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Study of the process of changing of the bottom hole pressure in time under the conditions of gaslift flowing

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SUMMARY

The paper puts forward the calculation of the change in time of the minimum downhole pressure of flowing due to the joint interaction of the well and the oil pool under the dissolved gas regime, as well as the method of calculating the conditions of joint operation of the oil pool and the folowing well. The method is based on solving the equations of fluid filtration in the oil pool and the movement of gas-oil flow in the wellbore.
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Introduction

Technological operational efficiency of the production wells depends on the degree of the use-up of the oil pool energy, which is going into the well from the oil pool, and it is connected to the work of the oil pool. The current amount of this energy is variable over time, especially in the mode of dissolved gas, and under such conditions, the energy characteristics of the process of rising oil in the well change (Boiko, 2008).

Method and Theory

The study of the coordination of the work of two consecutive elements of a closely-linked process of oil field exploitation (i.e. oil field and production well) has conducted by a number of researchers at a certain point in time, mostly at the end of the well flowing period in which it can also be observed corrosive degradation of tubing (Boiko, 2008, Basnyev, 2005). However, a problem of coordination of work of these elements in time (during a long period of "life" of the well) has not been adequately covered in the specialized literature (Suyarko, 2015, Baturyn, 2016). This paper studies the issue of joint mutually coordinated operation of a flowing well and an oil pool, under the existing regime of dissolved gas in the oil pool, when the inflow of oil to the well is not stable, the time frame is varying, and, therefore, the process of well flowing is varying as a result of not stable supply of the reservoir energy. This makes it possible to determine the change in time of the minimum down hole pressure.

The process of oil extraction from the well under the regime of dissolved gas is projected either according to the analytical techniques (Boiko, 2008, Baturyn, 2016), irrespective of the manner and nature of the oil wells exploitation (on the condition of an initially constant flow rate and, consequently, the constant down hole pressure), or by the numerical mathematical model (Boiko, 2011) — without taking into account the nature of the rising gas-liquid flows in the well. It is technologically and technically difficult to operate wells under such conditions (for example, there are required automatic regulators of gas oil flow or down hole pressure) and it is practically inexpedient (Kachmar, 2004).

The development of the oil pool under the dissolved gas regime, according to the analytical method is based on the correlation between the pressure in the oil pool and the oil saturation of the pore space. This dependence is illustrated by a nonlinear differential equation, which is solved by the method of successive change of steady states. One of the proposed ways to solve the equation is the simplest and the most acceptable method for engineering calculations, the widely used method of L.A. Zinovieva. This method determines the average down hole pressure, which equals to the pressure on the external boundary of a well, as well as oil saturation, gas factor and oil recovery factor. Further calculation of flow rates, pressure depressions and duration of the process of depletion of the oil pool depends on the following specified boundary conditions on the well boundary: a) a constant down hole pressure is set, then the time variable flow rates of the well are calculated; b) a constant oil flow rate is set (water content of the product in the dissolved gas mode equals to zero), and the time-varying down hole pressure is calculated. The pattern pressure in both cases is variable and connected to the oil saturation of the oil pool (or, alternatively, with the total extraction of oil). The duration of the process of the oil deposit extraction, as well as all technological indicators of extraction, are variable over time, and they are interconnected through the equation of material balance for oil. In both cases, either the flow rate of the well (at a given downhole pressure) or downhole pressure (at a given flow rate) are determined by a formula derived from the Dupuis formula with a variable productivity factor, which depends on the conditions of the oil deposit (Baturyn, 2016). Similar situation presents itself when the numerical model is calculated (Boiko, 2011). Still, there is no specification on the point whether it is be possible to raise this oil flowing into the well from the bottom to the surface, i.e. the work of the oil deposit is not consistent with the work of the next element, i.e. the production well, as the only inseparable process of oil production.

Gas lifting condition of the flow well of the third type where there has begun the process of gas exhaustion in the producing payout bed is given as effective gas factor G_{eff} [Boiko, 2008]:

$$G_{\text{eff}} \geq R_{0\text{opt}}\,, \tag{1}$$

or in the expanded view

$$\left[G_0 - \alpha_s\left(\frac{p_{\text{bh}} + p_2}{2} - p_0\right)\right](1 - n_w) \geq \frac{0,282L\rho g\left[L\rho g - (p_{\text{bh}} - p_2)\right]}{d^{0,5}(p_{bh} - p_2)\,p_0 \ln\dfrac{p_{bh}}{p_2}}\,, \tag{2}$$

де $R_{0\text{opt}}$ – specific gas consumption required for fluid lifting in a well; G_0 – operational gas factor; α_s – coefficient of solubility of gas in oil; p_{bh} – downhole pressure; p_2 – pressure at the mouth (on emission) of the well (connects the work of the well with the system of gathering and transportation of products in the field); p_0 – standard pressure; n_{w} – water content of products (in the mode of dissolved gas it mostly shows as $n_{\text{w}} = 0$); L – length of tubing in the well (in wells of the third type tubing should be lowered to the middle of the interval of inflow of liquid, i.e. to the middle of the interval of perforation); d – inner diameter of the tubing (for preliminary calculations one can set a priori depending on the flow rate; nominal diameter, which is set, usually equals to 73 mm); ρ – average density of oil in a well; g – free fall acceleration.

To substantiate the nature of the flowing well in terms of self-regulation with the operation of the formation, we limit ourselves to the probability-statistical cumulative S — similar growth curve, such as the Gompertz curve to describe the change in the accumulated operational gas factor $\overline{G_0}(t)$ over time t:

$$\overline{G_0}(t) = G_{00} + Ae^{-ae^{-bt}}\,, \tag{3}$$

where G_{00} stands for the operational gas factor at a time $t = 0$, which is equal to the formation gas-oil ratio (or, alternatively, the gas saturation of formation oil); A, a, b – constant coefficients.

After a series of calculations, the flowing condition looks like:

$$\left(G_{00} + Aabe^{-b\cdot t_1}e^{-a\cdot e^{-b\cdot t_1}}\right) - \alpha_s\left(\frac{p_{\text{bh}} + p_2}{2} - p_0\right) = \\ = \frac{0,282L\rho g\left[L\rho g - (p_{bh} - p_2)\right]}{d^{0,5}(p_{bh} - p_2)\,p_0 \ln\dfrac{p_{bh}}{p_2}}\,, \tag{4}$$

or

$$G_{\text{eff}}\left[p_{\text{bh}}(t)\right] \geq R_{0\text{opt}}\left[p_{\text{bh}}(t)\right], \tag{5}$$

therefore, we find the downhole pressure p_{bh} as a function of time t, that is

$$p_{\text{bh}} = p_{\text{bh}}(t)\,. \tag{6}$$

Having the value of the downhole pressure p_{bh}, that depends on t under the condition of gaslift flowing (Suyarko, 2015), one can create its graphical interpretation and find the minimum downhole flowing pressure. Figure 1 shows the results obtained.

Figure 1 demonstrates that the graph of gas consumption $R_0(p_{\text{bh}})$ shifts along the vertical depending on the accepted values of the diameter of the tubing d and well mouth pressure p_2. Effective gas factor $G_{\text{eff}}(p_{\text{bh}})$ decreases linearly with increasing pressure p_{bh}, as well as pressure p_2, and the slope of this line is determined by the solubility coefficient α_s. That is, the larger is α_s, the steeper the line $G_{\text{eff}}(p_{\text{bh}})$ is. The height of this line depends on the operational gas factor. It follows that for certain values of diameter d, pressure p_2 and solubility coefficient α_s the point of intersection of the lines $G_{\text{eff}}(p_{\text{bh}})$ i $R_0(p_{\text{bh}})$ – as the solution of the equation – moves towards either smaller or larger values of pressure p_{bh}. Therefore, the solution of the equation, that is the value of the required minimum downhole pressure flowing $p_{\text{bh min}}$, can be found either in the frame $p_{\text{bh}} < p_f$, or beyond the formation pressure p_f.

Shifting of the point of intersection of the curves due to the change in diameter and pressure p_2 opens the way to adjust the mode of operation of the well at the same gas factor.

Figure 2 shows the change in pressure $p_{\text{bh}}(t)$ according to the results of calculation.

Therefore, the bottom hole pressure will decrease with time, and later, after it passes the minimum (zero mark), it will increase, until the flowing of a well stops. Based on this, the prospect of the further research is to improve the design methodology of oil field development in the mode of dissolved gas by clarifying the boundary conditions. According to our approach, the boundary conditions are not set as constant, but they change with time irrespective of whether analytical methods or a modern numerical mathematical model is employed while working on the process of oil field exploitation.

Examples

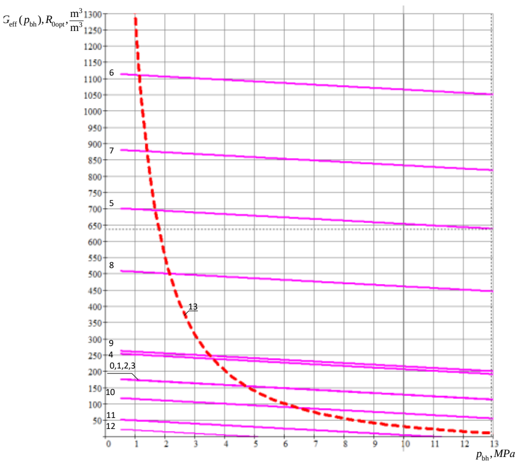

Figure 1 *– Calculation of the minimal bottom hole pressure* $p_{\text{bh}}(t)$ *at a certain moment of time* t*, years:* $0,1,2,3$ *lines* $(0,1,2,3)$*;* $4(4)$*;* $5(5)$*;* $6(6)$*;* $7(7)$*;* $8(8)$*;* $9(9)$*;* $10(10)$*;* $11(11)$*;* $12(12)$*, depending on the alternating/live pressure* p_{bh} *for a given function of specific flow rate* $R_0(t)$ *(line 13).*

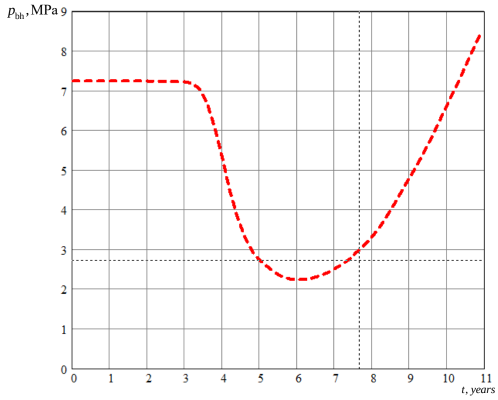

Figure 2 *– Change of bottom hole pressure p_{bh} of flowing with/against time t*

Conclusions

Therefore, the bottom hole pressure will decrease with time, and later, after it passes the minimum (zero mark), it will increase, until the flowing of a well stops. Based on this, the prospect of the further research is to improve the design methodology of oil field development in the mode of dissolved gas by clarifying the boundary conditions. According to our approach, the boundary conditions are not set as constant, but they change with time irrespective of whether analytical methods or a modern numerical mathematical model is employed while working on the process of oil field exploitation.

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