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Oleksandr Burachok*

INVESTIGATION OF HORIZONTAL WELLS INTERFERENCE IN THE WELL CLUSTER

1. INTRODUCTION

Most of the Ukrainian oil fields is on the final stage of the development. At this stage high drop of reservoir pressure and termination of filtration from low permeability areas take place. Drilling of well cluster is one of proposed methods of oil recovery from such areas. The main problem of rational usage of this method is correct determination of rational number of horizontal wells (rays), length of horizontal parts and radius of reservoir entry (remoteness from the main vertical part of the cluster). It is advisable to apply this scheme on new fields too. For example instead of drilling vertical wells to drill 3–4 clusters of horizontal wells. The problem of hydrodynamic horizontal wells interference will arise any way. These problems are solved in this paper.

2. MATHEMATICAL MODEL

The replacement of horizontal well with vertical with reduced well radius is proposed in work [1]

$$r_{whor} = r_w e^{-C_{hor}} \tag{1}$$

where:

r_{whor} – radius of horizontal well [m],
r_w – radius of equivalent vertical well [m],
C_{hor} – coefficient of hydraulic friction that was caused by well's horizontal location.

* Research and Design Institute of Joint Stock Company "Ukrnafta"

The formula for reduced radius of equivalent vertical well was obtained in work [2]

$$r_w = \frac{h}{2\pi} e^{-\frac{2\pi k h \Delta p}{q\mu}} \tag{2}$$

where:

- k – coefficient of reservoir permeability [m^2],
- h – reservoir thickness [m],
- Δp – depression [Pa],
- μ – coefficient of dynamic viscosity of reservoir fluid [Pa·s],
- L – length of horizontal part of the well [m],
- $R_\text{к}$ – radius of external boundary of reservoir [m].

There also has been proposed to replace horizontal well with line of vertical wells, that are located on distances h one from another. Let us solve the problems additionally finding the minimal number of vertical wells for replacement of horizontal ray.

We will make the following abstractions: reservoir is radial ad homogeneous, all horizontal rays have the same length and equidistant from the reservoir center, the wellbore pressures are the same in every ray.

3. PROBLEM SOLVE

Let us find economically and technically the expedient number of horizontal rays. The following problem we will solve with usage of joined method water course and superposition [3]. The calculation of day cluster production will be done in case of 2, 3, 4, 5 and 6 horizontal rays. In general case for a well cluster that contains m rays and n wells in every ray for the i well in j ray the potential on the bottom of the well will be

$$\begin{aligned}\Phi_{j,i} = \frac{1}{2\pi}[q_{1,1} \ln r_{1,1-j,i} + q_{1,2} \ln r_{1,2-j,i} + ... + q_{1,n} \ln r_{1,n-j,i} + ... + \\ + q_{j,i} \ln r_{cj,i} + ... + q_{m,n} \ln r_{m,n-j,i}] + c\end{aligned} \tag{3}$$

Taking into consideration the pressure on external boundary the formula (3) will be the following

$$\Phi_{R_\text{к}} - \Phi_{j,i} = \frac{1}{2\pi}\left[\begin{aligned} q_{1,1} \ln \frac{R_\text{к}}{r_{1,1-j,i}} + q_{1,2} \ln \frac{R_\text{к}}{r_{1,2-j,i}} + ... + q_{1,n} \ln \frac{R_\text{к}}{r_{1,n-j,i}} + ... + \\ + q_{j,i} \ln \frac{R_\text{к}}{r_{cj,i}} + ... + q_{m,n} \ln \frac{R_\text{к}}{r_{m,n-j,i}} \end{aligned}\right] \tag{4}$$

where:

$q_{j,i}$ – specific production of the vertical well j, i [m^2/s],
$r_{m,n-j,i}$ – distance from the well m, n to the well j, i [m],
c – random constant,
$R_К$ – radius of the external boundary [m].

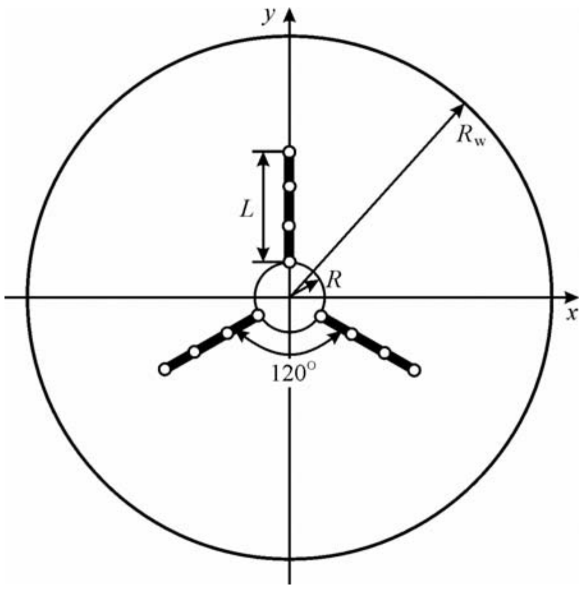

Fig. 1. Scheme of well cluster with three rays that were transformed into linear rows of vertical wells

An example of calculation scheme for the well cluster with three rays is given on Figure 1. With purpose of getting the specific numeric results we will operate with the following values $R = 100$ m, $p_w = 15 \cdot 10^6$ Pa, $p_{eb} = 18 \cdot 10^6$ Pa, $k = 0.05 \cdot 10^{-12}$ m^2, $\mu = 1{,}2 \cdot 10^{-3}$ Pa·s. Calculations will be conducted for three cases while rest values will be constant and the following condition will be preserved $L = 1/2\, R_К$ and $N = L/h + 1 = 6$:

– $R_{eb} = 600$ m, $L = \frac{1}{2} R_{eb} = 300$ m, $h = \frac{1}{10} R_{eb} = 60$ m;
– $R_{eb} = 1000$ m, $L = \frac{1}{2} R_{eb} = 500$ m, $h = \frac{1}{10} R_{eb} = 100$ m;
– $R_{eb} = 5000$ m, $L = \frac{1}{2} R_{eb} = 2500$ m, $h = \frac{1}{10} R_{eb} = 417$ m.

Calculation results are given in Table 1.

From the Table 1 we can see that:
– with distance from the external boundary the specific production of cluster decrease;
– huge growth of production corresponds to difference between two and three rays.

Table 1

Rational number of horizontal wells in the well cluster calculation results

External boundary radius, R_{eb} [m]	Length of the ray, L [m]	Reservoir thickness, h [m]	Number of the rays, N	Specific production from the well cluster, q [m^3/day]	Growth of specific production, Δq [m^3/day]
600	300	60	2	43,8441	–
			3	60,3286	16,4845
			4	70,9045	10,5759
			5	79,0045	8,1
			6	85,4961	6,4916
1000	500	100	2	41,8392	–
			3	53,5725	11,7333
			4	61,8604	8,2879
			5	68,1432	6,2828
			6	73,1425	4,9993
5000	2500	417	2	32,8375	–
			3	40,0897	7,2522
			4	45,0342	4,9445
			5	48,6874	3,6532
			6	51,5324	2,8450

Therefore, we can conclude that it is not advisable to drill more then 3 horizontal rays.

Let us examine the results of calculation the production from the well cluster (R_{eb} = = 1000 m, $L = \frac{1}{2} R_{eb} = 500$ m, $h = \frac{1}{10} R_{eb} = 100$ m) separately by the wells (Tab. 2).

Table 2

Calculation results of production from the well cluster with three horizontal rays

Number of the rays, N	Specific production from the well (number of the well from the reservoir center), q_w [m^3/day]						Specific production of the well line, Q_l [m^3/day]
	1	2	3	4	5	6	
2	3.0750	2.9305	3.0181	3.2749	3.7770	4.8439	20.9196
3	1.9806	2.1779	2.4940	2.9192	3.5534	4.7324	17.8575
4	1.3081	1.6335	2.0627	2.5891	3.3108	4.5609	15.4651
5	0.8914	1.2465	1.7203	2.3033	3.0837	4.3835	13.6287
6	0.6252	0.9682	1.4476	2.0580	2.8775	4.2139	12.1904

The calculation results are also given graphically on the Figure 2.

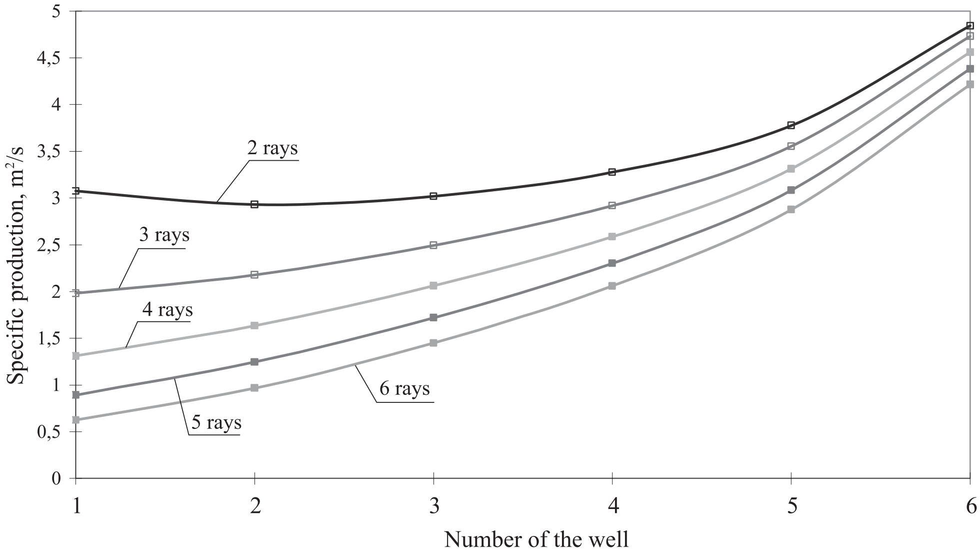

Fig. 2. Change of production for the wells in one rays

Making the analysis of Table 2 we can see that:

– in case of increase of ray number the specific production from it decrease;
– with increase of ray number the total production from the well cluster increase;
– only in case of 2 rays the production from the first well is bigger than from the second, therefore when we have a lot of rays (more than 2) the great interference of "central" wells and their mutual screening take place.

For the selected optimal number of rays (three) and reservoir with radius of external boundary R_{ex} = 1000 m we will conduct the rest of calculations with different thicknesses of reservoir (100, 65 and 30 m) in the way when distances between vertical wells will be more then h. Therefore, we will find the rational proportion between length of horizontal part and radius of external boundary, radius of reservoir entry and minimal number of vertical wells that can change horizontal one.

Calculation was conducted for different radiuses of reservoir entry with horizontal parts of the well with a step of 25 m. The radius of external radius Reb was proposed as a bases of horizontal well length $L = 0.1R_{eb}$; $L = 0.2R_{eb}$ and so on. The calculation results of production from one ray with different thicknesses of reservoir and length of the ray dependent on radius of stratum entry (Fig. 3). From the initial part of the graphs (R = 25 m) it can be seen that with growth of reservoir thickness the difference in production for L = 100 and L = 900 m increases not so greatly, therefore from the positions of economics and hydrodynamics the rational length of horizontal part of the well should be $L = 0.5R_{eb}$, and the radius of stratum entry $R = 0.1R_{eb}$. But taking into account the inevitable process of well watering during oil production author have proposed to accept the rational length of horizontal ray as $L = 0.4R_{eb}$, so with $R = 0.1R_{eb}$ the whole length from the center of the reservoir will be $0.5R_{eb}$. The change of production of horizontal ray with different thicknesses of the reservoir for $L = 0.4R_{eb}$ is given on Figure 4.

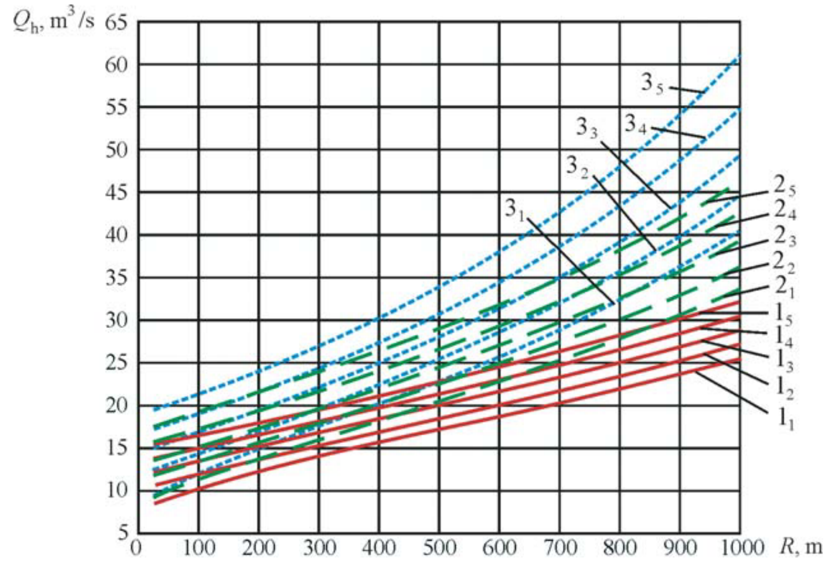

Fig. 3. Change of production for one horizontal ray in dependence of reservoir entry radius:
h = 30 m: 11, 12, 13, 14, 15 – L = 100, L = 300, L = 500, L = 700, L = 900 m;
h = 65 m: 21, 22, 23, 24, 25 – L = 100, L = 300, L = 500, L = 700, L = 900 m;
h = 100 m: 31, 32, 33, 34, 35 – L = 100, L = 300, L = 500, L = 700, L = 900 m

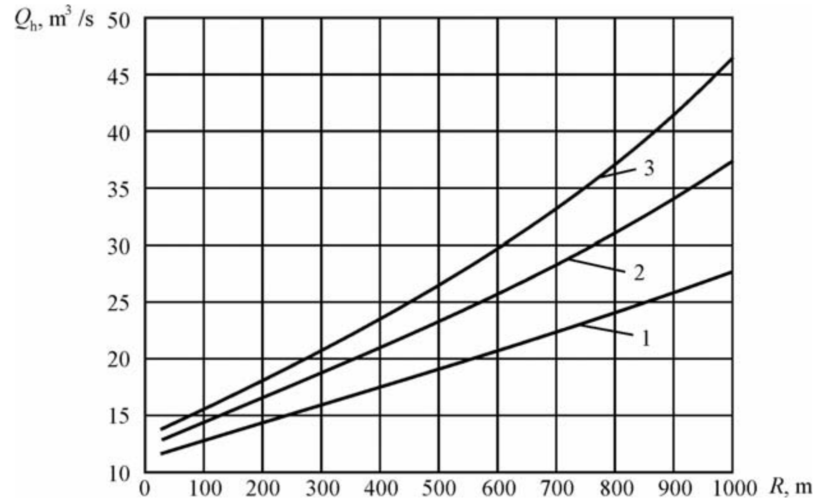

Fig. 4. Change of production for one horizontal ray in dependence of reservoir entry radius with L = 400 m: 1 – h = 30 m; 2 – h = 65 m; 3 – h = 100 m

Determination of optimal quantity of adequate number of vertical wells for creation of linear row was done with the following conditions: the number of wells in the row – from 2 to 10; radius of external boundary of reservoir – R_{eb} = 1000 m; length of horizontal ray – $L = 0.4R_{eb}$ = 400 m with change of reservoir entry radius, and also for optimal radius of reservoir entry R = 100 m. The change of production from horizontal ray in the dependence from the radius of reservoir entry is shown on the Figure 5. The change of production from horizontal ray in the dependence from the quantity of the vertical wells for R = 100 m is shown on the Figure 6. As it can be seen after 5 wells the increase in production is not sufficient, so it is advisable to take 5 wells as a optimal number of wells.

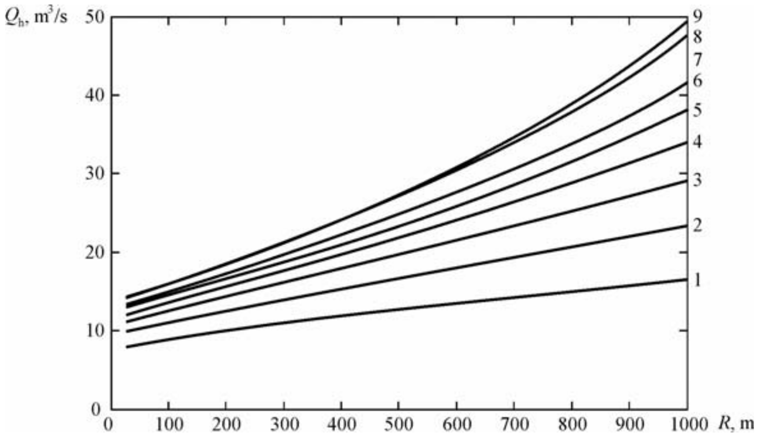

Fig. 5. Change of production for one horizontal ray in the dependence of reservoir entry radius with different number of the vertical wells in linear row: 1 – n = 2; 2 – n = 3; 3 – n = 4; 4 – n = 5; 5 – n = 6; 6 – n = 7; 7 – n = 8; 8 – n = 9; 9 – n = 10

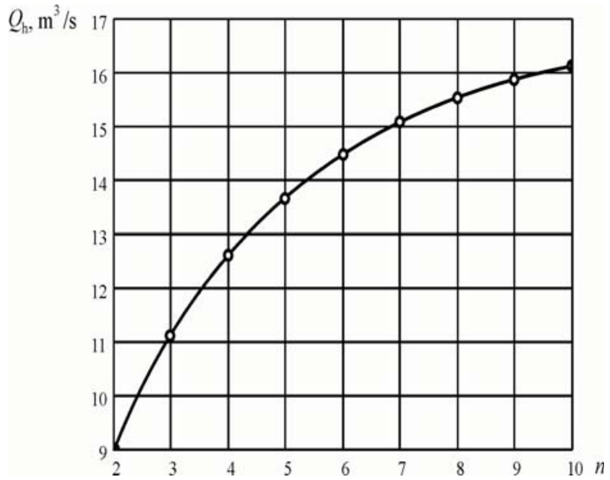

Fig. 6. Change of production for one horizontal ray with L = 400 m and R = 100 m in the dependence from number of vertical wells in linear row

4. CONCLUSIONS

The appropriateness of drilling the well cluster as a method of intensification of oil recovery was grounded in this paper. The calculations were conducted for radial reservoir with different radiuses of external boundary (600, 1000 deg 2500 m) and different thicknesses of reservoir (30, 65 deg 100 m). The optimal number of horizontal rays is 3, the optimal length of horizontal rays $-L = 0.4R_{eb}$, the optimal radius of reservoir entry is $L = 0.1R_{eb}$. The conducted calculations for determination of rational number of vertical wells for replacement of horizontal ray has shown that without substantial lose of production it is not necessary to drill more than 5 vertical wells, but from economic positions even such amount is not advisable, because it is cheaper to drill 3 horizontal rays instead of drilling circular battery of 15 vertical wells.

5. NOTES

High values of production were obtained due to:

1. Hydrodynamic well thoroughness.
2. Good filtration characteristics of the reservoir.
3. Large reservoir thickness.

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