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A METHOD FOR ASSESSING THE EFFECTIVENESS OF WATER ISOLATION WORKS BASED ON THE DEVELOPMENT OF A HYDRODYNAMIC MODEL

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ABSTRACT

An important task at the stage of designing any activity related to oil recovery enhancement (in the present case repair and isolation works), is process modeling, in particular, hydrodynamic modeling. Modeling is used to forecast the parameters of oil recovery as s function of the implemented technology at the design stage. As a result, the cost of works performed can be reduced and the profitability and success rate of the planned activities can be assessed. The paper considers the assessment of technological and economic effects using the developed two-phase hydrodynamic model simulating oil-saturated and water-bearing layers. Discussed are the calculated values and relationship between skin factor and various isolation factors. The graphs of oil flow rate and water cut as functions of the material isolation factor are given.

Keywords: water isolation; hydrodynamic model; skin factor; isolation factor; water inflow.

Introduction

To assess the effectiveness of measures aimed at isolating water inflow, a hydrodynamic model was created to calculate the required amount of water-isolation composition. The developed two-phase hydrodynamic model makes it possible to initiate overflow into water-bearing bed by perforation. This model already at the initial stage shows how currents change during the operation of the target layer and behind-the-casing overflow. Also, this hydrodynamic model shows a pronounced tendency of skin factor variation with an increase of isolation factor. This makes it possible to predict the increase of oil flow rate and decrease of water inflow at the design stage. The applied model makes it possible to determine the direct economic efficiency of measures in the process of designing works, without applying complex calculations and formulas, which will also greatly facilitate and simplify the work of engineering staff at the design stage [1-8].

Materials and methods

A two-phase hydrodynamic model is a simulation of a two-layer object, divided by a jumper, where the upper layer is completely oil-saturated, and the lower layer is water-bearing (fig. 1). According to the calculation conditions, the layers are operated by one well, with constant boundary conditions (pressure, saturation). The permeabilities and thicknesses of layers are given in table 1.

The well was launched for the designed operation period of 20 years. For the eighth year, the behind-the-casing circulation was modeled by creating a connection (perforation) to the upper cell of the aquifer (fig. 2).

The flow rate of the liquid in the calculation was set constant. Water isolation was modeled by adding calculated skin factors for a specific injection volume of 15 m^3/m for isolation factors of 85, 90, 95, 99 (table 2) according to the formula

$$s\left(K_{iso}, V_{reac}\right) = \left(\frac{k - k \cdot \left(\frac{100}{K_{iso}}\right)}{k} - 1 \right) \cdot \ln \frac{\sqrt{\frac{V_{reac}}{\pi \cdot h \cdot m}}}{r_{well}} \quad (1)$$

The results of the performed calculations are shown in figures 5 and 6.

The ratio of the oil flow rates after treatment and before the occurrence of behind-the-casing circulation is shown in table 3.

Figure 5 and table 3 show that for none of the calculated options, the oil flow rate after treatment is greater than that before the occurrence of behind-the-casing circulation.

Table 1
Filtration characteristics of layers in the model

Interlayer	Thickness	Permeability
1 layer	3.5	305.7
2 layer	4	1061

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http://dx.doi.org/10.5510/OGP20230100810

So it can be concluded that the technological effect of water isolation of the inflow from the aquifer is aimed at restoring the basic oil recovery, and for a given range of isolation factor, the recovery of the basic oil recovery is from 33 to 90 %.

This technique allows conducting an economic assessment of activities based on two components. The performed calculations allow us to select the minimum required vol-

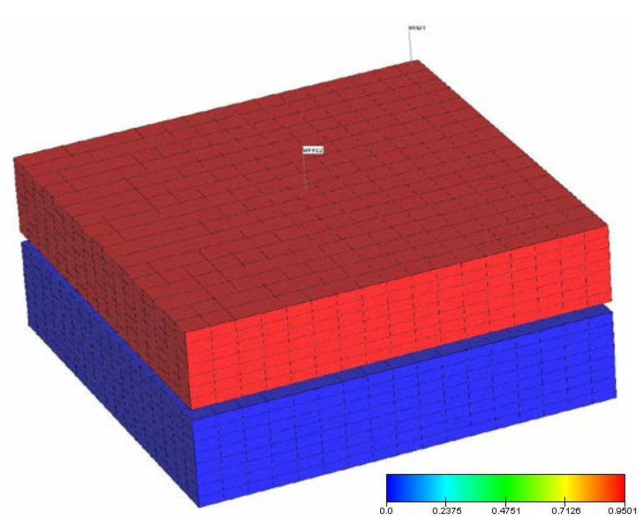

Fig. 1. Model for calculations (saturation)

Table 2
Calculated skin factors for various isolation factors

Specific volume per 1 m of layer thickness	K_{iso}=85 %	K_{iso}=90 %	K_{iso}=95 %	K_{iso}=98 %	K_{iso}=99 %
1	15	23	49	126	255
2	19	29	62	160	323
10	28	44	93	239	483
15	30	48	100	259	523

Table 3
The ratio of the oil flow rates after treatment and before the occurrence of behind-the-casing circulation

Isolation factor	85	90	95	98	99
Recovery percentage of the basic oil flow rate, %	33	44	62	81	90

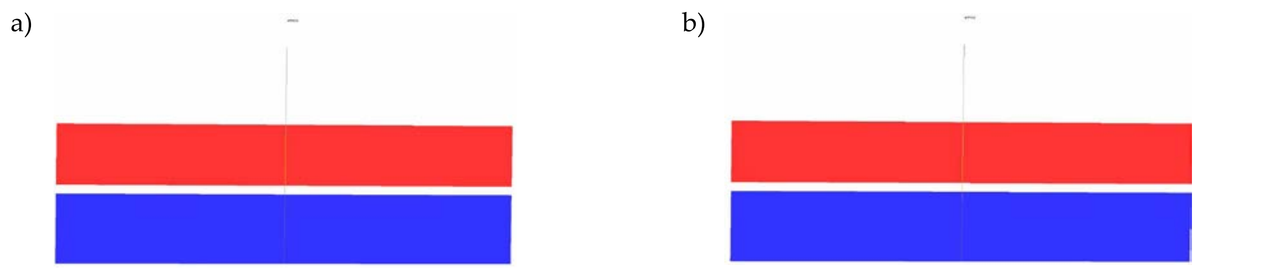

Fig. 2. Location of model perforation in the upper oil-saturated layer (a), partially in the aquifer (behind-the-casing overflow modeling) (b)

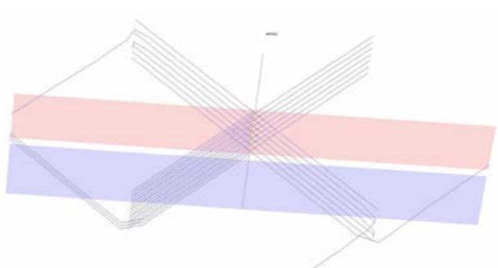

Fig. 3. Current lines during target layer operation

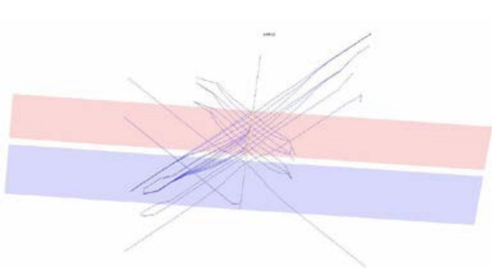

Fig. 4. Current lines upon occurrence of behind-the-casing circulation

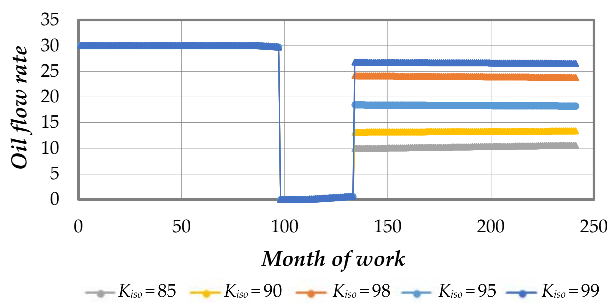

Fig. 5. Estimated change of oil flow rate for various isolation factors

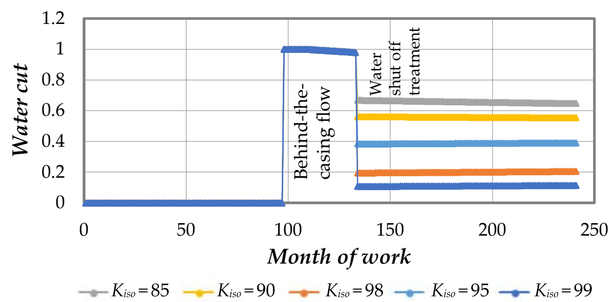

Fig. 6. Estimated change of water cut for various isolation factor

Table 4
Characteristics of well used in the calculations

Characteristics	Value	Measure unit
Liquid flow rate	100	m^3/day
Water flow rate	90	m^3/day
Water cut	90	%
Backfill pressure	50	atm
Aquifer permeability	120	mD
Aquifer porosity	0,2	unit fraction
Aquifer thickness	7.6	m
Well radius	0.073	m
Volume factor	1.0	unit fraction
Water viscosity	1.6	cP

Table 5
The calculated pressure profiles at various distances from the well

Radius from well, m	Pressure at radius, atm	Gradient dP/dr, atm/m	Total pressure change, atm	Relative pressure change, atm
0.076	50.0			
0.50	55.46	12.88	12.88	64 %
2.0	59.48	2.68	15.56	77 %
3.0	60.66	1.18	16.74	83 %
4.0	61.49	0.83	17.57	87 %
5.0	62.14	0.65	18.22	90 %
6.0	62.67	0.53	18.75	93 %
8.0	63.50	0.83	19.58	97 %
9.0	63.85	0.34	19.93	98 %
10.0	64.15	0.31	20.23	100 %

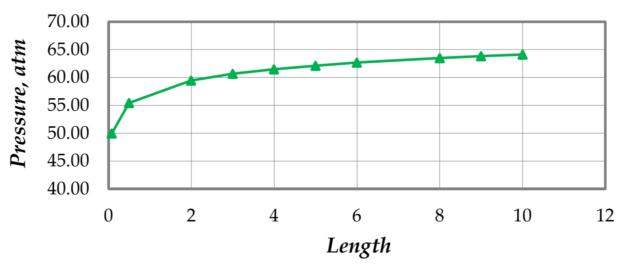

Fig. 7. The calculated pressure profile for various distances from the well

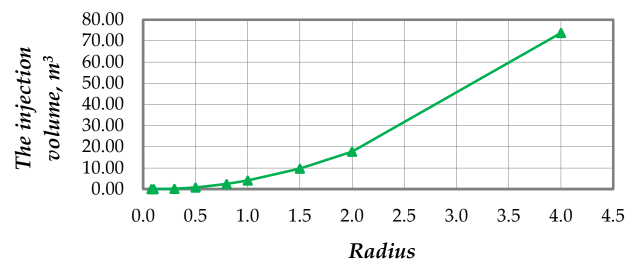

Fig. 8. The calculated required volume of reagent as a function of the treatment radius

ume of the water-isolation composition V for a particular well [9]. Knowing the specific cost (S_1, S_2, S_3, etc.) of each of the available water shut-off compositions, suitable in the existing geological and technical conditions, it is possible to calculate the costs S_Σ for each of the treatment options using the formula

$$S_\Sigma = V \cdot S_n \tag{2}$$

The technology variant with the lowest cost value S_Σ will provide the highest economic efficiency of the activity. The cost reduction will also be provided by the allowable (confirmed by calculations) reduction of water-isolation composition volume, not affecting the final result [10].

The developed methodology of planning water shut-off works was tested in a well with the geological and technical characteristics shown in table 4.

The following expressions were used in the calculations:

$$q_w = k \cdot (q_l - q_l \cdot (1 - B)) \tag{3}$$

где q_w is the water flow rate in the aquifer, m^3/day; q_l is the liquid flow rate in the well, m3/day, $м^3$/сут; B is the volumetric water cut of the well, unit fraction, д.ед; k – is the coefficient, taking into account the natural water cut of the target layer (under the condition that the target layer is oil-saturated, it is equal to 1, i.e. all water comes from the aquifer);

$$P(r) = P_{BHP} + \frac{q_w \cdot B_w \cdot \mu_w}{0.00708 \cdot k \cdot h} \cdot \ln\frac{r}{r_{well}} \cdot 0.130454 \tag{4}$$

где q_w is the water flow rate in the aquifer, m^3/day; k is the aquifer permeability, mD; h is the aquifer thickness, m; r_{well} is the well radius, m; B_w is the volume factor, unit fraction; μ_w is the water viscosity, cP.

The results obtained are shown in table 5 and figure 7.

The required volume of the water shut-off composition, depending on the radius of treatment, is found by the formula

$$V_{reac} = \pi \cdot r^2 \cdot h \cdot m \tag{5}$$

where r is the accepted treatment radius; h is the thickness of the aquifer; m – is the porosity of the layer.

The calculation results are shown in figure 8.

The following formulae were used to calculate the skin factor:

$$s = \left(\frac{K_s}{k} - 1\right) \cdot \ln\frac{R_s}{r_{well}} \tag{6}$$

where r_{well} is the well radius; R_s is the radius of treatment zone; k is the permeability of aquifer, mD; K_s is the permeability of skin zone and

$$K_s = k - k \cdot \left(\frac{100}{K_{iso}}\right) \tag{7}$$

The results obtained are shown in figure 9.

The following expressions were used in the calculations

$$q = \frac{0.00708 \cdot k \cdot h \cdot \left(P_{sp} - P_{bhp}\right)}{\mu \cdot B \cdot \left(\ln\frac{R_{erb}}{r_{well}} + s\right) \cdot 0.13} \tag{8}$$

The following expression was used to estimate the well flow rate and the reduction in water production after treatment (fig. 10).

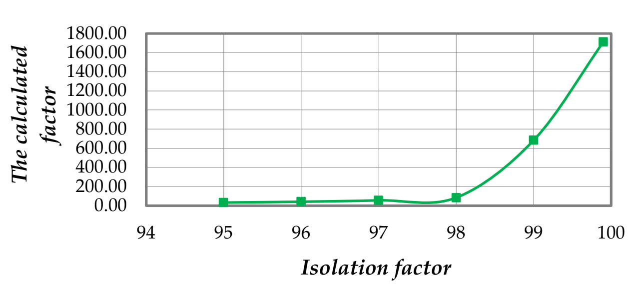

Fig. 9. The relationship between the skin factor and the isolation factor

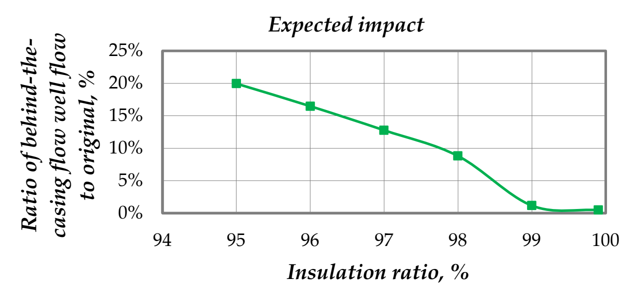

Fig. 10. The ratio of the water flow rate to the initial one as s function of the composition isolation factor

Results

Based on theoretical calculations, it was found that the required volume of injection of a water-isolation composition is mainly influenced by two factors - the strength characteristic of the composition and the required additional resistance in the bottom-hole zone of the aquifer [11-16]. At the same time, it is obvious that with an increase in the injection volume, the radius of the tr eatment zone increases, and the effect of water shut-off measures increases [17-19].

To analyze the impact of the isolation factor and the specific volume of treatment per meter of isolated thickness, analytical calculations were carried out using the proposed method. For calculations, the range of isolation factor was taken from 80 to 99%.

The calculation was carried out using the expressions (5)-(7), where skin factor is a function of isolation factor and reagent volume:

$$s\left(K_{isol}, V_{reac}\right) = \left(\frac{k - k \cdot \left(\frac{100}{K_{isol}} \right)}{k} - 1 \right) \cdot \ln \frac{\sqrt{\frac{V_{reac}}{\pi \cdot h \cdot m}}}{r_{well}} \qquad (9)$$

Herewith, the volume of water coming from the non-perforated interval is controlled by the achieved additional filtration resistance [20-22]. The water inflow is calculated using the expression (10)

$$Q_w = 0.00708 \cdot \frac{k_w \cdot h_w \cdot \left(P_{sp} - P_{bhp} \right)}{\mu_w \cdot B_w \cdot \left(\ln \frac{r}{r_{well}} + s \right) \cdot 0.130454} \qquad (10)$$

The calculation results are shown in figure 11. The calculated skin factors for various isolation factors are shown by dash-dotted lines, the calculated relationship between the flow rate and the skin factor is shown by the red line.

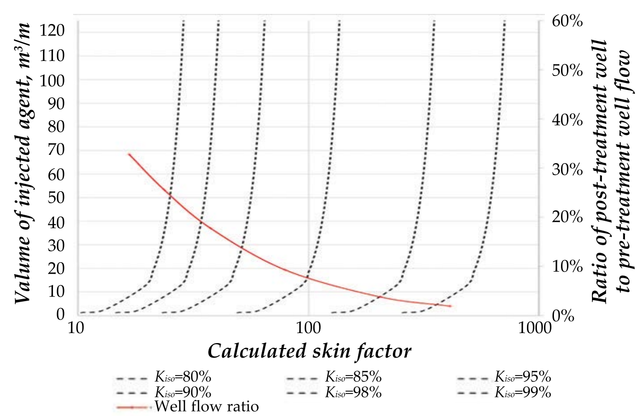

Fig. 11. Relationship between water flow rate and the composition volume

Conclusion

The obtained calculation results allowed us to make the following conclusions:

- The work results are influenced to a greater extent by the isolation factor rather than injection volume for isolation factors exceeding 90%;
- With injection volume higher than 12-15 m^3/m, the efficiency of further increase of the injection volume decreases, this is proved by flattening of injection volume-skin factor curves for any isolation factor;
- The technological effect of measures for water isolation from aquifer is used to restore the basic oil recovery.

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Метод определения эффективности водоизоляционных работ на примере создания гидродинамической модели

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Реферат

Важной задачей на этапе проектирования любого мероприятия, связанного с повышением нефтеотдачи пласта, в нашем случае ремонтно-изоляционных работ, является моделирование процесса, в частности, гидродинамическое моделирование. Оно дает возможность спрогнозировать параметры нефтеотдачи от применения технологии в процессе проектирования, тем самым снизить стоимость выполненных работ, и определить рентабельность и процент успешности планируемых мероприятий. В статье рассматривается оценка технологического и экономического эффекта с помощью, созданной двухфазной гидродинамической модели, имитирующей нефтенасыщенный и водоносный слои, приведены расчётные значения и графики зависимости скин-фактора для различных коэффициентов изоляции, а также график изменения дебита нефти и обводненности в зависимости от коэффициента изоляции состава.

Ключевые слова: водоизоляция; гидродинамическая модель; скин-фактор; коэффициент изоляции; водоприток.

Hidrodinamik modelin yaradılması nümunəsində suyun izolyasiya işlərinin effektivliyinin müəyyənləşdirilməsi üsulu

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Xülasə

Layın neft hasilatının artması ilə əlaqəqar hər hansı bir tədbirin layihələndirilməsi mərhələsində, baxılan məsələdə təmir və izolyasiya işlərinin vacib vəzifəsi prosesin modelləşdirilməsi, xüsusən də hidrodinamiki modelləşdirmədir. Layihə prosesində texnologiyanın istifadəsindən neftvermə parametrlərini proqnozlaşdırmağa və bununla da görülən işlərin dəyərini azaltmağa və planlaşdırılan tədbirlərin rentabelliyini və müvəffəqiyyət faizini təyin etməyə imkan verir. Məqalədə, neftlə doymuş və sulu təbəqəni təqlid edən yaradılmış iki fazalı hidrodinamik modelin köməyi ilə texnoloji və iqtisadi effektin qiymətləndirilməsi müzakirə olunur, müxtəlif izolyasiya əmsalları üçün hesablanmış dəyərlər və skin-faktorunun asılılıq qrafikləri, həmçinin tərkibin izolyasiya əmsalından asılı olaraq neft debitində və sulaşmada dəyişiklik qrafiki verilmişdir.

Açar sözlər: suyun izolyasiyası; hidrodinamik model; skin-faktor; izolyasiya əmsalı; su axını.