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FACTORS INFLUENCING THE PRODUCTIVITY OF HORIZONTAL WELLS ON AN EXAMPLE OF THE KARACHAGANAK DEPOSIT

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ABSTRACT

This article examines the factors affecting the productivity of horizontal oil wells in the example of the oil reservoir of the Karachaganak field. The paper presents several methods for calculating the productivity of horizontal wells, taking into account the geometry of the drainage zone. The formulas describing the productivity for each of the methods are analyzed, and the results of calculating the flow rates of horizontal wells for various parameters are presented. The authors considered the following methods: Yu. P. Borisov, S. D. Joshi F. M. Method Giger, method G. I. Renard, J. M. Dupug and Z. S. Alieva, V. V. Sheremet. All methods are based on the assumption of a stationary filtration regime, uniformity of the reservoir, and the location of the horizontal wellbore symmetrically or asymmetrically in thickness. Calculations were performed for well No. 918 in the Karachaganak field using various values of reservoir thickness, horizontal wellbore length, permeability, drawdown, and distance to the feed loop.

Keywords: viscosity of oil, volume factor of oil, pressure of saturation, length of a horizontal site, productivity of horizontal oil wells.

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INTRODUCTION

The Karachaganak oil field, located in the western part of Kazakhstan, is one of the largest fields in the world. It contains significant oil and gas reserves that can be produced by horizontal oil wells. Increasing the productivity of such wells is an important task for optimizing the production process in this field. In this literature review, we will consider the main factors affecting the productivity of horizontal oil wells using the example of the oil reservoir of the Karachaganak field [1]. The geological characteristics of the reservoir, such as its permeability, porosity, size, and shape, play a significant role in the productivity of horizontal wells. Permeability determines the ability of a rock to pass oil and gas, while porosity determines the volume of voids in a rock that can contain oil [2]. Higher permeability and porosity contribute to higher well productivity. In addition, geological inhomogeneities such as fractures and layers can significantly affect well performance.

The efficiency of horizontal wells depends on the selected production mode. This includes parameters such as fluid flow, pressure, and temperature. The optimal well operation mode should be determined taking into account the characteristics of the deposit and the characteristics of the oil.

The design and implementation of horizontal wells require taking into account various technical factors, including the choice of the type and diameter of the well, the use of high-quality drilling equipment, and hydraulic fracturing (hydro fractionation) technologies [3]. The quality of the drilling fluid used to drill horizontal wells can also affect well productivity.

The quality and condition of the equipment used to operate horizontal wells also play an important role in productivity. Prompt maintenance and regular equipment checks help prevent failures and loss of productivity.

Oil production process control includes monitoring and optimization of well performance parameters. This includes regular monitoring of pressure and flow rate, forecasting, and elimination of possible problems associated with an oil well. In addition, the optimal use of pressure maintenance techniques in the reservoir can significantly increase the productivity of horizontal wells.

The performance of horizontal oil wells in the Karachaganak field depends on many factors, including the geological features of the reservoir, the selected well operation, drilling and operating specifications, and production management. Optimizing each of these factors can lead to improved performance and production efficiency at the Karachaganak field.

To date, a significant number of methods have been proposed to determine the productivity of horizontal oil wells. The most important methods are:

The method of Yu. P. Borisova *et al.* [4] assumes that the zone drained by a horizontal well has the shape of a circle:

$$Q_{\text{н}} = \frac{2\pi k h \Delta P}{\mu_{\text{н}} B_{\text{н}} \left[ln \frac{4R_{\text{К}}}{L} + \frac{h}{L} ln \frac{h}{2\pi R_C} \right]} \quad (1)$$

The method of S.D. Joshi [4], assumes that the zone drained by a horizontal well in the area has the shape of an ellipsoid:

$$Q_{\text{н}} = \frac{2\pi k h \Delta P}{\mu_{\text{н}} B_{\text{н}} \left[ln \left(\frac{A + \sqrt{A^2 - (L/2)^2}}{L/2} \right) + \frac{h}{L} ln \frac{h}{2R_C} \right]} \quad (2)$$

VOL. 18, NO. 15, AUGUST 2023 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

$$A = \frac{L}{2}\left[\frac{1}{2} + \sqrt{\frac{1}{4} + \left(\frac{2R_{\text{K}}}{L}\right)^4}\right]^{0,5} \quad (3)$$

The method of F. M. Giger [6] who, like S. D. Joshi assumes that the area drained by a horizontal well has an ellipsoid shape:

$$Q_{\text{H}} = \frac{2\pi kh\Delta P}{\mu_{\text{H}} B_{\text{H}}} \frac{1}{\left[\frac{L}{h} ln\frac{1+\sqrt{1-(L/2R_{\text{K}})^2}}{L/(2R_{\text{K}})} + ln\frac{h}{2R_{\text{C}}}\right]} \quad (4)$$

The method of G. I. Renard, and J. M. Dupug [7] assumes that the zone drained by a horizontal well in terms of the area has similar shapes as in [Oklahoma, U.S.A 1991, p 74] and [SPE 13024, 1984, p 78]:

$$Q_{\text{H}} = \frac{2\pi kh\Delta P}{\mu_{\text{H}} B_{\text{H}}\left(\cos h^{-1}(X) + \frac{h}{L} ln\frac{h}{2\pi R_{\text{C}}}\right)} \quad (5)$$

The method of Z. S. Alieva and V. V. Sheremeta [8] assumes that the zone drained by a horizontal well has the form of a strip-like formation completely penetrated by a horizontal wellbore:

$$Q_{\text{H}} = \frac{2kL\Delta P}{\mu_{\text{H}} B_{\text{H}}} \frac{1}{\left[1+\frac{2R_{\text{C}}}{h-2R_{\text{C}}} ln\frac{2R_{\text{C}}}{h}\right] + \frac{R_{\text{K}}-(h-2R_{\text{C}})}{2h}} \quad (6)$$

All formulas use the following conditions: stationary filtration regime, homogeneous formation, and horizontal wellbore located symmetrically (or asymmetrically in [9]) in thickness, but these methods differ in the geometry of the drainage zone.

To calculate the oil production rate using the methods proposed above, the initial well data were taken. No. 918, which is located at the Karachaganak field (see Table-1). The flow rates of horizontal wells determined by formulas (1)÷(6) for different formation thicknesses h, horizontal wellbore length L_{hor}, absolute permeability k, drawdown ΔP and distance to the feed loop R_k, are shown in Table-2, in which Q_1 is the flow rate calculated by Yu. P. Borisova, Q_2 - by the method of S.D Joshi, Q_3 - by the method of F. M. Giger, Q_4 - according to the method of G. I. Renard, J. M. Dupug, Q_5 - according to the method of Z. S. Alieva, V. V. Sheremet.

Table-2 shows that the flow rates determined by these methods turned out to be quite different, and the difference in these flow rates is associated solely with the accepted geometry of the drainage zone. For the above formulas and the accepted forms of the drainage zone, there is no restriction on the length of the horizontal wellbore. However, in all methods, except formula (6), when the accepted drainage zone is completely opened by a horizontal wellbore, the bottom hole and contour pressures coincide, which makes the resulting calculation formulas for determining the oil production rate unstable. This means that most of the proposed formulas become unacceptable in the areas of horizontal wellbore lengths close to the feed loop parameters.

Table-1. Initial data of a fragment of an oil deposit is used in determining the oil production rate by various methods.

Parameters	Unit measurements	Values
Reservoir pressure	MPa	44,5
Bottom hole pressure	MPa	43,5
Well radius	m	0,076
Power loop radius	m	250
Permeability coefficient	Darcy	0,05÷0,237
Formation thickness	m	60
Reservoir temperature	C^0	89
Oil volume factor	fract.of unit	2,05
oil density	t/m^3	0,826
Porosity	fract.of unit	0,2
Viscosity of oil in reservoir conditions	mPa*s	0,57

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Table-2. The results of calculating the productivity of a horizontal oil well by various methods.

$R_к$, m	*Lhor*, m	*h*, m	*k*, Darcy	*ΔP*, MPa	Horizontal well flow rate, $Q_н$, m³/day				
					Borisov and etc.	Joshi S.D.	Giger F.M.	Renard G.I. and etc	Aliyev
250	600	30	0,225	1	1035,0	377,4	-	433,9	497,7
500	″	30	0,225	1	527,0	351,6	277,8	304,4	262,3
1000	″	30	0,225	1	353,4	321,0	174,3	177,0	134,8
250	″	30	0,225	0,1	103,6	37,7	-	43,4	49,8
250	″	30	0,225	0,5	517,0	188,7	-	216,9	248,9
250	″	30	0,225	1,5	1553,9	566,2	-	650,8	746,6
250	″	50	0,225	1	1379,5	364,4	-	594,7	774,4
500	″	10	0,225	1	197,6	362,3	105,2	116,8	90,8
1000	″	10	0,225	1	127,3	329,9	62,8	63,9	45,8
500	″	50	0,225	1	778,7	340,3	406,8	440,5	421,3
1000	″	50	0,225	1	542,5	311,5	267,3	271,1	220,4
250	″	30	0,0225	1	103,6	37,7	-	43,4	49,8
500	″	30	0,0225	1	52,7	35,2	27,8	30,4	26,2
1000	″	30	0,0225	1	35,3	32,1	17,4	17,7	13,5
250	″	30	0,5	1	2302,1	838,7	-	964,1	1106,1
500	″	30	0,5	1	1171,2	781,4	617,4	676,4	582,9
1000	″	30	0,5	1	785,4	713,4	387,4	393,4	299,5

EXPERIMENTAL PART

The reservoir thickness affects the productivity of a horizontal well to a lesser extent than the flow rate of vertical wells, which follows to study the effect of the reservoir thickness; calculations were carried out to determine the oil production rate of a horizontal well at various thicknesses. Below are the formulas for oil inflow to vertical and horizontal wells, from which it follows that the results obtained are objective.

$$Q_в = \frac{2\pi kh\Delta P}{\mu_н \ln\frac{R_к}{R_c}} \text{ и } Q_г = \frac{2kL\Delta P}{\mu_н B_н}\frac{1}{\left[1+\frac{2R_c}{h-2R_c}\ln\frac{2R_c}{h}\right]+\frac{R_к-(h-2R_c)}{2h}} \quad (7)$$

where $Q_в$ and $Q_г$ – respectively, the flow rates of vertical and horizontal wells.

This is one of the reasons that the drilling of horizontal wells for the development of oil resources is profitable. However, the above conclusion does not mean that the reservoir thickness has little effect on the productivity of horizontal wells. The oil rates of a horizontal well at various reservoir thicknesses are shown in Figure-1.

Figure-1 shows that with a small reservoir thickness, the increase in production rate with an increase in the length of a horizontal oil well is insignificant. An increase in the reservoir thickness from *h*=5 m to *h*=60 m, i.e. 12 times leads to an increase in oil production from $Q_н$≈91 m³/day to $Q_н$≈899 m³/day at *Lhor*=600 m, i.e. 10 once. The nature of the change in well production rate from the thickness of the reservoir is shown at *Lhor*=200; 400 and 600 m. At small formation thicknesses, the *L/h* ratio is higher than at significant thicknesses. So, for example, at *Lhor* =600 m and *h*=5 m, this ratio is *L/h*=120, which is 12 times more than at *h*=60 m, when *L/h*=10.

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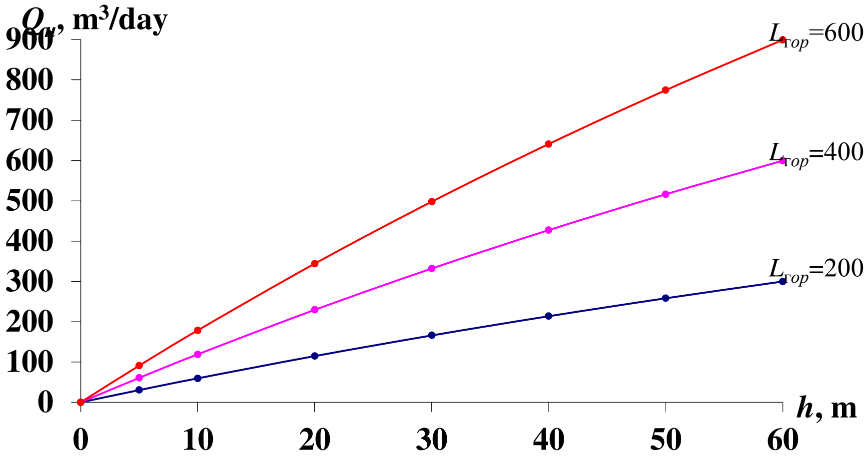

Figure-1. The dependence of the production rate of a horizontal oil well on the thickness of the reservoir at various *Lhor*.

The production rate of a horizontal well is directly proportional to drawdown *ΔP* and absolute permeability *k*. An increase or decrease in these parameters leads to an increase or decrease in the oil production rate of a horizontal well. The results of calculating the oil production rate of a horizontal well at various permeability and drawdowns are shown in Tables 3 and 4. In the case of a decrease in absolute permeability from *k*=0,5 to *k*=0,1 Darcy at *Lhor*=300 m, the oil production rate turned out to be $Q_н$=111 m^3/day instead of $Q_н$ =553 m^3/day (see Figure-2), and with a decrease in the value drawdown on the reservoir by 2 times for the same length of the horizontal section of the wellbore, the oil production rate decreases by 2 times (see Figure-3).

Table-3. Results of oil production rate calculations for various reservoir permeability.

Reservoir permeability k, Darcy	Flow rate of a horizontal well, $Q_н$ м^3/day, at different barrel lengths *Lhor*					
	***Lhor*=100 м**	***Lhor*=200 м**	***Lhor*=300 м**	***Lhor*=400 м**	***Lhor*=500 м**	***Lhor*=600 м**
0,05	18,4	36,9	55,3	73,7	92,2	110,6
0,1	36,9	73,7	110,6	147,5	184,3	221,2
0,5	184,3	368,7	553,0	737,4	921,7	1106,1
1	368,7	737,4	1106,1	1474,8	1843,5	2212,2

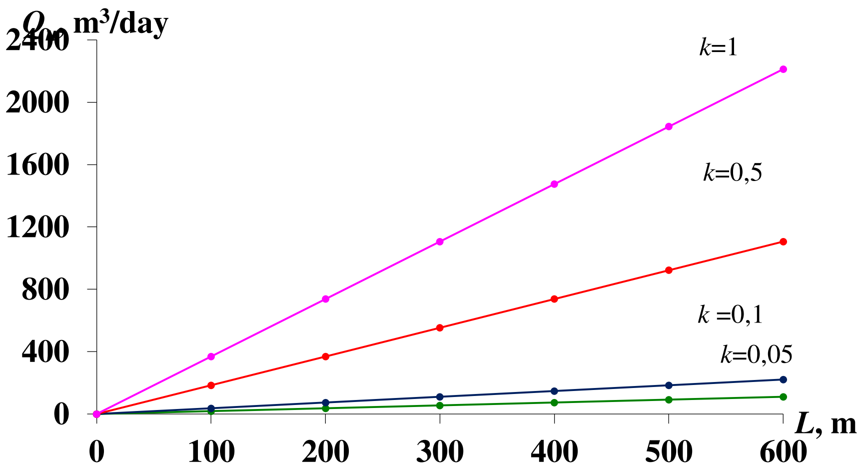

Figure-2. Dependence of horizontal well production rate on wellbore length at different reservoir permeability.

VOL. 18, NO. 15, AUGUST 2023 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-4. Results of oil production rate calculations for various formation depressions.

Drawdown pressure *ΔP*, MPa	Flow rate of a horizontal well, , $Q_н$ m³/day, at various barrel lengths, *Lhor*					
	Lhor=100 м	*Lhor*=200 м	*Lhor*=300 м	*Lhor*=400 м	*Lhor*=500 м	*Lhor*=600 м
0,1	8,3	16,6	24,9	33,2	41,5	49,8
0,5	41,5	83,0	124,4	165,9	207,4	248,9
1,0	83,0	165,9	248,9	331,8	414,8	497,7
1,5	124,4	248,9	373,3	497,7	622,2	746,6

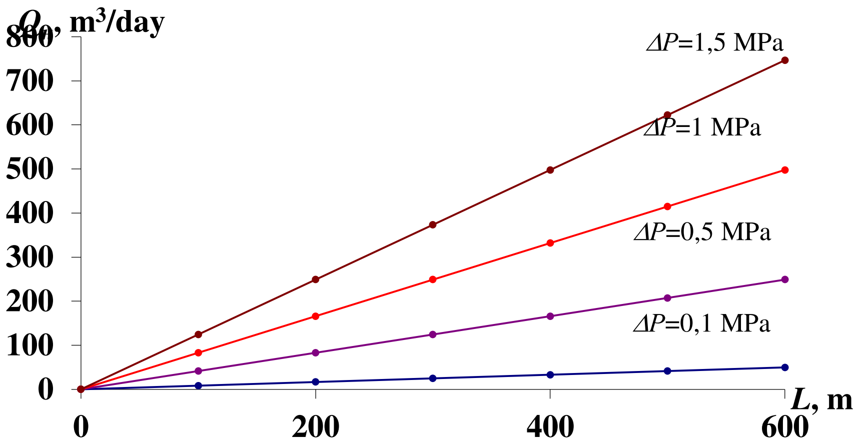

Figure-3. Dependence of the horizontal well production rate on the length of the wellbore at various drawdown pressures.

The anisotropy parameter affects the productivity of horizontal wells more than the flow rate of vertical wells. For an anisotropic reservoir, taking into account the anisotropy parameter, formula (6) will take the form:

$$Q_{\text{н}} = \frac{2kL\Delta P}{\mu_{\text{н}} B_{\text{н}}} \frac{1}{\left[\frac{1}{\nu h_i}\left(\nu h_i + R_c \ln \frac{R_c}{R_c + \nu h_i}\right)\right] + \frac{R_{\text{к}} - \nu h_i}{(R_c + \nu h_i)}} \qquad (8)$$

where h - reservoir thickness; h_i = (h-h_2) - R_c - layer thickness of the i-th zone minus the well radius; ν - anisotropy parameter determined from the equality:

ν =, k_{ver}, k_{hor} - permeability coefficients in vertical and horizontal directions.

Table-5 and in Figure-4 illustrate the results of calculating the oil production rate using formula (8) for various lengths of the horizontal wellbore and values of the anisotropy parameter v. The curve with the anisotropy parameter v = 1 in Figure-4 shows the dependence of the oil production rate $Q_{\text{н}}$ on the length of the trunk L in an isotropic reservoir. With the anisotropy parameter ν = 0.3162, which is equivalent to $k_v = k_h/10$, a threefold decrease in the anisotropy parameter reduces the oil production rate by almost three times due to the low reservoir permeability in the vertical direction.

Table-5. Results of oil production rate calculations for various formation anisotropy.

Anisotropy parameter $\nu = \sqrt{k_{\text{вер}}/k_{\text{гор}}}$	Flow rate of a horizontal well, $Q_н$ m³/day, at various barrel lengths *Lhor*					
	Lhor=100m	*Lhor*=200 m	*Lhor*=300 m	*Lhor*=400 m	*Lhor*=500 m	*Lhor*=600 m
0,03162	6,3	12,6	18,8	25,1	31,4	37,7
0,1	18,6	37,1	55,7	74,3	92,8	111,4
0,3162	55,0	110,0	165,0	220,0	275,0	330,0
1	150,2	300,4	450,6	600,7	750,9	901,1

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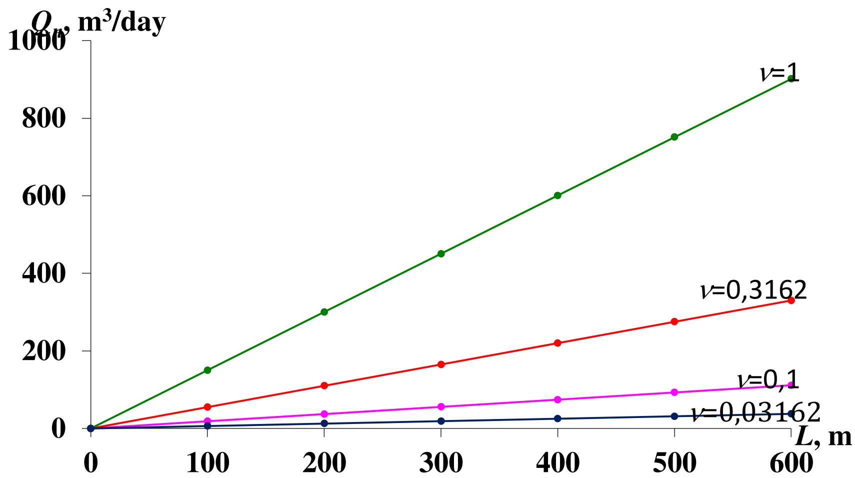

Figure-4. Dependence of the oil production rate of a horizontal well on the length of the wellbore for various anisotropy parameters.

RESULTS AND DISCUSSIONS

Table-6 shows the results of calculating the oil production rate of a horizontal well for various reservoir thicknesses and permeabilities k_{ver}/k_{hor}. Figure-5 shows the dependence of the production rate of a horizontal well on the thickness of the reservoir at various ratios k_{ver}/k_{hor} at L_{hor}=300 m. So, for example, with an increase in the ratio from k_{ver}/k_{hor}=0,1 to 0.5, the oil production rate according to (2.8) increases from 19.8 m^3/day to 450.6 m^3/day. The maximum value of $Q_н$=753.9 m^3/day is achieved at the value k_{ver}/k_{hor}=1.

Table-6. Results of oil production rate calculations for various ratios k_{ver}/k_{hor}.

Parameter k_v/k_h	Flow rate of a horizontal well, $Q_н$ m^3/day, at different reservoir thicknesses *h* and permeabilities						
	h=5 m	*h*=10 m	*h*=20 m	*h*=30 m	*h*=40 m	*h*=50 m	*h*=60 m
0,05	10,6	19,8	24,3	28,9	37,9	46,8	55,7
0,1	19,8	37,9	46,8	55,7	73,3	90,6	107,6
0,5	90,6	173,2	212,3	250,0	321,5	388,2	450,6
1	173,2	321,5	388,2	450,6	564,0	664,4	753,9

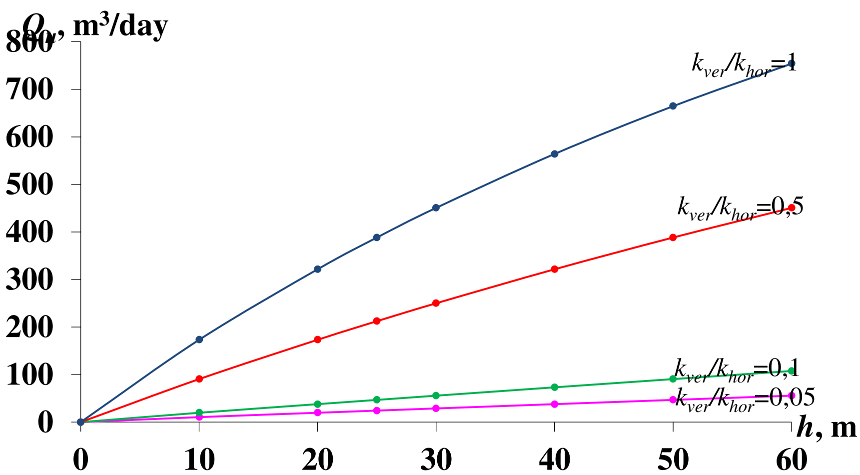

Figure-5. Dependence of horizontal well production rate on formation thickness at different ratios of k_{ver}/k_{hor} formation permeability.

VOL. 18, NO. 15, AUGUST 2023 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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The available theoretical foundations and methodology for determining the productivity of horizontal wells are closely related to the accepted schematizations of oil inflow to a horizontal well.

The fundamental difference between the oil inflow to the bottom of a horizontal well and the inflow to the bottom of a vertical well is that, as a rule, a horizontal well always has a significant inflow interval, up to several thousand meters [see work [5]. The large length of the filter, where oil flows to the wellbore, necessitates the creation of an appropriate drawdown on the formation, the permissible value of which should be at the point of transition of the wellbore from horizontal to vertical position in the absence of flow pipes in the horizontal part of the wellbore. If its value is limited by some factor - the presence of bottom water or reservoir instability, then with a significant length of the horizontal part of the wellbore, due to friction pressure losses that occur when oil moves along the wellbore, the drawdown in the final section of the wellbore can be negligible. In some cases, a variant is possible when, at the end of the wellbore, P_w will be close to P_d. In such cases, the length of the horizontal part of the wellbore should be limited by the drawdown at the point of transition of the wellbore from horizontal to vertical position and pressure losses in the horizontal part of the wellbore.

Taking into account various factors affecting the productivity of a horizontal well, depending on the specific properties of the reservoir: its thickness, the presence of bottom water near the bottom, the stability of the reservoirs, the length of the wellbore, the laws of oil filtration to a horizontal well become more significant than when filtration to a vertical a well that has opened a reservoir with a limited thickness.

The search for approximate analytical methods for determining the productivity of horizontal wells that have penetrated oil and gas reservoirs is aimed at choosing such a model of the problem under consideration, which, without distorting the physical essence of the filtration process, will make it possible to obtain simple formulas for determining the flow rate of such wells.

However, one of the most common ways to schematize filtration problems is to replace the true reservoir filtration area with an area that provides equivalent resistance, as proposed by Z. S. Aliev in [5].

A simplifying schematization of the problems of oil filtration to a horizontal well that has penetrated a strip-like formation can be represented in the following ways. For a symmetrical location within the radius R=*h*/2, the oil inflow along the length of a horizontal wellbore can be represented as a plane-radial one, and outside this circle, the inflow can be considered as a plane-parallel filtration to an enlarged well.

Let us consider a strip-like formation, completely penetrated by a horizontal well, to which there is an inflow of oil, located asymmetrically along the thickness of the formation. It is necessary to determine the flow rate of the well depending on the location of the horizontal wellbore along the thickness of the formation. In the exact formulation, the solution of such a problem is possible by a numerical method. Therefore, to obtain simple analytical formulas, it is necessary to use some simplifying assumptions. The scheme for solving the problem is shown in Figure-6.

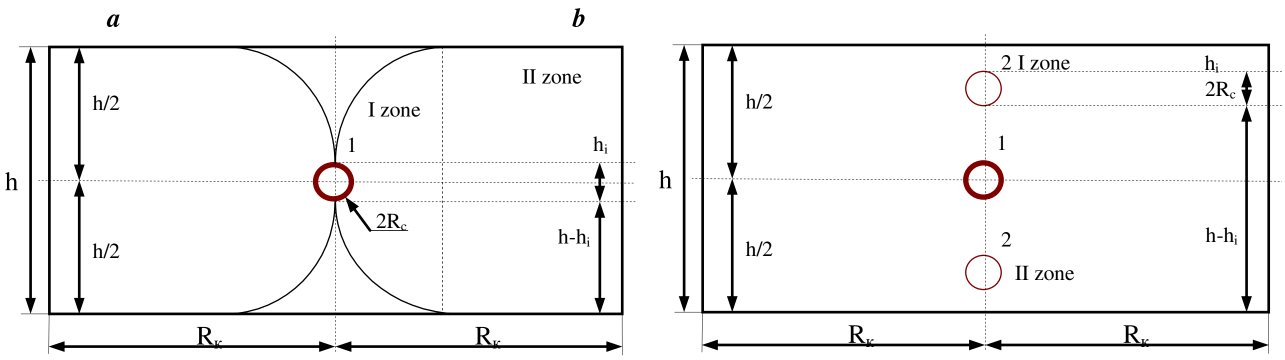

Figure-6. Layout of the table of a horizontal well along the thickness of the formation: 1 – symmetrical; 2 - asymmetric.

According to the formulas of Joshi S. D. [4] Z. S. Alieva, and V. V. Sheremeta [3] determined the flow rate of a horizontal oil well equidistant from the top and bottom of the reservoir. Of great practical interest to study is the effect of the location of the horizontal wellbore relative to the roof and bottom of the reservoir on the productivity of the well. In [2] and [3], formulas were proposed for determining the production rate of a horizontal well, asymmetrically located along the reservoir thickness, having the form:

$$Q_H = \frac{2\pi kh\Delta P}{\mu_H B_H\left[\ln\frac{A+\sqrt{A^2-(L/2)^2}}{L/2}+\frac{\nu h}{L}\ln\frac{(\nu h/2)^2-\nu^2\delta^2}{2R_C}\right]} \quad (9)$$

Where δ – vertical distance between the center of the well and the middle of the reservoir thickness. According to [1], formula (9) requires the following conditions to be met:

$L > \nu h,\ \delta < h/2,\ L < 1{,}8R_к$

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$$Q_{н} = \frac{2kL\Delta P}{\mu_{н} B_{н}} \sum_{i=1}^{2} \frac{1}{\frac{2}{h_i}\left[h_i + R_C \ln\frac{R_C}{h_i+R_C}\right] + \frac{R_{К}-h_i}{(h_i+R_C)}} \quad (10)$$

For each of the zones, the method for determining the flow rate of a horizontal well, adopted for a symmetrically located wellbore, was used.

According to the obtained formulas, calculations were carried out to determine the flow rate of a horizontal well located at different distances from the roof and bottom of the formation.

The calculation results are shown in Figure-7, from which it can be seen that the value of the production rate of a horizontal well that has opened a strip-like deposit changes when the wellbore moves from the middle of the productive formation to its top or bottom.

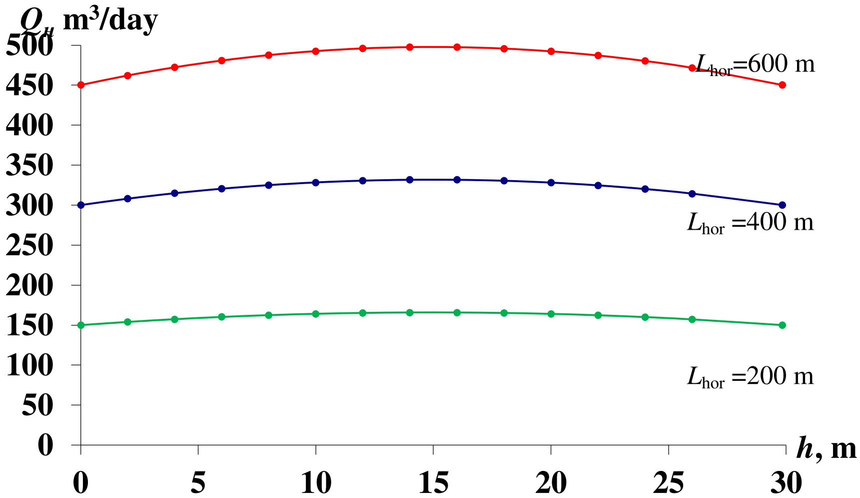

Figure-7. Dependence of the horizontal oil well production rate on the location of the wellbore along the reservoir thickness.

CONCLUSIONS

Calculations using approximate methods for determining the productivity of horizontal oil wells on the example of the oil facility of the Karachaganak field found that the flow rates turned out to be non-identical and the difference in these flow rates is associated solely with the accepted geometry of the drainage zone.

The calculation results show that the reservoir parameters are *k*, *v*, *ΔP*, etc. the productivity of a horizontal well is affected to a lesser extent than the flow rate of vertical wells. The productivity of a horizontal well increases linearly with an increase in drawdown, absolute permeability of the formation, anisotropy parameter, and formation thickness, and proportionally decreases with increasing distance to the feed loop.

It has been established that the value of the oil production rate of a horizontal well that has opened a strip-like deposit decreases with an asymmetric placement of the wellbore along the reservoir thickness. Moving the wellbore to the top or bottom equally affects the flow rate of a horizontal well. With the accepted value of the reservoir thickness *h*=30 m, the maximum decrease in the production rate of a horizontal oil well compared to the production rate of a symmetrical arrangement is 9.5%.

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