Lecture 10-11-12

MAIN HYDRODYNAMIC CALCULATIONS UNDER SOLUTION GAS DRIVE

- Solution gas drive is manifested in the oil reservoir when the main force that moves the oil layer on to the **bottom-hole is the energy of the gas dissolved in oil**.
- Exploitation under the solution gas drive characterized by a low coefficient oil recovery. Therefore, this drive will develop are small-screened deposits, where creating a system maintaining reservoir pressure economically appropriate or impossible.

The hydrodynamic theory of oil deposits under the **solution gas drive** today is approximate and is based on **assumptions:**

- 1. The movement of oil and gas have taken flat in the absence of the field of gravitational forces.
- 2. Consider the horizontal layer, which dissolved gas reserves are taken evenly distributed and there is no possibility of accumulation of the gas cap.
- 3. Not captured surface forces between gas bubbles and oil.
- 4. Accepted thermodynamic equilibrium in the system “dissolved gas-oil”.

Analytical solutions are approximately listed in solder even assumptions. Field of the existence of this drive lies below the saturation pressure. Difficulty hydrodynamic calculations under the solution gas drive are that while **reducing the pressure below the saturation pressure of the oil released gas**. And accordingly, the porous medium is a two-phase filtration flow.

Definition of oil saturation at the end of the interval pressure changes

Determination development indicators under the solution gas drive is a difficult task because the drive is characterized in descending time formation pressure and change properties reservoir oil. To calculate development indicators (**flowrates, pressures, gas-oil ratio, oil recovery factor, time development**) must first determine the relationship between oil saturation and pressure. This dependence is expressed by an approximate formula which was obtained Zinovyeva. By the method, Zinovyeva calculations are performed in that order.

Record oil saturation formula for determining the end of interval pressure changes

$$\rho_{k_{i+1}} = \frac{\dfrac{\overline{\Gamma} - S(P_{K_i})}{\beta(P_{K_i})} \cdot \rho_{K_i} - (1 - \rho_{K_i}) \cdot \dfrac{P_{K_i}}{z(P_{K_i})} + \dfrac{P_{K_{i+1}}}{z(P_{K_{i+1}})}}{\dfrac{\overline{\Gamma} - S(P_{K_{i+1}})}{\beta(P_{K_{i+1}})} + \dfrac{P_{K_{i+1}}}{z(P_{K_{i+1}})}} \qquad (1)$$

where Γ- average gas-oil ratio (GOR) at the interval of change of pressure from P_{ki} to P_{ki+1} (P_{ki} - pressure at the beginning of the interval pressure changes; P_{ki+1} - the pressure at the end of the interval changes in pressure, and $P_{ki} > P_{ki+1}$);

$S(P_{ki})$, $S(P_{ki+1})$ - the amount of gas that is dissolved in the oil under pressures P_{ki} and P_{ki+1}, m^3/m^3;

ß(P_{ki}), ß(P_{ki+1}) – volume formation factor at the appropriate pressures;

$\rho_{k\,i}$- initial oil saturation;

$z(P_{ki})$, $z(P_{ki+1})$ – gas compressibility factor under the appropriate pressures.

The average gas-oil ratio at the interval of change of pressure is given by the formula

$$\overline{G} = \psi(\rho_{\kappa_i}) \cdot \frac{\overline{P}}{z(\overline{P})} \cdot \frac{\mu_{oil}(\overline{P})}{\mu_{gas}(\overline{P})} \cdot b(\overline{P}) + S(\overline{P}) \qquad (2)$$

Where $\overline{P} = \frac{P_{k_i} + P_{k_{i+1}}}{2}$ average pressure;

$\psi(\rho_{\kappa_i})$ - Tsarevich function, represents the ratio from relative permeability to gas (F_{gas}) to the relative permeability to oil (F_{oil})

$$\psi(\rho_{\kappa_i}) = \frac{\overline{F_g}(\rho)}{\overline{F_o}(\rho)}$$

(depending on the relative permeability at the table oil saturation).

The values of all parameters included in the formula (1) must substitute the average pressure. The pressure in the formula (1) and (2) must be a substitute in MPa.

Dependences reservoir properties of oil and gas from the saturation pressure are shown in Fig. 1.

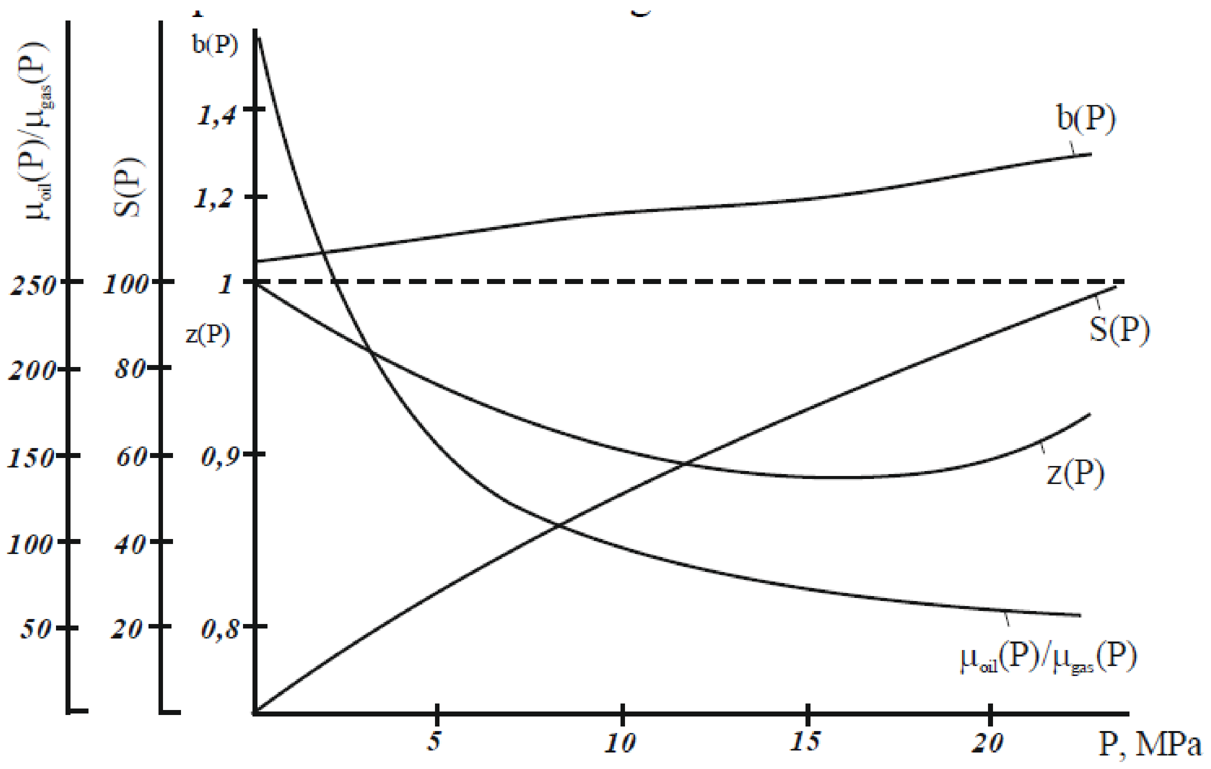

Fig. 1 - Dependences of the properties of reservoir oil and gas from saturation pressure

The procedure is the following calculations

- The whole interval of possible changes in the value of formation pressure is divided into small spaces.
- To ensure high accuracy of set pressure interval and $P_{k\,i}$ and $P_{k\ i+1}$ equal to 0.1-0.2 MPa. Practice shows that the smaller the interval between the commitments and values $P_{k\,i}$ and $P_{k\ i+1}$, the more precisely determined depending $\rho(P)$.
- In some cases, the amount of pressure $P_{k\,i}$ -$P_{k\ i+1}$ and can be increased and make 0.5-1.0 MPa. Then, set the initial value for the first interval oil saturation calculation (it is 1).
- From tables, Tsarevich determines Tsarevich function $\psi(\rho_{k_i})$

and for the graphics dependency of oil and gas properties define the parameters *S*, *b*, *z*, under appropriate pressures.

- Then determine the gas-oil factor formula (2) and the formula (1) determine oil saturation at the end of the selected interval pressure changes.
- Then move to the next interval changes in pressure, where the initial oil saturation serving predefined value.
- As a result of these calculations get graphic dependence (Fig. 2).

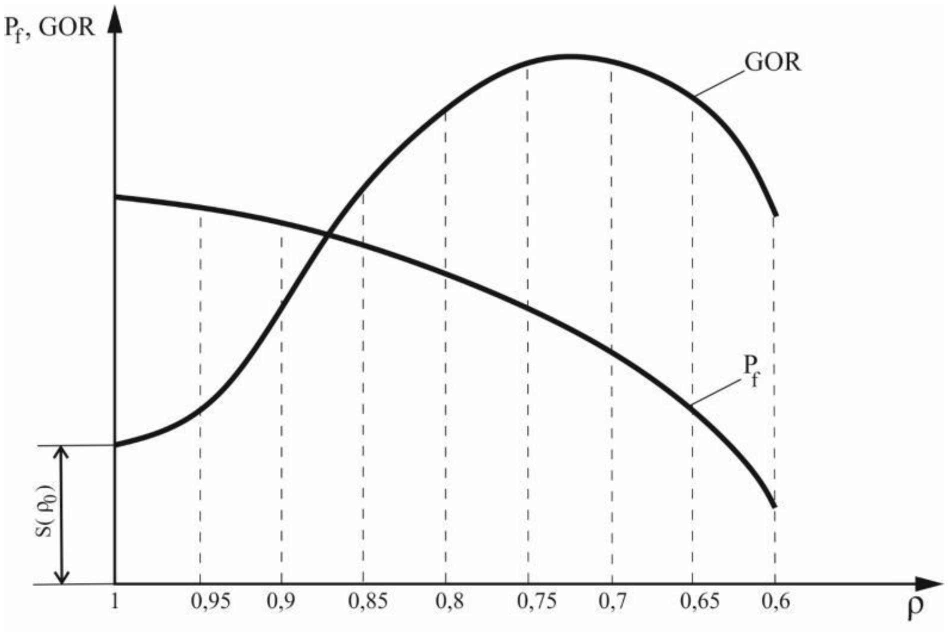

Fig. 2 – Dependence of average formation pressure and gas-oil ratio (GOR) from oil saturation

Condition ***Q*(*t*) = co**nst possible only for the **initial stage of development** of the field when the formation pressure is high and the condition of constant flow rate at the fountain and the mechanized methods, as in these conditions although a decrease in the formation and bottom-hole pressures, their value is still high and selection can be made adjustable oil.

At the **later stage of development**, when the formation and bottom-hole pressures do not provide flowing wells, and power mechanized method (increase immersion tubing or pump) is fully used, the condition of constancy exercise selection is not possible. Then justified wells in operation is ***Pвh* = c**onst.

Equation flow of oil from the reservoir into the well has the form

$$Q = \frac{2 \cdot \pi \cdot k \cdot h \cdot \left(H_f - H_{bh}\right)}{\mu \cdot \ln \frac{R_{db}}{r_w}} \qquad (4)$$

where $H_f - H_{bh}$ - Khristianovich difference functions; r_w - reduce the radius of well.

Khristianovich difference functions determined by the formula

$$H_f - H_{bh} = \int_{P_{bh}}^{P_f} \frac{F_{oil}(\rho)}{\mu_{oil}(P) \cdot b(P)} \cdot dP \qquad (5)$$

$$Q = \frac{2 \cdot \pi \cdot k \cdot h \cdot A \cdot \left(P_f - P_{bh}\right)}{\mu \cdot \ln \frac{R_{db}}{r_w}} \qquad (6)$$

$$Q = \frac{2 \cdot \pi \cdot k \cdot h \cdot \left(P_f - P_{bh}\right)}{\frac{\mu}{A} \cdot \ln \frac{R_{db}}{r_w}} \qquad (7)$$

Where $\frac{\mu}{A} = \mu_f$ fictional viscosity (8)

Using formulas (4) and (7), we get $\frac{1}{A} = \frac{P_f - P_{bh}}{H_f - H_{bh}}$

1/A- coefficient to increase filtration resistance due to the two-phase filtration flow.

Hlohovskyy, Rosenberg got the formula for determining the coefficient *A*

$A=0,944-21,43\alpha$,

where , $\alpha = \alpha_p \cdot \frac{\mu_g}{\mu_{oil}}$

α_p - solubility factor of gas in the oil.

Based on the formula (1) for more oil Zinovyeva was showed the possibility of approximation of the equation straight line

$$\frac{F_{oil}(\rho)}{\mu_{oil}(P) \cdot b(P)} = a \cdot P + в \qquad (9)$$

where *a* and *b* - approximation coefficients that are constant for a given oil and gas at a certain pressure.

There are two methods for determining coefficients *a* and *b*:

1) dependencies on graphics;

2) analytically.

To do this, we write the equation (9) for two values of P_{ki} and $P_{k\,i+1}$

$$\begin{cases} \dfrac{F_{oil}\left(\rho_{\kappa_i}\right)}{\mu_{oil}\left(P_{\kappa_i}\right)\cdot b\left(P_{\kappa_i}\right)} = a\cdot P_{\kappa_i} + в \\ \dfrac{F_{oil}\left(\rho_{\kappa_{i+1}}\right)}{\mu_{oil}\left(P_{\kappa_{i+1}}\right)\cdot b\left(P_{\kappa_{i+1}}\right)} = a\cdot P_{\kappa_{i+1}} + в \end{cases} \qquad (10)$$

Solving system of equations (10) determine the coefficients *a* and *b*. For this equation deducted from the first second. We have

$$a=\frac{\dfrac{F_{oil}(\rho_{\kappa_i})}{\mu_{oil}(P_{\kappa_i})\cdot b(P_{\kappa_i})}-\dfrac{F_{oil}(\rho_{\kappa_{i+1}})}{\mu_{oil}(P_{\kappa_{i+1}})\cdot b(P_{\kappa_{i+1}})}}{P_{\kappa_i}-P_{\kappa_{i+1}}} \qquad (11)$$

$$в=\frac{F_{oil}(\rho_{\kappa_i})}{\mu_{oil}(P_{\kappa_i})\cdot b(P_{\kappa_i})}-\frac{\dfrac{F_{oil}(\rho_{\kappa_i})}{\mu_{oil}(P_{\kappa_i})\cdot b(P_{\kappa_i})}-\dfrac{F_{oil}(\rho_{\kappa_{i+1}})}{\mu_{oil}(P_{\kappa_{i+1}})\cdot b(P_{\kappa_{i+1}})}}{P_{\kappa_i}-P_{\kappa_{i+1}}} \qquad (12)$$

Substituting (5) to (9) and following the integration, we get

$$H_f-H_{bh}=\frac{a}{2}\cdot\left(P_f^{\,2}-P_{bh}^{\,2}\right)+в\cdot\left(P_f-P_{bh}\right) \qquad (13)$$

Solving equation (13) for the expression of the bottom-hole pressure

$$P_f - P_{bh} = \left(-\frac{e}{a} + \sqrt{\left(\frac{e}{a}\right)^2 + \frac{2\cdot(H_f - H_{bh})}{a}}\right. \qquad (14)$$

$$P_{bh} = P_f + \frac{e}{a} - \sqrt{\left(\frac{e}{a}\right)^2 + \frac{2\cdot(H_f - H_{bh})}{a}} \qquad (15)$$

The proposed methodology for determining the flowrates at the set bottom hole pressures and determination of bottom hole pressures at the set flowrates.

Definition of validities under solution gas drive

Validities for condition ***Q*(*t*) = const** determined by the formula

$$t_{Q-const} = \frac{\Omega}{Q} \cdot \left[\frac{\rho_o}{b(P_o)} - \frac{\rho_{\kappa_{i+1}}}{b\left(P_{\kappa_{i+1}}\right)} \right] \qquad (16)$$

where Ω - pore volume per one well and determined by the formula

$$\Omega = \pi \cdot R_{db}^{\ 2} \cdot h \cdot m \qquad (17)$$

If the task solve for condition P_{bh} = const, then formulas (4), (7) changes for each interval pressure calculated average flowrate

- $$\bar{Q} = \frac{Q_{x_i} + Q_{x_{i+1}}}{2} \qquad (18)$$

- $$t_{P_{bh}-const} = \frac{-\Omega}{\bar{Q}} \cdot \left[\frac{\rho_{x_i}}{b(P_{x_i})} - \frac{\rho_{x_{i+1}}}{b(P_{x_{i+1}})} \right] \qquad (19)$$

The total validity determined by summing validities for intervals pressure changes

$$T_{P_{bh}-const} = \sum \Delta t_{P_{bh}-const} \qquad (20)$$

Placement of wells and oil recovery under solution gas drive

Under solution gas drive formation energy is evenly distributed around the oil areas and depends only on the amount of gas dissolved in a unit volume of oil. Placement of wells in the deposit must obey the following two conditions:

- 1) if the permeability of the layer area will put about the same, it is well placed for uniform grids;
- 2) the permeability of the layer area will put uneven, there is an increase in the consolidation grid of wells in the side of the layer permeability worse.

At the same formation parameters of the reservoir, as noted above, it is advisable to place production wells on the uniform grid, unless solution gas drive will be replaced by some other drive. Wells in this case placed on a square or triangular grids and formation divided into the same form of exclusion. Dimensions of form depending on the distance between the wells.

If the distance between the wells mark 2σ, then the square grid equivalent circle radius is

$$R_{k\Pi} = \frac{2\sigma}{\sqrt{\pi}} = 1{,}13\sigma \qquad (21)$$

and triangular grid

$$R_{k\Delta} = \frac{2\sigma\sqrt[4]{3}}{\sqrt{2\pi}} = 1{,}05\sigma \qquad (22)$$

Oil recovery factor under the solution gas drive is calculated using the pressure dependency of oil saturation

$$\eta = 1 - \frac{\rho_{ki} \cdot b_o}{\rho_0 \cdot b_{ki}} \qquad (23)$$

where ρ_{ki} and b_o – initial oil saturation and volume formation factor under saturation pressure;

ρ_0 and b_{ki} - oil saturation and volume formation factor under average pressure.

Final oil recovery factor depends on the properties of the formation of oil and gas, from the amount of gas dissolved in oil, and also the phase permeability. However, in all cases, the final oil recovery factor under solution gas drive is lower than the water drive.