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RESEARCH OF MULTICOMPONENT MIXTURE FILTRATION IN GAS-CONDENSATE RESERVOIR

1. INTRODUCTION

During the projecting of gas-condensate fields (GCF) development the main attention is paid to maximum extraction of propane-butane fractions [1]. In most of GCF the initial reservoir pressure is greater than the condensing pressure, therefore from the beginning their development is designed on depletion regime. The consecutive drop of reservoir pressure take place during the development process. The pressure gradient is necessary condition for fluid filtration, therefore first the pressure drops to condensation value within the depression cone near around production wells. Thus, an additional phase is appearing.

Figure 1 shows a theoretical character of additional flow phase (condensate) appearance.

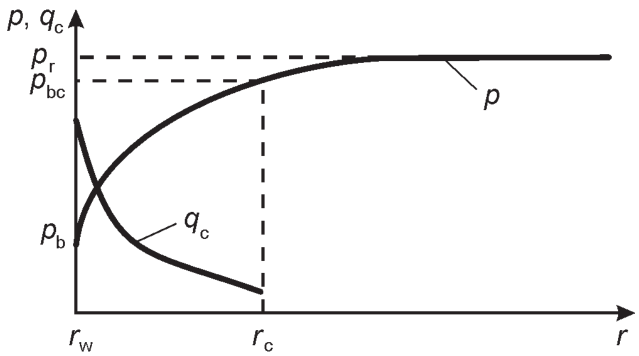

Fig. 1. Character of condensate quantity increase in the flow during gas-condensate mixture approach to the well: p_r – reservoir pressure, p_{bc} – pressure of the beginning of retrograde condensation, p_b – bottom-hole pressure, r_w – radius of the well

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It is clear that the character of $q_c(r)$ curve will depend on the properties (component contents) of gas-condensate mixture. The neglect of additional phase appearance during the projection of the development indexes usually take place. Only one phase (gas) or two phases (gas and water) are usually taking into consideration. Creation of new mathematical model for consideration of condensate phase in the flow is given in this paper.

The system of two differential equations for description of gas-condensate mixture filtration in the reservoir was proposed by Pykhachov and Isaev [2]. The equations were obtained based on Darcy's law of filtration and equation of continuity. This model doesn't consider actual phase transition during the pressure change and admits constancy of fluid properties in time.

The model presented in this paper is based on principles described in [3, 4] for calculation of non-isothermal and isothermal filtration of gas in porous medium within the presence of water. The author proposed to replace water by condensed gas. For simplification of the model only two phases (gas and condensate) are observed, without presence of water.

2. MATHEMATICAL MODEL

Given mathematical model includes three components (rock, gas, condensate) and two phases – a gaseous and a liquid. We will mark them as 0, 1 and 2, accordingly for the rock, gas and liquid (condensate). Flow velocities of gas and condensate will be v_1 and v_2, the rock is immovable, therefore $v_0 = 0$. Let us count, that Joule–Thomson effect in a wellbore zone is absent and arises directly in perforations (spasmodic decrease of temperature in the bottom-hole), that is, in the reservoir the isothermic filtration of gas-condensate mixture take place.

Equation of phase continuity will be written as:

$$\frac{\partial}{\partial t}(\rho_1 \alpha) + \operatorname{div}(\rho_1 \alpha \bar{v}_1) = \frac{1}{m}(I_{12} - I_{21}) \tag{1}$$

$$\frac{\partial}{\partial t}[\rho_2 (1-\alpha)] + \operatorname{div}[\rho_2 (1-\alpha) \bar{v}_2] = \frac{1}{m}(I_{21} - I_{12}) \tag{2}$$

where:

ρ_1, ρ_2 – densities of gas and condensate,
α – coefficient of gas saturation,
m – coefficient of porosity,
I_{12} – velocity of retrograde condensation,
I_{21} – velocity of retrograde evaporation.

Volumetric phase concentrations could be written as:

$$m_0 = 1 - m \tag{3}$$

$$m_1 = m\alpha \tag{4}$$

$$m_2 = m(1-\alpha) \tag{5}$$

Let us assume that filtration take place within the pressures $p_{be} < p < p_{bc}$ (p_{be} – pressure of the beginning of retrograde evaporation; p_{bc} – pressure of the beginning of retrograde condensation), therefore, $I_{21} = 0$. We will rewrite the equations (1) and (2) as:

$$\frac{\partial}{\partial t}(\rho_1 \alpha) + \operatorname{div}(\rho_1 \alpha \bar{v}_1) = \frac{1}{m} I_{12} \tag{6}$$

$$\frac{\partial}{\partial t}[\rho_2 (1-\alpha)] + \operatorname{div}[\rho_2 (1-\alpha) \bar{v}_2] = \frac{1}{m} I_{12} \tag{7}$$

Assuming that the density of gas and condensate stay constant, in this case the equation of momentum conservation is the following:

$$m\rho_1 \alpha(p)\frac{d\bar{v}_1}{dt} + \operatorname{grad}(m\alpha(p)p) - m\rho_1 (\bar{F}_1 + \bar{R}_1)\alpha(p) - \bar{v}_1 I_{12} = 0 \tag{8}$$

$$m\rho_2 [1-\alpha(p)]\frac{d\bar{v}_2}{dt} + \operatorname{grad}(m[1-\alpha(p)]p) - m\rho_2 (\bar{F}_2 + \bar{R}_2)[1-\alpha(p)] + \bar{v}_2 I_{12} = 0 \tag{9}$$

where:

p – pressure in the system gas-condensate,
$\bar{F}$ – real mass forces,
$\bar{R}$ – resultant of fictitious mass forces.

Fictitious mass forces of resistance for every phase are:

$$\bar{R}_1 = -\frac{\mu_1 m_1 \bar{v}_1}{k k_1' \rho_1} + \frac{p}{m_1 \rho_1}\operatorname{grad} m_1 \tag{10}$$

$$\bar{R}_2 = -\frac{\mu_2 m_2 \bar{v}_2}{k k_2' \rho_2} + \frac{p}{m_2 \rho_2}\operatorname{grad} m_2 \tag{11}$$

where:

k – reservoir permeability,
k_1', k_2' – relative phase permeability for gas and condensate.

Let us label as k_1 i k_2 the permeability for corresponding phases, that is $k_1 = kk_1'$, $k_2 = kk_2'$.

First items in formulas (10) and (11) are characterize the Darcy's law, the second – forces of resistance, that appear due to expansion of porous medium.

The biggest problem is determination of phase permeability. The best and most accurate method – conducting of laboratory experiments. Unfortunately, in Ukraine such kind of experiments on determination of phase permeability for condensate were never done and scarcely will be conducted in the nearest future. For approximate calculations of gassed liquid filtration we can use a method given in [2].

Putting (10) and (11) into (8) and (9) we will get:

$$\bar{v}_1 = -\frac{k_1}{m_1\mu_1}\text{grad}\, p = -\frac{k_1}{m_1\mu_1}\frac{dp}{dr} \quad (12)$$

$$\bar{v}_2 = -\frac{k_2}{m_2\mu_2}\text{grad}\, p = -\frac{k_2}{m_2\mu_2}\frac{dp}{dr} \quad (13)$$

Because the components located in one thermodynamic medium, the equation of energy conservation can be given as

$$C\frac{\partial T}{\partial t} = \text{div}[\Lambda \text{grad}\, T] - \overline{W}\,\text{grad}\, T + Q \quad (14)$$

where:

- T – absolute temperature of the medium,
- C – averaged thermal capacity,
- Λ – averaged thermal conductivity,
- $\overline{W}$ – averaged vector of convective heat transfer.

$$C = (1-m)c_0\rho_0 + m\alpha(p)\rho_1 c_{p1} + m[1-\alpha(p)]\rho_2 c_{p2} \quad (15)$$

$$\Lambda = (1-m)\lambda_0 + m\alpha(p)\lambda_1 + m[1-\alpha(p)]\lambda_2 \quad (16)$$

$$\overline{W} = m\alpha(p)\rho_1 c_{p1}\bar{v}_1 + m[1-\alpha(p)]\rho_2 c_{p2}\bar{v}_2 \quad (17)$$

where:

- c_{pi} – coefficient of isobaric thermal capacity for *i* phase,
- λ_i – coefficient of thermal conductivity for *i* phase.

In case, if we neglect the heat that eliminates during phase change, than in equation (14) $Q = 0$.

Thus, we got five differential equations (8), (9), (12)–(14), that include 7 unknown parameters: ρ_1, ρ_2, $\bar{v}_1$, $\bar{v}_2$, $\alpha(p)$, p, T. We should write two additional equations. The first – equation of state of gas phase for the condition $p = p_1 = p_2$, second for determination of gas saturation, based on laboratory research of gas-condensate mixture

$$p = z_1(p,T)\frac{\rho_1 RT}{M_1} \quad (18)$$

$$\alpha(p) = 1 - \int_{p_{bc}}^{p} q_c(p)dp \quad (19)$$

where:

$z_1(p, T)$ – gas-compressibility factor,
R – absolute gas constant,
M_1 – averaged molecular mass of reservoir gas,
q_c – condensate factor.

The graphic dependence for formula (19), based on laboratory research, is usually given in form shown on Figure 2.

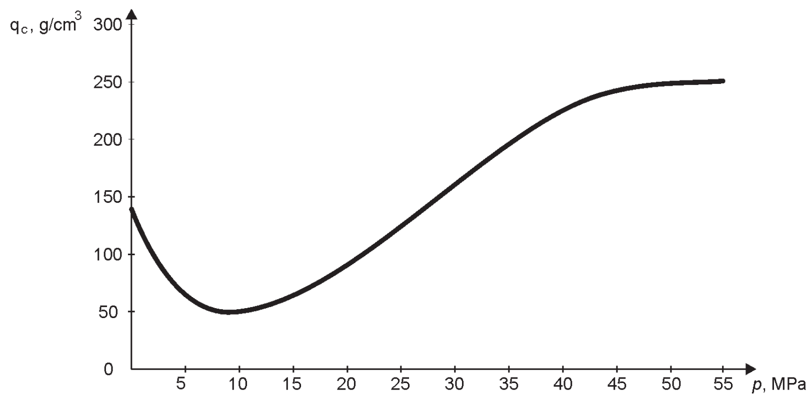

Fig. 2. Character of condensate content curve in reservoir gas depending on pressure

3. CONCLUSIONS

The system of differential equations that describes the process of simultaneous filtration of gas and condensate is given in this paper. The deficiencies of this calculation method are difficulty for practical application during filtration process calculation due to even impossibility of mathematical or physical description of the following properties: velocity of retrograde condensation, mass forces, averaged vector of convective heat transfer, phase permeability for gas and condensate. It doesn't consider thermal effects during change of phase, change of component composition with change of pressure. Given mathematical model allows complex description of complicated filtration process of gas-condensate mixture during retrograde condensation and can be realized in future for practical industrial calculations.

REFERENCES

[1] Zakirov S.N.: *Theory and design of gas and gas-condensate fields development: Study book for higher education establishments*. Moscow, Nedra 1989, 334 p (in Russian)

[2] Pykhachov G.B.: *Underground hydraulics*. Study book. Moscow, Nedra 1972, 360 p (in Russian)
[3] Bondarev E.A., Babe G.D., Groysman A.G., Kanibolotskiy M.A.: M*echanics of hydrates formation in gas flows*. Moscow, Nauka 1976, 159 (in Russian)
[4] Zakirov S.N., Somov B.E., Gordon V.Ya. *et al*.: *Multidimensional and multicomponent filtration: Reference book*. Moscow, Nauka 1988, 335 (in Russian)