# ТЕХНИЧЕСКИЕ НАУКИ

## VOLUME ACCOUNTING OF WATER LEAKAGE INJECTED INTO THE STRIPE LIKE VISCOUS-PLASTIC OIL RESERVOIR IN PERIMETER AND MARGINAL ARTIFICIAL FLOODING

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## РАСЧЕТ ОБЪЕМА УТЕЧЕК ВОДЫ ЗАКАЧИВАЕМОЙ В ПЛАСТ ВЯЗКО-ПЛАСТИЧНОЙ НЕФТИ ПРИ ЗАКОНТУРНОМ И ПРИКОНТУРНОМ ЗАВОДНЕНИЯХ

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**Abstract**

In the article problems of development of striplike deposit of viscous-elastic oil have been considered.

In the considered deposit a row of injection water wells and a row of exploitation oil wells operate. In order to support layer pressure in the deposit the method of perimetr or marginal flooding is used. For assessment leakage of the water pumped into the layer of oil deposit of water- bearing zone hydrodynamic task has been solved and formulae for of a number of water injection wells have been derived. For determination of dayly water consumption of a number of injection wells passing into the water bearing deposit zone, debit of a number of exploitation wells is subtracted from dayly productivity of a number of injection wells.

In order to increase oil recovery of the given deposit it is recommended to carry out the following procedures:

1) it is necessary to carry out thermal processing of bore-hole zone of exploitation oil wells;

2) to pump dirty effluents produced in the oil field from the wells located in water-bearing deposit zone behind a number of water injection wells into the layer to form the field with high hydraulic resistance contaminating the layer in that zone.

**Аннотация**

В статье рассматривались задачи разработки полосообразной залежи вязко-пластичной нефти. В залежи работают один ряд нагнетательных водяных скважин и один ряд эксплуатационных нефтяных скважин. С целью поддержания пластового давления в залежи применяется метод законтурного или приконтурного заводнения. Для оценки утечки воды, закачиваемой в пласт в водоносную зону нефтяной залежи, решена гидродинамическая задача и выведены формулы для расчета суточной производительности ряда нагнетательных водяных скважин. Для определения суточного расхода воды ряда нагнетательных скважин, уходящей в водоносную зону залежи, из суточной производительности ряда нагнетательных скважин вычитывается дебит ряда эксплуатационных скважин.

С целью увеличения коэффициента нефтеотдачи данного месторождения рекомендуется осуществить следующие мероприятия:

1) провести термическую обработку призабойной зоны эксплуатационных скважин;

2) провести закачку сточных грязных вод нефтяного промысла по скважинам расположенным в водоносной зоне залежи за рядом нагнетательных водяных скважин для повышения гидравлического сопротивления этой части залежи.

**Key words**: viscous-plastic oil, initial pressure drop, absolute permeability, internal resistance, external resistance, natural flooding, artificial flooding, water leakage, a number of wells, production growth, strip like deposits, ultimate shear stress.

**Ключевые слова**: вязко-пластичная нефть, начальный перепад давления, внутреннее сопротивление, внешнее сопротивление, естественное заводнение, искусственное заводнение, ряд скважин, утечка воды, прирост добычи, полосообразная залежь, предельное напряжение сдвига.

It is known that artificial influence on the oil reservoir for supporting pressure and increasing oil recovery by pumping pure water through injection wells is carried out on various schemes. These development schemes are accepted for concrete geologico-physical conditions depending both on tectonic structure and geometrical sizes of deposits.

Practice and analysis of the development of oil fields show that methods of perimeter and marginal artificial flooding are widely spread.

It is necessary to mention that while carrying the methods of oil reservoir flooding the following cases can be observed:

-total volume of all fluids taken from productive layer per day is more than total volume of the pumped water into the well at the same time period;

-total volume of all extracted fluids and total volume of water injected into the reservoir at the same time period are the same;

-total volume of all extracted fluids is less than total volume of the water injected into the reservoir at the same time period of development.

In first two cases, all volume of the water injected into the reservoir take part in the process of displacement of oil to exploitation wells, that is, in productive zone there is no leakage of injected water into marginal water-bearing zone. Water leakage takes place only in the third case.

Leakage of water into the marginal zone is calculated as losses in the volumes of the water injected into the reservoir and losses in the volumes of extracted oil and gas.

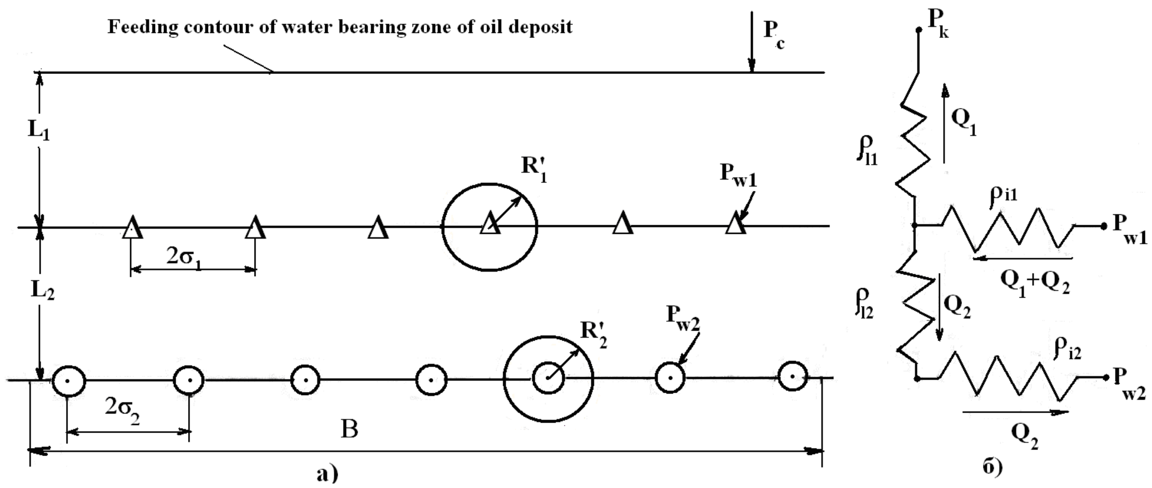
That's why, in oil and gas fields development it is necessary to work out and implement measurements on reducing the volume of water leakage injected into the layer which is a new improved method for oil recovery.

Measurements on the reducing the quantity of leakage of water injected into the Newtonian oil saturated reservoir in perimeter and marginal flooding have been suggested in work [1].

The method of determination of water leakage volume injected into the layer saturated with viscous-plastic oil in marginal and perimeter flooding has been suggested.

With this purpose the results of solution of hydrodynamic stationary task of development of horizontal stripe like deposit have been shown below. Here, layer homogeneous on permeability and power has been used and oil deposits have a row of water injection wells and a row of exploitation wells from which viscous-plastic oil is produced. The rows of the wells are located parallel to oil bearing contour. The row of injection wells is placed near to oil bearing contour and in $L_0$ distance from feeding contour of water bearing zone of the deposit. The distance between the rows of injection and exploitation wells is indicated as L.

Hydrodynamic task is solved by using hydrodynamic and electrical scheme of the given stripe like deposit of viscous-plastic oil and applying method of electro hydrodynamic analogue of the filtration theory and Kirchhoff law. For solving of this task it is necessary to derive formulae for calculation of both total daily consumption of the all injection water wells of $Q_1$ injection row and total daily discharge of all wells of $Q_2$ exploitation row.




*Fiq.1 The scheme of stripe like oil deposit where a row of oil exploitation wells and a row of injection wells operate*
*a) Hydrodynamic scheme of deposit, b) operate electrical scheme of the deposit*

We accept that the distance between injection wells in the row is equal to$2\sigma_1$, but between the exploitation ones it is$2\sigma_2$.

While developing the given stripe like field of viscous-plastic oil the difficult filtration flow of water injected into the layer and extraction of viscous-plastic oil from the layer take place. Precise solution of it has definite difficulties. That's why, for evaluation tasks solution by the approximate method is effective. Using the offered in [2], difficult filtration flows of water and viscous-plastic oil in the layer are divided into two following simple flows which take place consequently:

1) plane-radial withdrawal of water around the injection wells inside the circle with $R_1'$ radius,

2) plane-parallel withdrawal of water to the side of feeding contour of water bearing zone in $L_0$ distance,

3) plane-radial flow of viscous-plastic oil around the exploitation wells, inside the circle with $R_2'$ radius,

4) plane-parallel flow of viscous-plastic oil to the side of the row of producing wells in $L$ distance.

For calculation of values $Q_1$ and $Q_2$ following system of equations has been made up:

$$\begin{cases} P_{w1} - P_c = \rho_{i1}(Q_1 + Q_2) + \rho_{\ell 1}Q_1 \\ P_{w1} - P_{w2} - \Delta P_{01} - \Delta P_{02} = \rho_{i1}(Q_1 + Q_2) + (\rho_{\ell 2} + \rho_{i2})Q_2 \end{cases} \quad (1)$$

where $P_c$ is layer pressure, that's pressure in the feeding contour of water-bearing zone of deposit; $P_{w1}$ and $P_{w2}$ are well bottom pressures corresponding to injection water and exploitation oil wells; $\rho_{l1}$ and $\rho_{l2}$ are internal hydraulic resistances respectively to injection water and producing oil wells; $\rho_{i1}$ and $\rho_{i2}$ external hydraulic resistances of deposit areas corresponding to $L_0$ and $L$sizes; $\Delta P_{01}$ and $\Delta P_{02}$ are corresponding initial pressure drops at filtration of viscous-plastic oil on the way of $L$and in conditional drainage zone of producing wells with $R_2'$ radii.

Having solved the system of equations (1) formulae for calculation daily capacity of rows of injection and exploitation wells is found:

$$Q_1 = \frac{(\rho_{i1}+\rho_{\ell 2}+\rho_{i2})(P_{w1}-P_C)-\rho_{i1}(P_{w1}-P_{w2}-\Delta P_{01}-\Delta P_{02})}{(\rho_{i1}+\rho_{\ell 1})(\rho_{i1}+\rho_{\ell 2}+\rho_{i2})-\rho_{i2}^2} \quad (2)$$

$$Q_2 = \frac{1}{\rho_{i1}}[P_{w1} - P_C - (\rho_{i1} + \rho_{e1})Q_1] \quad (3)$$

Internal hydraulic resistances are expressed by the following formulae:

$$\rho_{i1} = \frac{\mu \, ln\frac{\sigma_1}{\pi r_w}}{2\pi kh}; \rho_{i2} = \frac{\eta \, ln\frac{\sigma_2}{\pi r_w}}{2\pi kh}$$

but external hydraulic resistances are expressed on formulae:

$$\rho_{e1} = \frac{\mu L_o}{2kh\sigma_1 n_1}; \rho_{e2} = \frac{\eta L}{2kh\sigma_2 n_2}$$

where $h$ -is effective power of productive layer, m; $r_w$-well radius, m; $k$ -absolute permeability of the layer on liquid, m$^2$; $\mu$ and $\eta$ -are correspondingly dynamic viscosity of water and structural viscosity of oil in layer conditions, Pa·s; $n_1$, $n_2$-are correspondingly number of wells in injection and exploitation rows; $L_0$-is the distance between the row of injection wells and feeding contour of water-bearing zone of deposit, m; $L$ - is the distance between the rows of the wells, m.

Initial pressure drops are expressed as follows:

$$\Delta P_{01} = \frac{167\cdot 10^{-4}\tau_0 L_0}{\sqrt{k'}}; \Delta P_{02} = \frac{167\cdot 10^{-4}\tau_0(R_2'-r_w)}{\sqrt{k'}}$$

where $\tau_0$ is limit stress of the displacement of viscous plastic oil in layer conditions, MPa; $k'$- is absolute permeability of the layer, determined on air, m$^2$.

The following values have been accepted for minimal errors in approximate hydrodynamic calculations using Y.P.Borisov scheme for radius of plane-radial flows around the wells:

$$R_1' = \frac{\sigma_1}{\pi}; R_2' = \frac{\sigma_2}{\pi}$$

In formula of external resistances for filtration area of all deposit the following expressions have been accepted:

$$F = Bh = 2\sigma_1 n_1 h = 2\sigma_2 n_2 h$$

where $B$ is the width of deposit, m.

The daily capacity of one injection well is found from formula (2) as follows:

$$q_1 = \frac{Q_1}{n_1}$$

and discharge of one exploitation oil well is determined from formula (3):

$$q_2 = \frac{Q_2}{n_2}$$

Below, number calculations for definite field conditions of the considered stripe like oil deposits have been given and daily capacity of the rows of injection and exploitation wells has been determined.

The following values of the initial data necessary for calculation have been accepted: deposit width $B = 3000$ m; distance $L_0$=100 m; $L$ =1500 m; halves of the distances between the wells in various rows are $\sigma_1 = 150$m; $\sigma_2 = 75$m; power of the layer is $h$ =5 m; permeability of the layer on liquid is $k$ =0,6·10$^{-12}$ m$^2$; absolute permeability of the layer on air is $k'$=3·10$^{-12}$ m$^2$; dynamic viscosity of water is $\mu$ =10$^{-9}$ MPa·s; structural viscosity of oil $\eta = 8 \cdot 10^{-9}$MPa·s; limited shear stress of oil is $\tau_0 = 2 \cdot 10^{-6}$MPa; layer pressure $P_k = 20$ MPa; well bottom pressure of operating injection water well is $P_{w1} = 25{,}0$MPa; dynamic well bottom pressure of exploitation oil well is $P_{w2} = 15{,}0$MPa; number of injection wells in the row is $n_1 = \frac{B}{2\sigma_1} = \frac{3000m}{300m} = 10$; number of exploitation oil wells in the row is $n_2 = \frac{B}{2\sigma_2} = \frac{3000м}{150м} = 20$.

Using geological field data we calculate internal and external hydraulic resistances:

$$\rho_{i1} = \frac{10^{-9} \cdot ln\frac{150}{3{,}14 \cdot 0{,}114}}{2 \cdot 3{,}14 \cdot 0{,}6 \cdot 10^{-12} \cdot 5} = 320{,}5\,\frac{MPa \cdot s}{m^3};$$

$$\rho_{i2} = \frac{8 \cdot 10^{-9} \cdot ln\frac{75}{3{,}14 \cdot 0{,}114}}{2 \cdot 3{,}14 \cdot 0{,}6 \cdot 10^{-12} \cdot 5} = 2269{,}6\,\frac{MPa \cdot s}{m^3};$$

$$\rho_{\ell 1} = \frac{10^{-9} \cdot 100}{2 \cdot 0{,}6 \cdot 10^{-12} \cdot 5 \cdot 150 \cdot 10} = 11{,}1\,\frac{MPa \cdot s}{m^3};$$

$$\rho_{\ell 2} = \frac{8 \cdot 10^{-9} \cdot 1500}{2 \cdot 0{,}6 \cdot 10^{-12} см^2 \cdot 5 \cdot 75 \cdot 20} = 1333\,\frac{MPa \cdot s}{m^3}$$

Initial pressure drops are calculated as follows:

$$\Delta P_{01} = \frac{167 \cdot 10^{-4} \cdot 2 \cdot 10^{-6} \cdot 100}{\sqrt{3 \cdot 10^{-12}}} = 1{,}93MPa$$

$$\Delta P_{02} = \frac{167 \cdot 10^{-4} \cdot 2 \cdot 10^{-6} \left(\frac{75}{3{,}14} - 0{,}114\right)}{\sqrt{3 \cdot 10^{-12}}} = 0{,}46MPa$$

Capacity of the row of injection wells is calculated as follows:

$$Q_1 = \frac{(320{,}5 + 1333 + 2269{,}6)(25 - 30) - 320{,}5(25 - 15 - 1{,}93 - 0{,}46))}{(320{,}5 + 11{,}1)(320{,}5 + 1333 + 2269{,}6) - 2269{,}6^2} =$$

$$= 0{,}0044644\,\frac{м^3}{c} = 385{,}7\,\frac{m^3}{day}$$

$$Q_1 = 385{,}7\,\frac{m^3}{day}$$

Daily capacity of one injection well will be:

$$q_1 = \frac{Q_1}{n_1} = \frac{385{,}7}{10} = 38{,}57\,\frac{m^3}{day}$$

The discharge of the row of producing oil wells is calculated as:

$$Q_2=\frac{1}{320{,}5}\left[25-20-(320{,}5+11{,}1)\cdot\frac{3923{,}1(25-20)-320{,}5(25-15-1{,}93-0{,}46)}{(320{,}5+11{,}1)\cdot 3923{,}1-2269{,}6^2}\right]=$$
$$=0{,}0202\,\frac{м^3}{c}=1745{,}3\,\frac{m^3}{day}$$

Discharge of one exploitation oil wells will be:

$$q_2=\frac{Q_2}{n_2}=\frac{1745{,}3}{20}=87{,}3\,\frac{m^3}{day}.$$

Total daily capacity of the row of injection water wells will be:

$$Q_1+Q_2=385{,}7+1745{,}3=2131\,\frac{m^3}{day}.$$

For determination of volume percent of water leakage $x$ from total volume of water injected into the layer the following proportion is made up:

2131,0 - 100 %

365,7 - $x$ %

From here, we find:

$$x=\frac{385{,}7\cdot 100}{2131{,}0}=18{,}1\%$$

As it is seen from the results of the calculations, $1/5$ part of the water injected into the layer flows to water bearing zone of the deposit.

Let's consider the case when viscous-plastic oil in other equal geologico-physical conditions has the following structural-mechanical properties: $\tau_o=2\cdot 10^{-5}\text{M}Pa$; $\eta=80\cdot 10^{-9}MPa$.

In above mentioned conditions values of hydraulic resistances $\rho_{i1}$ and $\rho_{e1}$ don't change, $\rho_{i2}$, $\rho_{e2}$ change, also values of initial pressure drops $\Delta P_{01}$ and $\Delta P_{02}$ change.

Changed values of these quantities have been shown below:
$\rho_{i2}=22696\,\frac{\text{M}Pa\cdot s}{m^3}$; $\rho_{\ell 2}=13330\,\frac{\text{M}Pa\cdot s}{m^3}$;
$\Delta P_{01}=19{,}3\text{M}Pa$; $\Delta P_{02}=4{,}6MPa$

Considering these changes capacities of the rows of wells have been calculated and the following values have been found: $Q_1'=2330{,}6\,\frac{m^3}{day}$; $Q_2'=1064{,}9\,\frac{m^3}{day}$.

Total capacity of the row of injection water wells will be:

$$Q_1'+Q_2'=2330{,}6+1064{,}9=3395{,}5\,\frac{m^3}{day}.$$

From these calculations it becomes evident that by the increase of structural and mechanical properties of viscous-plastic oil the leakage volume of the water injected into the layer increases and total daily capacity of the row of exploitation oil wells reduces.

## Conclusion

1. Hydrodynamic tasks of development of stripe like deposit of viscous plastic oil have been solved and formulae for determining daily capacity of the injection water wells row and debit of exploitation oil wells row have been derived. Difference of there capacities gives the value of consumption of water leakage into marginal water-bearing zone of deposit.

2. The following measures should be applied to increase of oil recovery coefficient of such oil deposit:

a) to realize heat methods influencing on the layer;

b) to form stripe like zone of high hydraulic resistance in water-bearing deposit behind the injection water wells by pumping field waste waters. Applying this measure on one hand ecological problem is solved, from other hand water leakage volume reduces.

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