Research on injection profile logging technology

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Abstract. In this paper, through the analysis of the existing problems and influencing factors in the application of historical data of injection profile, continuous correlation logging technology of injection well, electromagnetic flow and tracer correlation logging technology are applied to solve the problems of overflow and contamination of isotope profile test in low injection wells. In general injection wells, the current collecting electromagnetic flow logging technology is applied; in stratified injection wells with different water injection intensity, oxygen activation logging, isotope water injection profile logging, tracer correlation logging and other logging technologies are used to combine logging according to the injection volume and string structure testing instrument scope, so as to eliminate the contamination effect and improve the accuracy of interval water injection profile test.

Key words: current collecting electromagnetic flow logging, oxygen activation logging, various related logging technologies.

1. Preface
The content of clay minerals in Nantun Formation of Hailaer oilfield is high. In clay minerals, montmorillonite, illite and kaolinite are the main water sensitive minerals, and the distribution of clay minerals is uneven. The content of clay minerals varies greatly between wells and the same layer of a single well. The distribution of clay minerals is not obvious. The average water sensitivity index of the block is 0.79. It is a strong water sensitive reservoir, and the phenomenon of under injection in wells is serious.

In order to improve the effect of water injection, anti swelling agent is widely used in block wells, which aggravates the corrosion and scaling of water injection string to a certain extent. With the increasing production capacity of the block year by year, the well shut in process is carried out continuously. Because of the fluctuation of pressure, the phenomenon of liquid backflow is bound to occur after the well is shut in, and the dead oil in the backflow liquid will adhere to the pipe wall. These two factors lead to the tube wall contamination adsorbing isotope in isotope logging, and the interpretation can not distinguish whether it is the formation suction or the pipe wall contamination, which causes great errors in isotope interpretation, resulting in inaccurate judgment of the main water absorption layer in some wells.

At the same time, with the extension of well production time, the corrosion degree of water injection pipe network system is gradually serious, and the accumulation of impurities in the well increases. During the test process, the impurities in the well are excited to migrate, resulting in nozzle blockage...
and formation pollution, affecting the water volume and affecting the accuracy of the test data. Through the analysis of data from several wells, the leakage of water injection string packer results in abnormal water injection, which leads to the difficulty of data acquisition and interpretation and the decrease of accuracy. The subjective factor affecting the accuracy of the data is that the selected isotope size does not match with the well logging formation properties, resulting in less isotopic filtration or plugging the formation, resulting in the decline of test quality.

2. Adaptability analysis of different logging techniques

2.1. Application of current collecting electromagnetic flow logging technology in general injection wells

Through continuous tests and comparative verification in various blocks of Hailaer oilfield, it is considered that one of the most feasible logging methods is to test the small layer water injection profile of general injection wells by using the current collecting electromagnetic flow logging combination tool, which can solve the problems of contamination in the low injection water injection profile of general water injection wells and the difficulty in subdivision of small layers. It does not need radioactive sources and is more conducive to environmental protection.

This technology is mainly used in the injection profile measurement of general water injection and polymer injection wells with low and medium injection rate (less than 120 m³/D), and flow collection point measurement is carried out in casing by positioning or gamma depth correction. The bell mouth of the string is required to be above the top boundary of the perforation layer. The gamma and magnetic positioning parameters of the instrument can accurately correct the logging depth. The pressure parameters provide downhole flow pressure data and monitor the injection pressure fluctuation. The well temperature parameters can assist in analyzing and judging the main liquid absorbing layer and bottom boundary. The fixed-point measurement is not restricted by the interlayer thickness. The flow collecting umbrella can be used continuously for 4 wells without replacement, and other components can be used for more than 50 times. The instrument improves the flow rate by collecting flow, increases the measured value, improves the resolution and accuracy of flow measurement, and the minimum single layer flow rate of a single well is 0.5 m³/D; the fluid passes through the internal channel with fixed cross-sectional area, which eliminates the influence of flow cross-sectional area change on flow measurement results and improves the measurement accuracy. From 2019 to 2020, the project has been applied to 33 well times, with high measurement accuracy, good stability and relatively high accuracy of test data (Table 1).

Main technical indicators: flow measurement range: 0.5m³/d ~ 120m³/D; flow measurement accuracy: ± 1%; flow measurement sensitivity: 10Hz/(m³/D); zero flow measurement error: ± 0.1 m³/D; temperature resistance: 125 ℃; pressure resistance: 60 MPa.

| Order number | Well number | Monolayer minimum injection | Monolayer maximum injection |
|--------------|-------------|-----------------------------|----------------------------|
| 1            | Bei47-50    | 1.0 m³/d                   | 5.6 m³/d                   |
| 2            | Bei57-53    | 0.6 m³/d                   | 4.6 m³/d                   |
| 3            | Bei28-B63-80| 1.0 m³/d                   | 14.7 m³/d                 |
| 4            | Bei14-X50-46| 0.5 m³/d                   | 4.7 m³/d                   |
| 5            | Bei12-B53-60| 3.2 m³/d                   | 31 m³/d                    |
| 6            | Xi49-43     | 1.3 m³/d                   | 3.5 m³/d                   |

2.2. Application of oxygen activation logging technology in profile logging of high injection rate wells

The formation dip angle of Bei301 block is relatively large, the oil-water relationship is relatively simple, and it has the characteristics of oil and water supply, no interlayer water, strong water sensitivity reservoir and strong heterogeneity. In the development, it has the problems of low block pressure level, rapid decline of internal oil wells and rapid water cut rise of edge oil wells affected by structural dip angle and formation water invasion, which makes the thickness of water absorption decrease, and the
contradiction between plane and interlayer is prominent. The water content rises rapidly. According to statistics, about 17% of the whole oilfield has been injected more than 50 m$^3$ / D. The advanced and mature oxygen activation logging technology of the company has been introduced to the injection profile logging of these wells.

Oxygen activation flowmeter belongs to a kind of tracer flowmeter. Tracer is produced by thermal neutron generated by neutron tube inside the instrument to activate oxygen in water in wellbore (or water outside wellbore), which is used to detect water flow inside and outside wellbore. The instrument generally consists of a neutron generator and two gamma detectors. The neutron generator emits thermal neutrons with energy of 14MeV, which activates oxygen in water into isotope nitrogen with half-life of 7.13s. Nitrogen also emits 6.13meV gamma ray in addition to beta particles during decay. As a tracer, activated water is detected when it flows through the lower detector. By measuring the time of activated water passing through the detector, the flow velocity can be determined by $V = \frac{L}{\Delta t}$, where $l$ is the source distance (distance between the transmitter and the detector) and $\Delta t$ is the average time between activation and detection. The discharge can be calculated according to the cross-sectional area of the flow space.

This method is suitable for the measurement of injection allocation wells, general injection wells, upper return wells under general injection conditions and polymer injection wells. The measured flow range: 5-87m$^3$ / D in 62mm tubing, 15-598m$^3$ / D in 5.5in casing, and 10-446m$^3$ / D in annular space of oil casing. The water flow in the tubing, casing and casing space can be measured; the logging method does not use radioactive materials, has nothing to do with the size of formation suction pores, and has no isotopic contamination and sinking problems. It can measure the water flow velocity in different directions in the tubing and the oil casing space, and is less affected by the fluid viscosity. It can be used for injection profile logging of injection wells with serious isotope contamination.

The injection rate of single well in Bei301 block is relatively high. At present, 25 well times of field test have been completed by using this logging method. 7 out of 12 wells tested before May 2020 are found to be unsealed (including 2 leakage). A high injection well has been tested for channeling and leakage, and the logging results are obvious. From the analysis of oxygen activation logging data, affected by the lower limit of measurement, some wells reflect that the thickness of water absorption (the number of water absorption in a small layer) is reduced, and there is a laminated layer interpretation. From the test results reflecting the condition of downhole tools, it is consistent with well testing and sealing. This project can be the first choice for channeling, leakage detection and packer sealing in high injection wells.

2.3. experimental application of multiple correlation logging techniques in profile logging of low injection wells

For wells with injection rate less than 60 m$^3$ / D, there are main problems in the process of injection profile logging: first, it is difficult to accurately interpret stratified water absorption by using conventional isotope injection profile five parameter logging. According to the water injection profile data of wells Bei 44-54, Bei 40-52 and Bei 40-56, there are many subdivision layers, small interval between layers, and the recovery of isotope curve is not obvious. Second, during the testing process, the contamination in the well is serious, basically all the water absorbing layers, strings and downhole tools are contaminated to a certain extent, which seriously affects the interpretation quality of isotope logging. In view of the problems in the injection profile logging process, the continuous tracer logging technology for injection wells, electromagnetic flow and tracer correlation logging technology, and ultrasonic flowmeter tracer correlation combination logging technology are tested and applied, and certain results and understandings are obtained.

The downhole instrument for continuous tracer of injection well is composed of well temperature, pressure, magnetic positioning, injector, gamma, flow rate and so on. Its advantage is that the water absorption of each formation injected by the water nozzle can be measured clearly by releasing the tracer only once, and the sealing condition of the packer above and below the water nozzle can also be measured. Ba131 liquid isotope was selected as the mother liquor, and appropriate additives were added
to prepare liquid isotope tracer. Its specific gravity is 1.0 g/cm³, which is not easy to diffuse. The interpretation method is to obtain the relative and absolute water absorption of each nozzle or formation according to the change of the position of tracer activated liquid with time in the well.

At present, the continuous tracer correlation logging method has been used to complete 22 well field tests. For the well group in block Bei 301, there are many sub layers and the isotope stratification is not obvious. The continuous tracer related instruments can be used to solve the problem. At the same time, the technology can better overcome the contamination problem of downhole tools for isotope testing, and can obviously judge the leakage of downhole tools such as packers.

Well Bei 44-54 is a well with injection rate of 132.5 m³/d, relatively large, pressure of 8.6 mpa, measuring well section of 1115.0-1242.0m, length of about 127m, and a total of 27 perforated layers. Five parameter water injection profile has been measured in this well, but the test result is not ideal due to the serious contamination on the well wall. Figure 1 is the interpretation result of water injection profile, purple is water absorption and blue is contamination. It can be seen from the figure that the tool and coupling are seriously contaminated, so the sealing condition of the packer can not be judged. The tracer correlation continuous logging technology is used to measure the data, and good test results are obtained. Fig. 2 shows the original logging curve of the well and Fig. 3 shows the interpretation result. It can be seen from Figure 4 that there is water absorption in 6 layers of the well, and the third graded water device.

![Fig. 1 interpretation results of isotope water injection profile of well Bei 44-54](image-url)
The perforation thickness and interval of some water injection wells in block Bei 301 are very small (the minimum interval between layers is 0.4 m). During the test operation, because the minimum width of gamma peak generated by tracer is about 1 m, sometimes it is difficult to accurately record the peak velocity between layers, especially when the injection volume is large, it is difficult to judge the water absorption of small layer. At the same time, for injection allocation wells, there is a superposition of casing peak and tubing peak, which affects the interpretation accuracy to a certain extent.

Electromagnetic flow and tracer correlation logging technology has been applied in 5 wells. As the liquid isotope is used, this method can overcome the contamination problem of downhole tools and identify the sealing condition of packer as well as continuous tracer correlation logging. However, due to the problem of source diffusion, it is difficult to identify the tracer peak, and the measurement error of artificial peak is large. At the same time, this technology is also used to measure the liquid flow rate, and the pipe wall conditions have great influence on the measurement results.

The injection rate of well Bei 59-55 is 30 m³/D and the pressure is 7.0 MPa. Before logging, the well test method has been used to detect the sealing condition of the well string, and the test result is that the whole well is sealed. At the same time, the water absorption capacity of the three graded water distributor was tested by well test ultrasonic flowmeter. The results (Table 2) showed that the water absorption of partial 1 water distributor was 20 m³/D, partial 2 was dead mouth and did not absorb water. The water absorption of partial 3 water distributor was 10 m³/D, which was different from the injection allocation scheme.

| Injection allocation interval | Injection volume(m³/d) | Actual injection volume (m³/d) |
|------------------------------|------------------------|-------------------------------|
| N2I1～N2I6                  | 10                     | 20                            |
| N2II11～N2II12               | Stop injection         | 0                             |
| N2II15～N2II19               | 20                     | 10                            |
| Whole well                   | 30                     | 30                            |

The results of using electromagnetic flowmeter to measure water distributor are consistent with that of well testing ultrasonic flowmeter by using correlation flow combination logging (Fig. 5), which shows that the logging results of flow rate of each nozzle are correct. The liquid isotope is released from the water distributor of Pian 1. After the water absorption of each interval of Pian 1 is recorded, water absorption is still detected in the formation where Pian 2 is located. This indicates that the secondary packer is not sealed, which conflicts with the result of well test. It is considered that in the process of
sealing test, the bridge eccentric sealing section is used to check the sealing due to the fact that Yu Pian 2 is dead mouth and needs to replace the normal water nozzle. There is pressure difference inside and outside the packer, and the packer is in sealing state.

The combined logging tool for tracing related flow rate by ultrasonic flowmeter is composed of well temperature, pressure, magnetic positioning, injector, gamma ray and ultrasonic flowmeter. Its measuring principle is that when the tracer is released to the wellbore, the instrument with two sensors is quickly lowered to the position where the tracer will flow. When the tracer in the oil jacket space flows through these two sensors, gamma ray. The time for tracer to flow through upstream and downstream can be calculated by correlation calculation method. Since the cross-sectional area of velocity profile is known, the fluid flow can be calculated. The logging method is fixed point measurement. The injection profile logging of well Bei59-55, Bei48-52, Bei3-2 and Bei60-56 was carried out by using ultrasonic flowmeter tracer correlation flow combination logging tool, and good logging results were obtained.

The injection rate is 38.6 m³/D and the injection pressure is 8.15 MPa during the logging operation of well Bei 3-2. Tracer correlation logging and oxygen activation logging are applied in the same well. The logging conditions of the two tools are compared and analyzed. The comprehensive logging results improve the interpretation accuracy and make a relatively accurate judgment on the abnormal water injection.

Table 3 shows the data obtained by the two methods. From the analysis of two kinds of logging results, it is concluded that the primary and secondary water absorbing layers measured by the two methods are consistent, which are nii12 sublayer and nii4 + 5 + 6 + 7 sublayer, and the two methods have good consistency; the oxygen activation instrument can not effectively identify the low injection interval due to its own technical indicators, such as nii1 + 2 ~ nii3 and nii11 intervals, with the suction capacity of 7 m³/D and 6 m³/D, respectively 3 m³/D, and tracer correlation combination logging can also effectively identify the 3 m³/D water loss of the well.

### Table 3. Comparison of oxygen activation logging and tracer correlation logging data

| Serial number | Horizon  | Measuring point depth (m) | Tubing-casing annular space | Injection rate of formation (m³/d) | Absolute formation volume (m³) | Relative formation volume (%) | Measuring point depth (m) | Tubing-casing annular space | Injection rate of formation (m³/d) | Absolute formation volume (m³) | Relative formation volume (%) |
|---------------|---------|---------------------------|----------------------------|-----------------------------------|-------------------------------|-----------------------------|---------------------------|----------------------------|-----------------------------------|-------------------------------|-----------------------------|
| 1             | NII 1-2 | 1168.7                    | Upward                     | 38.6                              | 1150                          | 40                          | Downward                  |                           |                                    |                                |                             |
| 2             | NII 1-3 | 1200                      |                           |                                   | 1200                          | 40                          |                           |                           |                                    |                                |                             |
| 3             |        | 1207.1                    | 15.9                       |                                   | 1207 (downward)               | 10                          | 23                        | 10                         | 23                               | 17.5                          |                             |
| 4             | NII 4+5 | 1214.6                    | 0                          | 22.7                              | 1220                          | 0                           | 23                        |                           |                                    |                                |                             |
| 5             | NII 10  | 1229.6                    | 0                          |                                    | 1240                          | 0                           |                           |                           |                                    |                                |                             |
| 6             | NII 11  | 1251                      | 0                          |                                    | 1251                          | 14                          | 23                        | 6                          | 15                               | 17.5                          |                             |
| 7             | NII 12  | 1268.1                    | 22.7                       | 0                                  | 1273                          | 3                           | 14                        | 3                          | 36                               | 17.5                          |                             |

### 3. Conclusion and understanding

To sum up, the liquid isotope is used in various logging techniques, which can overcome the contamination problem of downhole tools for isotope testing. Compared with oxygen activation logging, tracer correlation combination logging has some advantages in low injection well logging. Tracer correlation combination logging can also identify the sealing condition of packer.

Isotope five parameter combination logging is suitable for all injection wells in principle, but there is contamination problem; in general injection wells, it is recommended to apply current collecting electromagnetic flow logging technology; in separate injection wells, if contamination occurs or logging results need to be verified, continuous tracer correlation logging technology is recommended in injection wells with daily water injection less than 10m³/D; daily water injection is 10m³/D ~ 30 In m³/D.
injection wells, it is recommended to use point logging tracer correlation combination logging technology and pulse neutron oxygen activation logging technology; in injection wells with daily water injection of more than 30m³ / D, pulsed neutron oxygen activation logging technology is recommended. Oxygen activation and continuous tracer correlation method are used for water sensitive glutenite reservoir water injection profile; isotope and oxygen activation method are used for water injection profile of buried hill reservoir with relatively developed pores, fractures and caves; isotope, spot logging and oxygen activation method are used for water injection profile of ultra-low permeability reservoir.

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