі оның кеуектілігі мен өткізгіштігінің төмендеуімен бірге жүреді, ал резервуардың кеуектілігімен салыстырғанда едәуір өзгеріс қысымның бірдей өзгеруімен өткізгіштікке ұшырайды. Сызықтық емес әсерлерді тудыратын осы ауытқулардың резервуарлық жағдайдағы көрінісі кен орнын игерудің бүкіл процесіне айтарлықтай әсер етуі мүмкін және байқалған фактілер мен есептелген көрсеткіштер арасындағы әр түрлі сапалық және сандық айырмашылықтарға әкелуі мүмкін.

Түйін сөздер: көлденең ұңғымалар, өнімді қабат, бұрғылау, көлденең оқпан.

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Горизонтальные скважины как средство интенсификации добычи нефти

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АННОТАЦИЯ

Многочисленными экспериментальными и промысловыми исследованиями установлено, что в процессе разработки нефтяных и газовых месторождений имеются деформации пород, происходящие вследствие изменения пластового давления. Установлено, что с падением пластового давления объём порового пространства пласта уменьшается вследствие упругого расширения зерен породы и возрастания сжимающих усилий, передающихся на скелет от масс вышележащих пород. В результате происходит изменение деформационных процессов в пористой среде, сопровождаемое снижением её пористости и проницаемости, причём более значительное изменение, по сравнению с пористостью пласта, претерпевает проницаемость при одном и том же изменении давления. Проявление в пластовых условиях указанных аномалий, вызывающие нелинейные эффекты, может значительно влиять на весь процесс разработки залежи и приводить к различным качественным и количественным расхождениям между наблюдаемыми фактами и теми показателями, которые рассчитывались по обычным методикам.

Ключевые слова: горизонтальные скважины, продуктивный пласт, бурение, горизонтальный ствол.

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