Research and Improvement of Calculation Method of Flow Pressure in Mechanical Recovery Wells

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Abstract: This paper takes the flow pressure of oil recovery wells in polymer flooding blocks in the past two years as the research data, and conducts field test research based on the analysis of test principles and technical indicators of the equipment. By taking the oil wells at the actual static pressure measurement points as the research object, the author compares the flow pressure of the static fluid with that calculated by the low-pressure test data management and analysis software so as to analyze the rationality and data modification method of the formula. By giving full play to the role of the data of the flow pressure and working liquid level in the dynamic analysis and development program preparation, this paper formulates a reasonable working system for mechanical recovery wells, thereby helping to ensure the sustainable and stable production of oil fields.

1. Test principle and calculation method

The main method of detecting the working level is the echo method. The principle is that when the sound pulse propagates in the gas medium and encounters an obstacle, it will generate a reflected pulse. If the pulse propagation speed and the pulse reflection time are known, then we can obtain the distance between the obstacle and the impulsive sound source, thereby obtaining the depth of the liquid level underground [1].

The current low-pressure test equipment in the polymer flooding block has been promoted and used since 2008. It consists of a TD01D silent nitrogen wellhead sounder, a dynamometer and a comprehensive tester. The low-pressure test data management and analysis software for mechanical recovery wells has been used since 2004, and the test equipment and software have not changed recently.

According to the latest regulations listed in the Planning Interpretation of Dynamic Level Data for Mechanical Recovery Wells, the formulas for calculating the working liquid level and flow pressure are as follows:

Calculation method of working liquid level:
\[
\bar{e} = \sum_{n} e
\]
\[
\nu = \frac{200 \sum h}{ne}
\]
\[
H = \frac{\sum h \cdot L}{n \cdot e}
\]

For wells with a liquid level depth less than 50m and with no obvious coupling wave, the average sound velocity in the area where the well is located can be used to calculate the liquid level depth \[^2\]. The calculation formula is:

\[
H = \frac{\nu' L}{200}
\]

In the formula:
- \(\bar{e}\) represents the length of the average tubing coupling wave, mm;
- \(\sum e\) represents the total length of \(n\) tubing coupling wave(s), mm;
- \(n\) represents the number of tubing coupling wave(s) used in the calculation;
- \(\nu\) represents the speed of sound, m/s;
- \(\sum h\) represents the total length of \(n\) oil pipes, m;
- \(H\) represents the working liquid depth, m;
- \(L\) represents the length of liquid surface wave, mm;
- \(\nu'\) represents the average speed of sound in the area, m/s.

The calculation method of flow pressure is:

\[
P_f = P_0 + P_1 + P_2 = P_0 + r_1 \times (H_B - H_D) \times g + r_2 \times (H_Z - H_B) \times g
\]

\[
r_1 = 0.1 \times [a - (b + (c - (d - e \times X) \times X) \times X - B]
\]

\[
X = 10 \times \left(\frac{P_0 + P_1}{P_0} \right) \frac{1}{P_0 - 9}
\]

\[
r_2 = 0.69 + 0.4 \times f_w \quad (f_w \leq 0.78)
\]

\[
r_2 = 0.69 + 0.4 = 1.09 \quad (f_w > 0.78)
\]

In the formula, \(P_f\) represents the flow pressure, MPa;
- \(P_0\) represents the casing pressure, MPa;
- \(P_1\) represents the liquid pressure above the pump, MPa;
- \(P_2\) represents the liquid pressure below the pump, MPa;
- \(P_h\) represents the saturation pressure, MPa;
- \(r_1\) represents the density of mixed liquid above the pump, \(10^3\) kg/m\(^3\);
- \(r_2\) represents the density of mixed liquid below the pump, \(10^3\) kg/m\(^3\);
- \(H_Z\) represents the depth of the middle layer of the oil well, m;
- \(H_D\) represents the depth of the working liquid level, m;
- \(H_B\) represents the depth of the pump, m;

where \(a - e\) are empirical data that can be given according to the actual situation in each region. Generally, \(a=8.1007, b=0.01863, c=0.00273, d=0.004902, e=0.000139\).

2. Problems encountered in on-site testing of working level and corresponding solutions

When testing the working liquid depth of a mechanical recovery well on site, the following two situations may be encountered:

2.1 No wave is detected

According to the principle of liquid level test, it can be seen that the factors influencing the liquid level include the propagation medium, the propagation speed, and the condition in the wellbore. The main
reasons that the wave cannot be detected include: 1) the wave of relatively deep liquid level transmitted to the surface is too weak to be identified; 2) the wellbore is dirty, hindering the wave transmission; 3) the casing pressure is low or does not exist, and there is a lack of conductive medium.

(1) When the casing pressure is low or the liquid level is deep, the waveform will be too weak to be recognized after it reaches the ground (see Figure 1). The pause pumping method can be used for testing after the liquid level or casing pressure is restored. If the working liquid level is very deep, a pressure gauge can be used to detect the position of the working liquid level, providing accurate sinking depth for mechanical oil extraction. During the calculation, select as many continuous, uniform and clear tubing coupling waves as possible on the high frequency curve, and measure the total length of the tubing coupling wave; substitute them into the formula ① to obtain the average tubing coupling wave length. Substitute the average pipeline length and the number of pipelines into the formula ② to obtain the speed of sound, and then into the formula ③ to obtain the depth of the working liquid level.

(2) Dirty wellbore will attenuate the impulsive sound source, resulting in undetectable waves (see Figure 2). It is feasible to take a shutdown test to artificially filter out the effects such as wellhead vibration, that is, stop the machine for more than 5 minutes before measuring the working liquid level curve. From the test results, it can be seen that the liquid surface wave becomes obviously better than before, and the coupling wave is also very clear (Figure 3).
2.2 Depth of working level is less than 50m or is at the wellhead
When the working level is suspected to be at the wellhead, if the indicator diagram and the production situation of the well is normal, then a tank truck can be used to connect the well with the casing to release dead oil near the wellhead before testing. When the depth of the working level is less than 50m, the regional average sound velocity \( v' \) and the total length of the liquid level wave \( L \) can be substituted into the formula (9) for calculation according to the regulations[3].

3. Research and improvement of the calculation method of flow pressure in mechanical recovery wells
After the dynamic liquid level depth is measured correctly, we can calculate the flow pressure of the mechanical recovery well [4]:

\[
P_1 = P_0 + P_1 + P_2 = P_0 + r_1 \times (H_B - H_D) \times g + r_2 \times (H_B - H_D) \times g
\]

(9)

This paper takes mechanical recovery wells in polymer flooding blocks as the research object, pointing out that the average flow pressure \( P_f \) of mechanical oil recovery wells has increased significantly in the past two years. From Table 1 and formula (5), it can be seen that when the middle layer depth of the well is set, the flow pressure \( P_f \) can be reduced by properly increasing hanging depth of the oil pump and lowering dynamic liquid level.

Table 1 2017-2018 data comparison between flowing pressure and working submergence of polymer flooding area

| Item                | Flowing pressure and working submergence in the third season of 2017 | Flowing pressure and working submergence in the third season of 2018 |
|---------------------|--------------------------|--------------------------|
|                     | Number of test wells     | Averagé pump setting depth (m) | Average working fluid level (m) |< 200 m (number of wells) | > 400 m (number of wells) | Average pressure (MPa) | Number of test wells | Average pump setting depth (m) | Average working fluid level (m) |< 200 m (number of wells) | > 400 m (number of wells) | Averagé pressure (MPa) |
| Rod-pumped well (with screws) | 287 | 941.7 | 376.1 | 27 | 58 | 202 | 6.01 | 267 | 932.7 | 286.9 | 30 | 23 | 214 | 6.34 |
| Electric-pumped well | 59 | 989.9 | 424.9 | 0 | 12 | 47 | 5.42 | 59 | 995.8 | 343.7 | 0 | 7 | 52 | 5.45 |
| Total               | 346 | 949.9 | 384.4 | 27 | 70 | 249 | 5.91 | 326 | 944.2 | 297.2 | 30 | 30 | 266 | 6.18 |

The author found that when calculating \( P_r \), the density of mixture \( r_2 \) below the pump is fixed at 1.09 when the water content of the oil well is greater than 78%. While in the calculation formula (5) of the mixture density above the pump \( r_1 \), there are many adjustment factors, especially \( a \), the adjustment coefficient. The author takes the flow pressure of the static pressure flow of the static pressure well in the 24-port polymer flooding and 24 water-drive blocks, and makes inverse deductions of the above coefficients according to the formulas (5)–(8), pointing out that the flow pressure calculated when using \( a=8.1007 \) in the formula is significantly different from that obtained through the static flow. After calculation, the value \( a \) of the mechanical recovery well in polymer flooding blocks and the flow pressure calculated using the adjusted coefficient are shown in Table 2.

Table 2. Water-flooding flow pressure in the polymer flooding area in June 2018

| Type        | Stratum | Number of wells | Saturation pressure (MPa) | Mid-depth of the well (m) | Average flow pressure (MPa) | Adjustment coefficient \( a \) | Modified average flow pressure (MPa) |
|-------------|---------|----------------|--------------------------|--------------------------|-----------------------------|-----------------------------|-----------------------------------|
4. Conclusion
When there is no wave that can be detected, it is necessary to classify the causes first, and then conduct tests to form corresponding measures. When the downhole working level is relatively deep and the casing pressure is low, the echo method is limited by the performance of the instrument, so it is difficult to determine the position of the downhole liquid level. The pause pumping method can be adopted for testing after the liquid level or casing pressure has recovered; then convert the test results to the level before the pump stops. If the working level is very deep, it is feasible to use a pressure gauge to detect the accurate submergence depth for mechanical oil extraction, thereby providing a basis for further formulating reasonable technical measures and a reasonable working system for oil extraction. In the later production stage with high water cut, we shall consider the limitations of test instruments and software, and adjust the coefficients in the calculation formula appropriately while ensuring the production of oil wells under a reasonable working system. It is necessary to give full play to the role of flow pressure and the data of working level in the dynamic analysis and the development program preparation, and to formulate a reasonable working system for mechanical recovery wells, thereby ensuring the sustainable and stable production of oil fields.

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