The Research and Well Performance Simulation under Conditions of West Siberia

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Abstract. The paper proposes a new method of calculating the pressure at the pump intake, taking into account changes in the density of the gas-liquid mixture in the well depth. An algorithm for performing the pressure calculation is presented. Graphs of pressure distribution in the well depth with different gas content in comparison with the traditional method for calculating pressure are given. The importance of taking into account the physical properties of gas depending on the depth was proved.

1. Introduction
The determination of the static or dynamic fluid level in the well is one of the main and most common types of research conducted in the fields. In many cases, methods for assessing the level of the liquid give an unreliable result. This is most often associated with three problems:
- the difficulty of recognizing the position on the echogram of the reflection from the liquid level;
- low accuracy of estimates of time intervals on the echogram;
- low accuracy estimates of the sound velocity in the annular gas of the well under study.

The level recognition problems on the echogram are associated with deficiencies of the sounding methods used. An acoustic wave is reflected not only from the fluid, but also from any interface between media, where the density varies significantly, or from any well object that significantly changes the shape or sectional area of the annular space. According to some estimates, with a gas-liquid mixture density of 200 kg/m³, the reflection of the echo signal from the mixture boundary is reliably fixed. Such medium is not a liquid. If we consider the ESP with a gas separator, then at the exit from it a column of gas-liquid mixture, or "foam", is formed, whose density varies depending on the depth. This medium is not a liquid. If we consider the ESP with a gas separator, then at the exit from it a column of gas-liquid mixture, or "foam", is formed, the density of which varies with depth.

At various fields in Western Siberia, the sound velocity in gas varies from 250 to 400 m/s and depends on temperature, pressure, density and gas composition in the well annulus. With the same annular pressure, the sound velocity changes at different fields and from well to well within one field.

2. Results and discussion
Let us consider the well log data carried out at the wells of the Sugmutskoye field, equipped with ESP. According to the research data (Figure 1) in the well 1925/38 in the range of 50–1550 m, the level of the “oil-gas” section is not clearly marked using the gamma-gamma density method. The
intermediate section "oil-foam" is noted at the depth of 810 m and practically does not change in time. The section "foam" is along the column to a depth of 240 m.

Figure 1. Gamma-gamma density log data of the annular space for the well 1925/38 at the Sugmutskoye field.

Measurements of the dynamic level in the annulus of the same well were carried out. According to 36 measurements, the dynamic level is within 350-396 m, and with each subsequent measurement, the level is found below the previous one. Apparently, this is due to the destruction of the "foam", which occurs under the action of an acoustic wave in the measurement process.

Similar studies were conducted in other wells at the Sugmutskoye field. In all the wells, “foam” benches with a length of 10 to 300 m are marked at various intervals of the annulus, both above and below the dynamic level.

Based on the experiments performed to measure dynamic levels, it was found that almost always in wells with a gas factor within 100-200 m$^3$/m$^3$ a bench of “foam” is formed with a specific weight of about 400-500 kg/m$^3$, which is a mixture of liquid and gas.

Such a bench may be also above the dynamic level. Inaccuracy in determining the dynamic level can lead to final errors in determining the pressure at the pump intake up to 1.0-1.5 MPa.

Pump separators send most of the gas from the gas-oil mixture to the annulus. Then, migrating through the oil column, the gas enters the wellhead, and the valve enters the collector system through the bypass and, together with the oil, moves to the collection point. Depending on the gas flow rate, the density of the mixture over the borehole changes and decreases as the mixture moves through the annular space.

Standard techniques based on determining the pressure at the pump intake as the height of the fluid level multiplied by the average density of the fluid in the annulus are inaccurate. More precisely, the pressure at the pump inlet can be determined taking into account changes in $T$, $z$, and $\rho_g$ in depth based on iterative or successive approximations.

The initial data for the calculation are: $P_{an}$ – annular pressure, Pa; $\rho_{oil}$ – oil density (under surface conditions), g/m$^3$; $T_w$ – temperature at the wellhead, °C; $H_p$ – the pump intake level, m; $H_{dyn}$ – dynamic level, m; $GF$ – gas factor, m$^3$/m$^3$; $C_1$, $C_2$, $C_3$ – component ingredients of the gas.

1. For a gas mixture, the critical parameters, molecular weight and relative density are determined as follows.

   - critical pressure and temperature
     \[
     P_{cr} = C_1 \cdot P_{cr}(CH_4) + C_2 \cdot P_{cr}(C_2H_5) + C_3 \cdot P_{cr}(C_3H_6),
     \]
     \[
     T_{cr} = C_1 \cdot T_{cr}(CH_4) + C_2 \cdot T_{cr}(C_2H_5) + C_3 \cdot T_{cr}(C_3H_6).
     \]

   - molecular weight of gas
     \[
     M_g = C_1 \cdot M_g(CH_4) + C_2 \cdot M_g(C_2H_5) + C_3 \cdot M_g(C_3H_6).
     \]
- relative gas density.

\[ \rho_g^* = \frac{M_g}{M_{air}}, \]  

(2.4)

where \( M_{air} \) - is the molecular weight of air \( M_{air} = 29 \).

2. The pressure at the dynamic level, equal to the annular pressure plus the weight of the gas in the annulus, is found by the approximate formula:

\[ P_d = P_{an} \cdot e^{0.000342 \cdot h_d} \]  

(2.5)

3. At the first stage of the calculation, we take the pressure at the pump intake equal to the weight of the liquid (oil) column in the annulus, without taking into account the gas flow from the separator

\[ P_p = P_{an} + \rho_{oil} g(H_p - H_d) \]  

(2.6)

4. The density of gas in the annulus at the pump intake level, \( \rho_g \) (kg/m\(^3\)), is determined by the formula:

\[ \rho_g = 0.000342 \cdot \rho_g^* \cdot P_P / (z \cdot T_p), \]  

(2.7)

where \( P_p \) is the pressure at the pump intake (preliminary), Pa;
\( T_p \) is the temperature at the pump intake, °K;
\( z \) is the gas super-compressibility factor (at \( P_p \) and \( T_p \)).

The gas super-compressibility factor \( z \) is found in the Brown-Katz graphs for the corresponding values of the reduced pressure parameters \( P_r \) and temperature \( T_r \):

\[ P_r = P/P_{cr}; \]
\[ T_r = T/T_{cr} \]

where \( P_{cr} \) and \( T_{cr} \) are critical pressure and temperature.

5. Since the gas-liquid mixture is an inhomogeneous medium consisting of liquid and gas phases of various volumes, the density of the gas-liquid mixture is defined as follows:

\[ \rho_{mix} = \frac{V_g \rho_g + V_l \rho_l}{V_g + V_l}, \]  

(2.8)

where \( V_g, V_l \) are the volumes of liquid and gas, respectively, m\(^3\);
\( \rho_g \) - gas density, kg/m\(^3\);
\( \rho_l \) - density of liquid, kg/m\(^3\).

The total gas and liquid volume will be equal to the well annulus volume on the calculated interval \( V_{an} \), which is calculated as the product of the area of the annular space \( S_{an} \) and the height of the calculated interval \( h \):

\[ V_g + V_l = V_{an} = S_{an} \cdot h \]  

(2.9)

Then the expression (2.8) will be rewritten in the following form:

\[ \rho_{mix} = \frac{V_g \rho_g + (V_{an} - V_g) \cdot \rho_l}{V_{an}} \]  

(2.10)

At the first stage of the calculation, the volume of gas entering the pump intake is calculated based on the fact that gas occupies 10% of the annular space. If at the end of the calculation the gas volume in the upper interval turns out to be greater than the volume of the annular space in this interval, then the calculation is repeated, reducing the fraction of the annular space occupied by the gas, and accordingly the gas volume at the pump intake.

6. Finding the density of the mixture at the pump intake level, let us substitute the value into the expression for finding the pressure and determine the pressure at the depth \((H_p - h)\)

\[ P = P_d + \rho_{mix} g h \]  

(2.11)

7. Since a new pressure value for a given interval of the annular space was obtained, the gas density in this interval and the density of the gas-liquid mixture will change accordingly. To find the average values in the interval, the average values of pressure and temperature in this area are found:

\[ P_{av} = \frac{P + P_p}{2}, \quad T_{av} = \frac{T_p + \lambda}{2} \]  

(h/2)
8. According to formulas (2.7), (2.10) and (2.11), respectively, the new values of the gas density and gas-liquid mixture and pressure at a given interval are found.

9. If the pressure value calculated by the formula (2.11) differs from the one calculated at the previous stage by no more than 5%, it is proceed to the calculation of the next interval of the well annulus. If the deviation is more than 5%, steps 4-9 are repeated.

Figure 2 shows the results of calculating the pressure at the pump intake in a vertical well, performed according to the proposed method and in the traditional way.

![Figure 2. Pressure distribution over the well depth at the different gas content.](image)

3. Conclusion
As it can be seen from the graph, ignoring changes in the physical properties of a gas, depending on the depth and pressure, leads to errors in calculating the pressure at the pump intake up to 50%. By recalculating the gas flow rate at the pump intake to the gas flow at the wellhead (depending on the pressure at the pump intake), it is possible to determine the maximum gas flow through the annulus at a given pressure and fluid flow rate. Taking into account the above mentioned, in the proposed method for calculating, the pressure at the pump intake, the gas flow rate is initially taken at a rate of 10% of the annular space, taking into account the gas expansion along the well borehole.

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