ANAS Transactions **Earth Sciences** **Special Issue / 2023**

http://www.journalesgia.com

ALGORITHM FOR DETERMINING THE OPTIMAL COORDINATES OF THE WATER-SHUTOFF COMPOSITION IN THE BOTTOMHOLE ZONE

Suleimanov B.A., Jamalbayov M.A., Ibrahimov Kh.M.

SOCAR OilGasScientificResearchProject Institute: mehemmed.camalbeyov@socar.az

Keywords: *watering, water shut-off, optimal placement, mathematical modeling*

Summary. Watering is one of the main problems in the development of oil and gas fields. Regardless of the principle of technology, one of the indicators of the effectiveness of water shut-off methods is the stability time of the water shielding. The water shielding stability time, apart from other factors related to the water shielding composition itself and the porous medium, also depends on the distance of the water shielding zone from the well. Distances that are too remote, where the flow rates are much lower, require significant costs. And near, due to high speeds, the probability of destruction of the water shielding zone is much higher. Therefore, determining the optimal distance of the water shielding zone from the well is of interest. The purpose of this study is the development a mathematical model for the determination of the optimal distance of the water-shielding zone from the well.

Introduction

Watering is one of the main problems in the development of oil and gas fields. It leads to serious problems both technically and economically and technologically. Firstly, watering affects the productivity of production wells and reduces their service life. The presence of water in the wellbore increases the weight of the liquid column, which leads to an increase in the power consumption of the lift, increases operating costs. Watering also contributes to the formation of scale, corrosion and degradation of field structures, from the wellbore to surface structures. Another serious problem associated with watering is the increased requirement for the separation, purification and disposal of formation water, leading to an increase in the cost of oil produced (Taha, Amani, 2019). Therefore, the development of existing and the creation of more effective methods for preventing and reducing the inflow of formation water to the well is one of the urgent problems in the development and operation of oil and gas fields. To combat watering, there are various technologies for influencing the reservoir and the bottomhole zone. However, they are connected by one common drawback – the fragility of the created insulation as a result of its flushing under the influence of formation fluid flows. Regardless of the principle of technology, one of the indicators of the effectiveness of water shut-off methods is the stability time of the water shielding. This is the time during which the shielding does not lose (or loses slightly) its functionality. This parameter, in addition to being a purely characteristic of the shielding composition itself, depends on the reservoir pressure and fluid flow rate in the reservoir. Therefore, the isolation screen should be located at such a distance from the well (see Fig. 1) where the fluid flow rate does not exceed the critical value. It should be noted that with increasing distance, the flow velocity becomes lower, but the consumption of the shielding composition and energy costs increase. Therefore, the determination of the minimum (critical) distance along the radius from the well of the treatment zone by the criterion of critical speed is of interest.

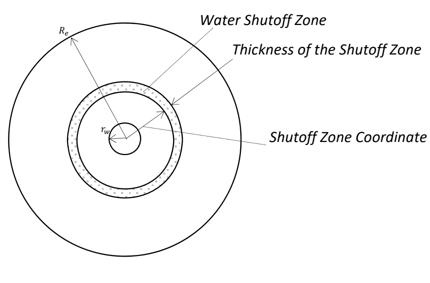

Fig. 1. The layout of the water-shutoff zone around the well draining the zone with a radius of R_e

The paper is devoted to this particular issue - the issue of determining, on the basis of a mathematical model of oil filtration in a porous reservoir, the minimum distance of the treatment zone around the well, where the flow rate is not greater than the critical velocity, at which this sheilding composition begins to lose its function. For this purpose, we use the Binary flow model, taking into account the deformation of the reservoir rocks, the PVT properties of the hydrocarbon system, and the mass transfer between the phases. Below we propose a solution to the problem under consideration.

Mathematical model

The equations of motion for oil, gas and water (assuming that there is no mutual solubility of oil-water and gas-water) in a porous medium based on the Binary Model are written in the following form, respectively:

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\varphi_g(p,s_g)\frac{\partial p}{\partial r}\right] = -\frac{\partial}{\partial t} f_g(p,s_g), \tag{2.1}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\varphi_o(p,s_o)\frac{\partial p}{\partial r}\right] = -\frac{\partial}{\partial t} f_o(p,s_o), \tag{2.2}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\varphi_w(p,s_w)\frac{\partial p}{\partial r}\right] = -\frac{\partial}{\partial t} f_w(p,s_w), \tag{2.3}$$

where

$$\varphi_o(p,s_o) = \left[\frac{k_{ro}(s_o)}{\mu_o(p)B_o(p)} + \frac{k_{rg}(s_o)\,p\beta c(p)}{\mu_g(p)z(p)p_{at}}\right]k(p), \tag{2.4}$$

$$\varphi_g(p,s_g) = \left[\frac{k_{rg}(s_g)\,p\beta[1-c(p)\gamma(p)]}{\mu_g(p)z(p)p_{at}} + \frac{k_{ro}(s_o)R_s(p)}{\mu_o(p)B_o(p)}\right]k(p), \tag{2.5}$$

$$\varphi_w(p,s_w) = \left[\frac{k_{rw}(s_w)}{\mu_w(p)B_w(p)}\right]k(p), \tag{2.6}$$

$$f_o(p,s_o) = \left[\frac{s_o}{B_o(p)} + s_g\frac{p\beta c(p)}{z(p)p_{at}}\right]\phi(p), \tag{2.7}$$

$$f_g(p,s) = \left[\frac{s_g p\beta[1-c(p)\gamma(p)]}{z(p)p_{at}} + s_o\frac{R_s(p)}{B_o(p)}\right]\phi(p),$$

$f_w(p,s_w) = s_w\dfrac{\phi(p)}{B_w(p)}$; k – initial and current permeability, $10^{-12}m^2$; $k_{ro}(s_o)$, $k_{rg}(s_g)$, $k_{rw}(s_w)$ – relative phase permeability for oil, gas and water; ϕ – initial, current porosity; s_o, s_g, s_w – pore saturation with oil, gas and water; $s_g + s_o + s_w = 1$; μ_o, μ_g, μ_w – the viscosities of oil, gas and water, $atm \cdot s$; Parameters with indices g, o, w correspond to gas, oil and water, respectively.

Equations (2.1), (2.2) and (2.3) describe the filtration of oil, gas and water in the reservoir. They take into account the mutual dissolution of oil and gas, the PVT properties of the hydrocarbon system, the deformation of the reservoir, resulting in changes in porosity and permeability. It is assumed that gas and oil do not dissolve in water.

Since the main production of the well is oil, therefore, equation (2.1) is considered, which is solved using the methodology presented in (Aliev et al., 2010) and an expression for the flow rate in general form is obtained:

$$q = \frac{2\pi h(H_e - H_w)}{\ln\frac{R_e}{r_w} - \frac{1}{2}}, \tag{2.8}$$

where

$$H = \int \varphi\ (p,s)dp + const, \tag{2.9}$$

H_e, H_w are the values of the H function on the boundary of the well drainage zone and at the bottomhole, respectively.

To apply (2.8), it is necessary to determine the pseudo depression $(H_e - H_w)$, for which the integrand φ in (2.9) is approximated by the following polynomial of the second degree: $\varphi(p,s) = ap^2 + bp + c$

In this case, from (2.9) to determine $(H_e - H_w)$, the following formula is obtained:

$$H_e - H_w = \frac{a}{3}(p_e^3 - p_w^3) + \frac{b}{2}(p_e^2 - p_w^2) + c(p_e - p_w) \tag{2.10}$$

Here, the coefficients a, b and c are determined by the values of the φ function on the boundary of the well drainage zone and at the bottomhole as follows:

$$a = \frac{(\tilde{\varphi} - \varphi_w)(p_e - p_w) - (\varphi_e - \varphi_w)(\tilde{p} - p_w)}{(p_e - p_w)(\tilde{p} - p_w)(\tilde{p} - p_e)},\ b = \frac{(\varphi_e - \varphi_s) - a(p_e^2 - p_w^2)}{p_e - p_w},\ c = \varphi_w - ap_w^2 - bp_w, \tag{2.11}$$

where φ_e, φ_w and $\tilde{\varphi}$ are the values of the φ function on the boundary of the well drainage zone, at the bottomhole and the average value, respectively; $\tilde{\varphi} = \varphi(\tilde{p}, \tilde{s})$, $\tilde{p} = \frac{p_e + p_w}{2}$.

Let us rewrite (2.8) taking into account (2.10) as follows:

$$q = \frac{2\pi h\left[\frac{a}{3}(p_e^3 - p_w^3) + \frac{b}{2}(p_e^2 - p_w^2) + c(p_e - p_w)\right]}{\ln\frac{R_e}{r_w} - \frac{1}{2}} \tag{2.12}$$

For the formation cross section at r, the flow rate:

$$q = vS = v \cdot 2\pi rh \tag{2.13}$$

Assuming the constancy of the flow rate in a fairly short distance around the well with a radius of r_w, we write from equalities (2.12) and (2.13) as follows:

$$v \cdot 2\pi rh = \frac{2\pi h\left[\frac{a}{3}(p_e^3 - p_w^3) + \frac{b}{2}(p_e^2 - p_w^2) + c(p_e - p_w)\right]}{\ln\frac{R_e}{r_w} - \frac{1}{2}}$$

From here we get an expression for determining the filtration rate along the cross section of the reservoir with the r radius at the $p_e - p_w$ drawdown:

$$v = \frac{\left[\frac{a}{3}(p_e^3 - p_w^3) + \frac{b}{2}(p_e^2 - p_w^2) + c(p_e - p_w)\right]}{r\left(\ln\frac{R_e}{r_w} - \frac{1}{2}\right)} \tag{2.14}$$

Using expression (2.14), it is possible to determine the optimal coordinates of the screen if the critical filtration rate for a given shielding composition is known in advance, above which the composition is washed out:

$$r_{opt} = \frac{\frac{a}{3}(p_e^3 - p_w^3) + \frac{b}{2}(p_e^2 - p_w^2) + c(p_e - p_w)}{\left(\ln\frac{R_e}{r_w} - \frac{1}{2}\right)\tilde{v}} \tag{2.15}$$

Having data on the well flow rate (q), it is possible obtain a similar expression from (2.14) by multiplying the denominator and numerator by $2\pi h$ and taking into account (2.12) in the following form: $v = \frac{q}{2\pi hr}$, and so: $r_{opt} = \frac{q}{2\pi h\tilde{v}}$

Results of computer study and conclusions

On the basis of (2.14), taking into account (2.11) and the necessary relations, some computer studies were carried out, the results of which are shown in Fig. 2. Note that as data on the stability of the shielding composition, a hypothetical dependence of the stability time on the oil flow rate was used. All calculations were performed at a constant depression of 20 atm. Fig. 2 shows the curves of the change in flow rate from the distance around the well at reservoir pressure of 245 atm (blue curve), 163 atm (red curve) and 123 atm (blue curve) calculated by expression (2.14). According to these data, it can be seen that with distance from the well, the flow rate drops sharply, but after 1.0-1.5 meters, in this case, the rate reaches a minimum value and practically does not change. In addition, it can be seen that the higher the reservoir pressure, the greater the filtration rate, despite the identity of the drawdowns in the variants.

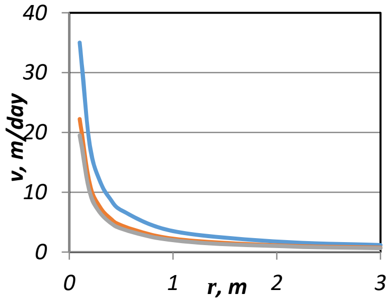

Fig. 2. Curves of changes in flow rate from distance around the well at reservoir pressure of 245 atm (blue curve), 163 atm (red curve) and 123 atm (green curve)

Nomenclature

a_m – is a rock compacting factor, $1/atm$; z, β – z-factor and gas temperature factor; c – content of potentially liquid hydrocarbons in the gas phase, m^3/m^3; B_o, B_w – volume factor of oil and water; s –solubility of gas in liquid, m^3/m^3; p_0, p – initial and current reservoir pressure, atm; p_{at} – atmospheric pressure, atm; p_w = bottom-hole pressure, atm; p_e – pressure at the external boundary, atm; $\bar{\gamma} = \dfrac{\gamma_o(p)}{\gamma_g(p)}$ – ratio of the specific gravities of oil and gas at reservoir pressure; r – radial coordinate; R_e – well drainage area radius, m; r_w – wellbore radius, m; v – velocity, m/s; h – formation thickness, m; t – time, s.

REFERENCES

Taha A., Amani M. Overview of Water Shutoff Operations in Oil and Gas Wells; Chemical and Mechanical Solutions. ChemEngineering, Vol. 3, 2019, 51, DOI:10.3390/chemengineering3020051.

Aliev F.A., Jamalbayov M.A., Nasibov S.M. Mathematical modeling of the well-bed system under the gaslift operation. TWMS Journal of Pure and Applied Mathematics, Vol. 1, No.1, 2010, pp. 5-14.

Suleimanov B.A., Ismailov F.S., Veliyev E.F., Dyshin O.A. The influence of light metalnanoparticles on the strength of polymer gels used in oil industry. SOCAR Proceedings, No. 2, 2013, pp. 24-28.