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METHOD OF CALCULATION OF OIL-WATER MIXTURE DENSITY AT THE BOTTOM-HOLE WITH THE PRESSURE EXCEEDING GAS SATURATION PRESSURE OF OIL

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Abstract

Based on the analysis of the vertical drift flow structure, we propose the experimental method for calculating the density of oil-water mixture at the bottomhole of the wellbore which considers well gross rate, water cut, diameter of production string, as well as density of oil and water. This formula is applicable for calculations of the pressure from the fluid column at the bottomhole section of the lower reservoir under condition of applying dual pump production technology for calculation of the well operation modes.

Keywords: *Oil-water mixtures; Dual pump production technology.*

1. Introduction

One of the key issues in performing well studies and obtaining required information during the dual production is measuring bottomhole and formation pressure of the reservoirs [1]. In the West Siberian region of Russia, a dual production technology using dual electric submersible pumps with common downhole motor drive, has become very widespread [2-3]. With that the most important parameter for calculation of bottomhole pressure and well operation modes is average fluid density at the bottomhole of the wellbore. This problem is severed in dual oil production technologies applied for stacked reservoirs, especially for the lowest reservoir with restricted measurement capabilities. This raises the necessity to improve the calculation methods applied. Presently, the process of pressure measurement and calculation in the perforation interval is significantly complicated by water cut, especially when suction pressure becomes less than gas saturation pressure of oil. The difficulty in pressure measurement in the perforation interval is caused by inability to run the downhole gauge to the perforation interval. The top of the upper pay zone is located much lower of the ESP intake, and it is impossible to run a pressure gauge to the top of the upper reservoir, also due to the presence of sliding slot in the intake nozzle of the dual pump lower section.

In this work, we report an innovative approach towards the calculation of the density of oil-water mixture at the bottomhole, considering all key parameters, and discuss its applicability on the data obtained on Arlan oilfield (Bashkortostan, Russia).

2. Methods and theoretical background

Pressure measurement at the bottomhole is performed with maximum proximity of the gauges to the tops of both reservoirs, and the bottomhole and formation pressure is determined through empirical dependence. For the upper reservoir the pressure gauge is installed inside the ESP telemetry system (TMS), and for the lower- at the level of sliding slot in the intake nozzle of the lower pump. In this case the gauge is installed in the lower tubing at the intake nozzle of the lower reservoir pump.

Earlier studies were carried out on the density of water-oil mixture in the bottomhole section from the pump intake to the reservoir top using gamma-density meter, which allows to obtain the parameters of the dual-phase flow, which include fluid density at the bottomhole and the actual phases content in the production string. The tool provides registration of gamma rays, which are absorbed proportionally to the density of the fluid under study (Arlan Oilfield) [4].

When processing the results of the study the average fluid density was taken into account between the reservoir top and the level corresponding to the gas saturation pressure of oil ($\rho_{sat} \approx 8$ MPa). Having the value of the actual density of the oil-water mixture ρ_l at depth, water density ρ_w and oil density ρ_o, the actual water content of the mixture was determined by the formula (1)

$$\varphi = \frac{\rho_l - \rho_{sat}}{\rho_w - \rho_o} \quad (1)$$

It is known that the actual water content φ varies from 0 to 1, i.e. from complete filling of the string with oil to complete filling with water. The value (1-φ) characterizes the actual oil content at the bottomhole. Direct measurement of the actual fluid density combined with measurements of water cut, BHA performance and density of oil and water in the surface conditions allows for determination of almost all flow parameters. These include the actual and the relative phase velocity, density of oil drift flow, the actual content of oil and water, maximum oil flow rate through a fixed water column and flooding conditions for the drift flow.

Cross-sectional areas Ω_o and Ω_w relate to the volumes occupied by oil and water in the string.

Therefore $\varphi = \Omega_o/\Omega_w$, $Q_o = Q_{well} - Q_w$ and $B = Q_w/Q_{well}$.

It results in obvious ratio for calculation of relative oil flow speed "u" (Formula 2)

$$u = \frac{(\varphi - B)}{\varphi(1-\varphi)}\,\omega_c \quad (2)$$

where $\omega_s = Q_{well}/\Omega$; Ω – string cross section.

The author analyzed the data of earlier studies of fluid density performed in Arlan field wells. The measurements were made by lowering the subsurface pressure gauge through the annulus past the pump to the bottom hole [4]. Experimental records of density values in almost all cases demonstrated a spike in fluid density at the transition point from oil to water column (Fig. 1).

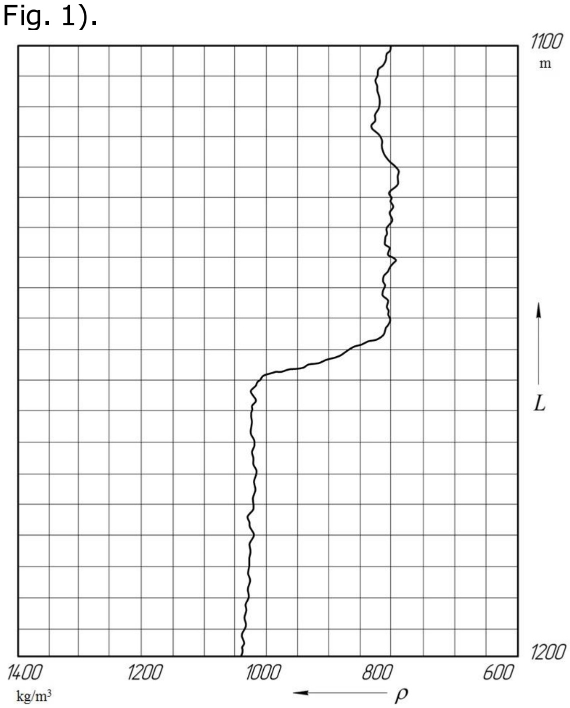

Figure 1. Change in fluid density in well 3426 at the level of pump intake

Right above the pump intake in the annulus there was oil column with 830-870 kg/m³ density. Under the pump the fluid density increased abruptly up to 1080-1150 kg/m³. This spike in density tells about the phase inversion at the level of the pump intake.

Additionally empirical dependence of the average oil and water emulsion speed on the parameter $\frac{1-\varphi}{1-B}$ obtained during the Arlan field studies. The nature of vertical drift flow illustrated by the dots on the graph showed linear interrelation between the parameters, described by the formula 3:

$$\frac{1-\varphi}{1-B} = 0{,}136\ \omega_c \quad (3)$$

3. Results and discussion

Based on the data reported in [4], by substituting φ with its expression in (3), and ω_s with Q_{well}/Ω, the authors obtained the expression for calculation of fluid density at the bottomhole section of the wellbore (Formula 4):

$$\rho_f = \rho_o + [1 - 0{,}173\ Qwell(1 - B)/D_c^2](\rho_w - \rho_o) \qquad (4)$$

where D_C is the inside diameter of production string.

The resulting experimental formula (4) allows for high precision calculation of pressure at the formation top with known values of Q_{well}, D_c, B, ρ_w, ρ_o and gas absence using the already used formula:

$$P_{bth} = \rho_f gH \qquad (5)$$

where H is the height of the fluid column between the formation top and the downhole gauge in the production string.

It should be noted that the formula (5) can be used with bottomhole values not exceeding the respective values of gas saturation pressure of oil P_{sat}. Beyond this level, the release of gas begins, i.e. the fluid density will start changing along the wellbore, and the bottomhole pressure $P_t<P_{sat}$ will be determined by a different value.

Conclusion

We suggest that the calculation based on the experimental formula should be applied for the cases when it is impossible to perform pressure measurement in the perforated interval using downhole pressure gauges.

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