Research and application of logging technology for annulus fluid production profile in highly deviated wells

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Abstract. In view of the low success rate of logging in annulus fluid production profile in domestic oil fields, the relationship between instrument string and well deviation is carried out Requirements of downhole instruments for annular testing construction in highly deviated wells; The lifting and lowering technology of well entry instruments in highly deviated wells has been systematically studied. After field application, the logging technology has been updated and improved. By using large diameter cable, flexibly connecting and splitting instruments, reducing the outer diameter of instruments, configuring automatic direction finder, enhancing the umbrella collecting strength and other improvements in technology and construction methods, the problem of difficulty in measuring the logging data of liquid production profile in the annulus of highly inclined pumping wells is well solved, and the demand of dynamic monitoring of highly inclined wells in oil fields is met.

Keywords: Output profile; Encounter resistance; Pattern method; Downhole scale.

1. Introduction
Due to the restriction of ground conditions on the allocation of underground resources, some oil wells are highly deviated wells and adopt mechanical pumping method. If the conventional logging method is used for this kind of well, the instrument can't be lowered to the monitoring interval, and the downhole dynamic monitoring can't be carried out effectively.

At present, the main problems in dynamic monitoring are as follows: First, due to the large deviation and complex annular space, the instrument can not be lowered to the target interval and the data can not be collected; Second, the inclination of the test well section is large, and the sealing effect of instrument collecting is poor, which leads to inaccurate flow rate and water cut data; Third, the influence of oil-water distribution in highly deviated section on data is unclear, so it is difficult to interpret data.

Therefore, it is necessary to carry out technical research and tackle key problems on annulus logging instruments, logging technology, data interpretation methods and downhole environment, so as to improve the logging success rate of annulus fluid production profile, obtain oil well production performance information in time, provide basis for oilfield development adjustment, and further improve oil well development benefits.
2. Current logging situation of oil field annulus fluid production profile

In recent years, although we have taken some measures and achieved certain results in the construction process, due to various reasons, the success rate of measurement is about 75% every year, among which the success rate of measurement for wells with well deviation above 30 is less than 30%, and the wells with unsuccessful logging are shown in Table 1.

Table 1. Statistical table of annulus logging in highly deviated wells

| Serial number | Well No. | Maximum deviation/depth (°/m) | Guide cone position (m) | Remarks |
|---------------|---------|--------------------------------|-------------------------|---------|
| 1             | C3-7    | 44.0/2100.0                    | 1565.0                  | The flange can't turn and is blocked |
| 2             | C2-14   | 38.0/1950.0                    | 1753.0                  | 1698m is blocked |
| 3             | C3-61   | 44.9/2175.0                    | 1708.0                  | 690m is blocked |
| 4             | C50     | 20.5/1450.0                    | 1894.0                  | The flange can't turn and is blocked |
| 5             | D2-5    | 31.1/925.0                     | 1699.4                  | 890m is blocked |
| 6             | S26-6   | 36.0/1974.0                    | 1699.0                  | 1950m is blocked |
| 7             | C3      | 41.5/2025.0                    | 1700.0                  | 1024m is blocked |
| 8             | S20-12  | 39.0/2075.0                    | 1801.0                  | 1730m is blocked |
| 9             | S20-21  | 34.0/1725.0                    | 2003.0                  | 1330ma resistance |
| 10            | M5-15   | 23.7/1350.0                    | 1509.4                  | 1540 tool position is blocked |
| 11            | W38     | 37.3/1625.0                    | 1551.0                  | Flow rate/water cut is not measured |
| 12            | M4-6    | 26.6/1225.0                    | 1400.6                  | 1238m is blocked |
| 13            | M4-6    | 26.6/1225.0                    | 1400.6                  | 1238m is blocked |
| 14            | S20-31  | 25.0/1050.0                    | 1900.0                  | 950m is blocked |

From Table 1, it can be seen that the main reasons why the production profile of high-angle annulus is not successfully tested are: ① The friction resistance of well deviation is large, and the instrument is not easy to run in; ② The steps are large and the instrument can't go down; ③ The depth of caudal vertebra is large, and it is difficult to get the instrument up and down; ④ The winding probability is high, and the instrument can't get out; ⑤ The deviation azimuth changes, and it is easy to get stuck. Therefore, it is necessary to improve or update the testing technology of annulus fluid production profile and improve the success rate of testing.

3. Study on logging technology of production profile in highly deviated annulus

3.1. Diameter and rigid length of logging instrument

3.1.1. Determination of diameter of logging instrument. The structure of oil production string commonly used in oil field is: 140mm casing (inner diameter 124mm) is used for completion, and 73mm tubing and 38 pump body (outer diameter 51 ~ 51 ~ 55mm) are used to connect with 2-7/8"(89mm)TBG coupling outer diameter, leaving only 35.26mm; in the annular space of oil casing; The 38 bridge pump is externally connected with 3-1/2"(101.6mm)TBG coupling outer diameter, and only 22.66mm is left in the annular space of the oil jacket. Therefore, the diameter of testing instrument for annular production profile in highly deviated wells is selected between 22.66 and 35 mm.

3.1.2. Determination of rigid Length of Instrument.

3.1.2.1 Calculation of allowable bending radius of casing pipe body in inclined shaft

Determining the bending radius of the hole in the maximum deviation-making section is determined by referring to the bending radius of the casing obtained by theoretical calculation. The allowable bending radius r of casing is recommended to be calculated by the following formula, namely...
In which:

\[ R = E \times D \times K_1 \times K_2 \div r_p \div 200 \]  

(1)

In which:

- \( R \) — The allowable bending radius of casing, (m);
- \( E \) — Elastic modulus of steel, \((206\times10^6\text{kPa})\);
- \( D \) — Outer diameter of casing, (cm);
- \( r_p \) — Yield limit of steel, (kPa);
- \( K_1 \) — Safety factor of bending, \( K_1 = 1.8 \) is recommended;
- \( K_2 \) — Safety factor of threaded joint, \( K_2 = 3 \) is recommended.

3.1.2.2 By calculating the length of the instrument at the inflection point

The maximum straight line length \( L \) of running downhole instrument string in the bending section can be obtained by substituting the allowable bending radius of casing obtained by theoretical calculation into the following formula, namely:

\[ L = \frac{1}{6} \left[ R^2 - \left( R^2 - (D_n - d) \right)^{0.5} \right] \]  

(2)

In which:

- \( L \) — Maximum straight-line length running downhole instruments in curved section, (m);
- \( D_n \) — Maximum inner diameter of casing, (cm);
- \( d \) — Maximum outer diameter downhole instruments, (cm).

According to the above calculation, the maximum straight line length allowed to run downhole instruments in the theoretical maximum deviation section of 139.7 mm casing can be obtained. However, this simply considers that there is no tubing in the casing. The actual situation is that the tripping of the instrument is carried out in the annular space of the oil casing. Coupled with the change of well deviation and azimuth, the gap of the annular space of the oil casing is complicated. Therefore, the length of the straight line that can successfully pass through the instrument in the maximum deviation-making section in the annular space is less than the above calculated value. Through production practice, it is more reliable to calculate the maximum outer diameter of downhole instruments from the outer diameter of tubing.

4. Stress analysis and weighting configuration of downhole instrument string

4.1. Force analysis

The low success rate of tool lowering has always been a major problem that puzzles us in the logging of annular fluid production profile in highly deviated wells. There are mainly three kinds of resistance encountered by downhole instruments in the process of descending: buoyancy and viscous force of wellbore fluid and friction resistance between downhole instruments and pipe wall, the latter has less influence in vertical wells. However, in inclined shaft, due to the existence of inclination angle (see Figure 1), friction becomes an important resistance for downhole instruments to descend (see Figure 2).

Figure 1. Schematic diagram of instrument operation
In the formula of fig. 2, \( P \) : Gravity of downhole instruments in wellbore fluid; \( \Phi \) : Inclination angle of oil well; \( \Phi \times \cos \Phi \times P \times \cos \Phi \) : Downward force of downhole instruments; \( F_1 = \mu \times P \times \cos \Phi \) : Downward frictional resistance of downhole instruments; \( \mu \) : Sliding friction. Downward force \( F_1 \) of downhole tools decreases with the increase of angle, while friction force \( F_2 \) is opposite to \( F_1 \) and increases with the increase of \( \Phi \) angle.

4.2. Emphasis configuration

When the instrument goes down, it is necessary to overcome the buoyancy and viscous force of the barrel fluid and the friction resistance between the downhole instrument and the pipe wall. The weighting configuration of the instrument can be calculated by formula (3).

\[
G_{\text{Theory}} - (F_2 - F_1) - F_3 - F_4 + G_y + G_d
\]

In which:
- \( G \) : Heavy rod weight, kg;
- \( F_1 \) : Downward force of the instrument, kg;
- \( F_2 \) : Friction, kg;
- \( F_3 \) : Buoyancy, kg;
- \( F_4 \) : The viscous force, kg;
- \( G_y \) : Instrument weight, kg;
- \( G_d \) : Cable weight, kg.

Formula (3) is a theoretical calculation model. In fact, the annular space between tubing and casing is much smaller and more complex than the annular space between tubing and casing, and there is surface contact or multi-point contact. Therefore, the theoretical calculation in formula (3) is revised as follows:

\[
G_{\text{Actual}} > G_y + G_d - (F_2 - F_1) \times 2 - F_3 - F_4
\]

The formula has been proved by field practice, and it is more appropriate to use the revised formula (4) to configure the weighting.

5. Instrument tool configuration

5.1. Flexible nipple

Because the instrument shell is made of titanium alloy, it has bending resistance and rigidity. Because of the deviation and azimuth change in the deviation-making section, the instrument can't pass smoothly, resulting in sticking. The flexible short circuit (see fig. 3) is connected in series between two instruments to shorten the rigid length and improve the bending ability of the instruments.
5.2. Direction finder

There are dog legs with different sizes in the wellbore of directional wells, especially in the deflecting section. Even if the flexible sub is connected in series, the instrument string cannot enter and pass through the well section with large dogleg angle. Therefore, the roller flexible direction finder (see Figure 4) is used to guide the instrument over the step or through the well section with great change in azimuth.

5.3. Roller centralizer

In vertical wells and wells with inclination < 45, the weight of logging instruments can overcome the friction of the wells and run into the wells. As far as the annular production profile test is concerned, in the mechanical oil production wells with 140mm casing, 73mm tubing and 38 pump bodies and 38 bridge pumps, the annular space between tubing and casing is between 22.66\textasciitilde{}35.26mm and 35.26 mm. Logging instruments slide in the crescent-shaped gap between casing and tubing, and usually the instrument string lies obliquely on the inner wall of casing and the outer wall of tubing, with large friction. In order to change the surface contact or line contact between the instrument string and the tubing and casing into point contact, a roller centralizer (see Figure 5) is inserted into the instrument string to reduce the downward friction and upward resistance, which is convenient for the smooth tripping of the instrument and the completion of the test task.

5.4. Rotary short circuit

Add a rotary sub at the top of the instrument string to avoid or reduce the torsional force of the instrument and ensure the normal lifting and running of the instrument.

5.5. Metal+cloth collecting umbrella

The metal steel sheet is used as the collecting umbrella. During the measurement, the metal sheet is opened to form an open umbrella by a mechanical transmission device, which blocks and blocks the pipe wall passage of the upward flow of fluid, thus forming the collecting flow. Due to the influence of the collecting flow and the layered test combination instrument is located in the center of the collecting umbrella, the fluid produced by the production layer is in the process of upward flow. It must pass through the overflow pipe of the instrument. Because the inner diameter of the overflow pipe of the instrument is much smaller than the inner diameter of the casing, it is easier to detect the information of producing zones with low flow and high water cut, and to a great extent, it reduces the adverse influence of the accumulated water column in the wellbore on the test accuracy, and can reflect the production situation of oil layers more truly.

The metal umbrella seal has high current collecting strength, but there is leakage. The cloth umbrella seal is good, but the wear resistance is poor. Considering the strength and tightness of umbrella, metal+cloth collecting umbrella is used in the production profile test of highly deviated wells (see Figure 6).

Figure 3. Interpretation chart of logging technology

1. Configuration of well entry instrument string

At present, the measuring instrument for φ22mm liquid production profile is a small diameter instrument string, which includes six measuring parameters: temperature, pressure, magnetic positioning, gamma, water holding capacity and flow rate. See Figure 7 for the specific structure.
Figure 4. Schematic diagram of test instrument string for annular production profile in highly deviated wells

(2) **Cable configuration**

The toughness and weight of large-diameter cables are larger than those of small-diameter cables. The cross-annulus logging cable head suitable for 11.8mm seven-core cables shall be used, and the surface system and downhole instruments shall be calibrated online to adapt to the impedance (capacitance) of large-diameter multi-core cables. According to the situation of the wellhead in the annulus, the Tiandi pulley is improved, and the crane is used to cooperate with the wellhead installation during logging to ensure the construction safety. After taking this measure and configuring the test instrument string for highly deviated wells, the success rate of tripping in and out of the annular liquid production profile logging instrument has been increased by 40%.

(3) **Logging control**

1. Logging instrument running: before running the instrument into the well, inspect and calibrate the instrument, and run it into the well after everything is normal;
2. Speed control during instrument running: the speed of cable running in vertical section is ≤ 2000 m/h; At 200m above the deflecting section, the cable lowering speed is ≤ 500m/h; After passing through the well section with large build-up rate, the cable lowering speed is controlled within 1500m/h;
3. When the instrument is lowered to 1000 m/h at a distance of 50m from the pump (or 100 m from the top of the survey interval), lower the instrument to the survey interval for 50 m;
4. When the instrument goes down to the cable mark depth close to the measuring interval, correct the logging depth.
5. Log the temperature and pressure curves, and the velocity is less than or equal to 600 m/h.
6. The magnetic positioning curve is measured, and the velocity measurement is not more than 1000m/h. The measured interval is within the perforated interval, and the length is not less than 50 m.
7. Repeatedly measure well temperature and pressure curves according to the requirements of (5).
8. Lower the instrument to the first measuring point, and measure the flow rate and water cut for three times. For instruments whose upper limit of measurement is greater than 20 m³/d, if the maximum value of the relative error (the difference between the flow value, the water cut value and the average value of the three measurements and then the ratio between the average value and the average value) is greater than 5%, replace the instruments for verification; For instruments whose upper limit of measurement is not more than 20 m³/d, if the absolute error of three measurements is more than 0.5 m³/d, replace the instruments for verification.
9. Repeated measurement, the absolute value of relative error of repeated measurement at the first measuring point should be less than 5%, otherwise, replace the instrument for verification. If the absolute value of relative error of other repeated measurements is greater than 5%, repeat the verification again.
10. After the admission, take back the current collector and lift the instrument at a speed of ≤2000m/h. Slow down to 500m/h when it is 50m away from the guide cone or enters the deflecting section, and recover to the cable lifting speed of 2000m/h after passing through the guide cone, pump or highly inclined section for 20m. Slow down to 1000 m/h when it is 100m away from the wellhead, stop when it is 20 m away from the wellhead, and pull the instrument out of the wellhead by manpower.

6. **Flow/water cut interpretation chart**

Due to the increasing deviation of production wells in the oilfield, the original calibration method is carried out in the vertical direction, and errors are easy to appear in logging data interpretation. The collecting umbrella flowmeter is calibrated from multiple angles in the calibration device to correct the
flow calibration data: Adjust the mechanical range of collecting umbrella to increase the collecting effect. Use the combination of multi-angle, multi-flow, multi-oil-water percentage, increase the use of calibration instruments, and use mathematical calculation (interpolation method) to obtain the average value of fixed angle; According to the actual logging situation, the calibration range of well deviation is 0 ~ 45.

By establishing flow/water cut relation charts of different well inclinations, the study on flow calibration and correction methods of collecting flowmeter in inclined wells can reduce the influence of high inclination on logging data interpretation conclusion, improve the accuracy of data interpretation, and provide scientific basis for subsequent stimulation measures of production wells.

7. Logging effect of highly deviated wells

① Actual effect of field logging

Through the improvement of production profile testing technology in highly deviated wells, 40 wells were actually completed in 53 wells tested in an oilfield in 2019, with a success rate of 75.5%. The angle of inclination of the annular production profile test is between 20 and 43.9, and the maximum deviation angle of the actually completed test well is 40.6, which has achieved good results.

② Test data interpretation effect

Taking P180-X168 as an example, 5 sublayers between 1215.5 m and 1240.2 m have been mined. The annulus 6-parameter liquid production profile test was carried out, and the points at 1215.5 m, 1219.1 m, 1221.5 m, 1225.5 m and 1333.5m were measured by a 22mm motor-driven full-flow flow water-cut tester. The liquid production recorded on the ground is 7m^3/d, and the water cut is 20%. The plate interpretation results are corrected by plate interpolation method and downhole calibration method with measured data, and the results are shown in Table 2. It can be seen from Table 1 that the interpretation results are close to the ground measurement data.

| Serial number | Well    | Liquid | Water | Moisture |
|--------------|---------|--------|-------|----------|
| 1            | 1215.5  | 1.1    | 0.292 | 26.5     |
| 2            | 1219.1  | 0.5    | 0.052 | 10       |
| 3            | 1221.5  | 2.2    | 0.451 | 20.5     |
| 4            | 1225.5  | 2.3    | 0.593 | 25.8     |
| 5            | 1333.5  | 1.0    | 0.126 | 12.6     |
| Total        |         | 7.1    | 1.512 | 21       |
| Ground       |         | 7.0    | 1.4   | 20       |

8. Conclusions

① The field operation of 53 wells in an oilfield has achieved good results. The test technology of deviated well annular liquid production profile basically meets the requirements of deviated well annular liquid production profile test within 40;

② Through the research and implementation of the test instrument string of deviated well annular liquid production profile, the test data obtained are true and reliable without changing the working state of the oil well;

③ On the basis of interpreting the chart, the interpretation results of the chart are corrected by downhole calibration, which can reduce the interpretation error

④ Dynamic data of oil well production can be obtained by continuously testing downhole temperature, pressure, flow rate and water holding capacity, which provides reliable technical support for comprehensive treatment of production wells.

References

[1] Wu Qi, etc. Professional technical training materials for China Petroleum Exploration and Production Corporation-Logging Supervision
[2] Wang Xueru, etc. Overview of advanced logging interpretation technology. Chemical management 2014.11.

[3] Yang Wenrui. Factors influencing the development effect of low permeability reservoirs and improvement measures [J]. Chemical Engineering and Equipment, 2019(07): 84-85.

[4] Zhu Yunzhao. Analysis of low-permeability reservoir development methods [J]. Petrochemical Technology, 2019, 26(04): 110+116.

[5] Wang Zhifu. Technical analysis of low permeability oilfield water injection development technology [J]. Contemporary Research in Chemical Industry, 2019(03): 152-153.