Research and Application of Fine Intelligent Injection Technology of Cable Type in Dagang Oilfield

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Abstract. Dagang oilfield belongs to typical multi-layer system, heterogeneity of complex fault block reservoir, reservoir and the large difference of physical property of crude oil, water, etc, the longitudinal permeability difference is obvious, separate injection interval is not detailed. The existing bridge eccentric note, bridge concentric injection technology can't meet the needs of the fine water injection, real-time measurement and control because of drift, well depth, pressure and other factors, and there is poor adaptability, measuring problem of long time and low efficiency. Cable type fine intelligent water injection technology in underground intelligent water distributor, the ground controller as the core tools, cable as transmission medium, the computer network communication technology, intelligent control technology combined with oil field water injection demand, developed a new and reliable water injection system, realized the layered injection allocation under different deviation, full automatic control and monitoring data, and direct reading test. The technology in the implementation of 5 Wells in dagang oilfield, the implementation of maximum deviation 80 °, the maximum depth of 3661.52 m, the highest water flooding pressure 25 mpa, construction success rate reaches 100%, downhole test times 5 Wells, inspection accuracy of 100%. The results show that the cable type intelligent water flooding technology can not only realize downhole data real-time monitoring, real-time traffic regulation, and can complete the packer direct reading test, and the measurement process is reliable and efficient, at the same time solve the high Angle well, horizontal well can't test the technical problem, provides the high Angle well, horizontal well fine water injection technology support.

1. Introduction
The purpose of implementing fine water injection is to supplement formation energy to heterogeneous, multi-reservoir and complex fault block reservoirs, and to adopt scientific technological measures according to the number and property differences of target layers to control the water injection rate of water-absorbing layers in high permeability reservoirs. Increase the water injection volume of low permeability reservoirs with poor water absorption, and start the technical measures for non-water absorption reservoirs to achieve the effects of vertically balanced water injection, supplement formation energy, relieve interlayer contradictions and maintain formation pressure. Dagang oilfield belongs to a typical multi-layer system, heterogeneous complex fault block oil reservoir, with a buried depth of 800-4000m and a water injection pressure of 3-40MPa. The physical properties and water
properties of the oil reservoir and crude oil vary greatly. After 50 years of development, the main body has entered the middle and late stages of water injection development, and interlayer contradictions and water absorption differences have become increasingly prominent. At present, 95.6% of the blocks (130) and 86% of the reserves (7.6*10⁸ tons) belong to artificial water flooding. The water flooding conditions in the blocks are unbalanced and interlayer conflicts are prominent. Separate injection is required to improve interlayer treatment effect on a large scale.

The main separate injection technologies in Dagang oilfield are bridge eccentric separate injection and bridge concentric separate injection. There are mainly the following deficiencies:

1) The steel wire or cable operations used for water injection flow adjustment and sealing inspection cannot avoid the risks of fishing operations, and the measurement and adjustment time is long and the use in highly deviated wells and horizontal wells is limited.

2) Real-time monitoring and control cannot be carried out, only the instantaneous injection quantity can be monitored, and the water absorption change of each small layer cannot be reflected in real time;

3) When the change of water injection pressure or formation pressure disturbance causes the change of water injection volume, the flow rate cannot be adjusted in time when the water injection is unqualified.

In order to solve the existing technical problems of fine water injection technology, meet the needs of fine separate injection for highly deviated wells and horizontal wells, realize real-time monitoring and control of flow rate in each layer, and real-time monitoring of downhole pressure and temperature, the research and application of cable-type fine intelligent water injection technology were carried out.

2. **Cable type fine intelligent water injection technology**

Cable type fine intelligent water injection technology makes full use of mechatronics research results, takes underground intelligent water distributor and surface controller as core tools, takes cable as transmission medium, combines computer network communication technology, intelligent control technology and oilfield water injection demand, and forms a set of new and reliable water injection system. According to the technology, an intelligent water distributor is installed on each water injection layer, and the layers are separated by packers. The intelligent water distributor monitors the water injection amount of each layer in real time. The microprocessor adjusts the valve opening according to the settings to control the water injection amount to the required level. The microprocessor can communicate with the ground in two directions through cables, monitor the ground instructions at any time, and reconfigure the water injection amount of each layer.

2.1. **Cable type fine intelligent water injection technology system**

Cable type intelligent water injection process consists of underground intelligent water distributor, cable, sealing device, surface controller and data acquisition control system (as shown in Figure 1). Its core components are intelligent measuring and adjusting system composed of underground intelligent water distributor and surface control system.

![Figure 1. Block diagram of Cable type fine intelligent water injection technology system.](image-url)
2.1.1. Underground intelligent water distributor. The underground intelligent water distributor is composed of main body, flow passage, integrated adjustable water nozzle (including water nozzle, transmission mechanism and motor, etc.), circuit control sub-section, sealing test gauge sub-section and flowmeter sub-section (as shown in Figure 2). Each part is relatively independent and is connected by signal and control line for power supply and communication. The lower water injection flows through the flow passage, and the water injection in this layer is injected into the formation after passing through the flowmeter and adjustable water nozzle. The sealing test pressure gauge can monitor the water injection pressure in the pipe and the pressure in the outer layer of the pipe in real time, and has the sealing test function. The flow passage and each functional sub are completely sealed.

Figure 2. Underground intelligent water distributor

The upper part of the integrated adjustable water nozzle ceramic piston is a sealed cavity and is not affected by pressure. The stress areas at both ends of the connecting rod are exactly the same, and the pressure acting on the connecting rod will not exert a force on the whole, thus achieving the purpose of balanced pressure design. Therefore, the opening and closing of the piston downhole is not affected by the downhole high pressure. A travel switch and a displacement sensor are installed in the transmission mechanism to measure the position of the piston and the opening of the water nozzle.

An in-tube pressure sensor and an out-of-tube pressure sensor are installed on the nipple of the sealing test pressure gauge. After the adjustable water nozzle is completely closed, the automatic sealing inspection function can be realized by measuring the internal and external pressure difference. The pressure sensor is imported sensor, and the temperature sensor is pt1000 platinum resistor. Flow rate, formation pressure, water injection pressure and temperature can be monitored in real time and for a long time through cables, which has important guiding significance for fine description of formation characteristics and improvement of water injection efficiency.

Table 1. Technical indexes of underground intelligent water distributor

| Parameter                                    | Value                                          |
|----------------------------------------------|-----------------------------------------------|
| Outside diameter of water distributor        | Φ114mm                                        |
| Internal drift diameter of water distributor | Φ46mm                                         |
| Length of water distributor                  | 1900mm                                        |
| Maximum working temperature                  | 150℃ (297℉)                                  |
| Maximum working pressure                     | 60MPa (8702psi)                               |
| Effective working hours                      | ≥3 years                                      |
| Pressure measuring range                     | (0–60) MPa Accuracy 0.1%FS                    |
| Temperature measurement range                | (0–150) ℃ Accuracy±0.5℃                      |
| Single layer flow measurement range          | (0–400) Cubic/Day Accuracy±2%, Range selectable |
| Single layer flow regulation range           | 0–30(101), 15–150(102), 40–500(103) Cubic/Day |
| Maximum number of instruments in series      | 8                                             |
| Operating voltage and current                | (60–70) VDC/44mA                              |
| Maximum transmission distance                | 5000m (Φ5.6mm Double armored cable)           |
| Maximum regulated pressure difference        | 30MPa (4350psi)                               |
| End Thread (Upper/Lower)                     | TBG2 7/8”Flat type                            |
| End Cable Head (Upper/Lower)                 | Φ5.6mm, Φ8.0mm Double armored cable           |
| End connector (upper/lower)                  | Φ5.6mm, Φ8.0mm Double armored cable           |
The outer diameter of the high-temperature motor and reducer set is 21mm, the rated torque is 4N·m, the maximum working temperature is 150℃, and the performance is reliable. A travel switch is designed on the transmission mechanism to cut off the power supply of the motor after the water nozzle is fully opened and closed in place. At the same time, measures such as current limiting and short circuit protection are also designed on the circuit to ensure the reliability of the motor in long-term operation. The technical indexes of underground intelligent water distributor are shown in Table 1.

2.1.2. Ground control system. The ground control system consists of ground controller and operation control software. The ground controller (as shown in fig. 3) adopts bus addressing mode. A single-core cable can be used to connect up to 8 underground water injection horizon intelligent water measuring and distributing devices. The reliable communication distance is more than 5000 meters. Its main functions include: power supply function, codec function, control function, data storage function and wireless remote transmission function.

1) Power supply function: input commercial power (165~265) VAC to supply power to downhole instrument, with adjustable output voltage of 60~150V and output current of 0~1A.

2) Encoding and decoding function: receive the command from the upper computer and send it to the corresponding downhole instrument. The downhole instrument receives the command and returns the corresponding data. The controller receives the data returned by the downhole instrument and returns it to the upper computer.

3) Control function: the controller monitors downhole flow, internal and external pressure and temperature data in real time. It has a manual mode and an automatic mode. The manual mode is used for manual adjustment on site. In the automatic mode, the user sets the parameters and writes them into the controller, which automatically performs measurement and acquisition according to the set parameters.

4) Storage function: the surface controller can store the logging data of each water injection layer in the U disk module to facilitate the upper computer software to play back the data of each layer and analyze the water injection results.

5) Wireless remote transmission function: the ground controller can communicate with the remote central control room in two directions through the digital oil field network, and the central control room personnel can remotely control the state of each layer of water distributor.

Figure 3. Ground controller

The operation control software can carry out real-time two-way communication with the underground intelligent water measuring and distributing device through the surface controller, and issue commands to change the water injection volume of each horizon; Receive the flow rate, pressure and other measurement data sent by the downhole water distributor for permanent monitoring. The monitoring results can be displayed on the screen in the form of logging curves or stored in the
database. There are two ways to control and allocate underground water injection on site: automatic and manual. During automatic gear shifting, only the water injection quantity to be adjusted in a certain horizon needs to be input, and the underground intelligent water measuring and adjusting device and control software automatically adjust according to the algorithm; In manual operation, the upper computer control software manually sends the controller an instruction to increase or decrease the flow rate, so as to adjust to reach the required water injection rate. The technical indexes of the ground controller are shown in Table 2.

Table 2. Technical specifications of ground controllers

| Specification                                                      | Value                  |
|------------------------------------------------------------------|------------------------|
| Working temperature                                              | (-40~85) °C            |
| Effective time                                                   | ≥3year                 |
| Rated operational voltage                                        | 220VAC±10%/50Hz        |
| Output current range                                             | (0~1) A                |
| Output voltage range                                             | (60~130) VDC           |
| Minimum adjustment interval for automatic measurement and adjustment | 1 day                  |
| Minimum sampling interval                                        | 4 second               |

2.1.3. Power supply communication cable. The tool section uses Φ6.25mm steel pipe cable as the communication and power supply cable. The corrosion resistance, impact resistance and sealing performance of steel pipe cable are superior to plastic armored cable, and the sealing method is Swagelok metal sealing. It is reliable for long-term use and simple and fast to manufacture on site. Φ8.0 single-core double-layer plastic armored cable is used in the oil pipe section to reduce the cable cost. The power supply is connected to the middle cable core, while the cathode is connected to the outer steel wire or steel pipe. The signal shares the same cable core with the power supply in the form of carrier wave. Only a single cable core needs to be operated during sealing and butt-joint of field cables, which is convenient and reliable.

2.2. Main parameters of Cable type intelligent fine water injection technology

| Parameter                                 | Value          |
|-------------------------------------------|----------------|
| Applicable well deviation                | ≤90°           |
| Applicable well depth                     | 0~5000m        |
| Maximum single layer injection           | 500 m3/d       |
| Pressure working range                    | 0~60MPa        |
| Temperature operating range               | 0~150 °C       |

2.3. Features of Cable type intelligent fine water injection technology

1) The layered water injection control can be completed in one pipe string construction, the injection allocation does not need surface test adjustment, and the application problems of inclined wells and horizontal wells can be solved at the same time.

2) Each water distributor has a unique address code, and the confirmation of underground water distributors is simple and reliable, which can meet the requirements of fine layered water injection or small interlayer layered water injection.

3) The water injection flow rate of each layer is automatically detected and adjusted, which is not affected by water injection pressure and formation disturbance and ensures long-term stability and accuracy of injection allocation.

4) It can monitor the temperature, formation pressure and flow rate of each horizon for a long time and realize automatic sealing inspection underground.

5) Ultra-low power consumption circuit design and advanced mechatronics technology ensure reliable underground work for a long time.
3. **Cable type fine intelligent water injection process string matching**

The structure of the three-stage and three-section Cable type fine intelligent water injection process string is: anchor device+cable packer+intelligent water distributor+cable packer+ intelligent water distributor+cable packer+intelligent water distributor+intelligent water distributor+double ball seat+screen pipe+plug and other downhole tools. The underground intelligent water distributor is connected by cables, as shown in Figure 4 below.

![Cable type fine intelligent water injection process string diagram](image)

**Figure 4.** Cable type fine intelligent water injection process string diagram

4. **Field application of Cable type fine intelligent water injection technology**

The application of cable type fine intelligent water injection technology to five wells in Dagang Oilfield has achieved remarkable results. The maximum well deviation is 80°, the maximum well depth is 3661.52m, and the maximum water injection pressure is 25MPa. Among them, the first floor flow of Zhuanghai 4-H4 shows 31.254 ㎡/d, the temperature value is 54.71℃, the internal pressure value is 26.708Mpa, and the external pressure value is 25.951Mpa; The second floor flow shows 19.993 ㎡/d, temperature value 57.56℃, internal masonry value 26.875Mpa, and external pressure value 26.752Mpa. Statistics of specific implementation wells are shown in Table 3 below.

| Well No      | Well deviation/(°) | Well depth/(m) | Number of layers for separate injection | Injection volume/(m³) | Actual injection quantity/(m³) |
|--------------|--------------------|----------------|-----------------------------------------|------------------------|--------------------------------|
| Zhuang hai4-H4 | 80                 | 1758.22m       | Three levels and three segments         | 30/20/0                | 31.2/19.9/0                    |
| Zhang hai29-32L | 74.8              | 3610m          | Two level two segments                  | 20/30                  | 18.9/31                        |
| Zhuang hai8Es-L6 | 75.3             | 3368.1m        | Two level two segments                  | 60/40                  | 62/40.2                        |
| Ban68-22       | 23.83             | 1975m          | Three levels and three segments         | 30/50/30               | 30.5/51/32                     |
| Banxin43-1     | 30                | 3661.52m       | Three levels and three segments         | 30/50/30               | 29.3/50/31                     |
5. Conclusion

1) Cable type intelligent fine water injection technology has been applied to 5 wells in Tanhai Oilfield and Banqiao Oilfield with a maximum deviation of 80°. The maximum well depth is 3661.52m, the maximum water injection pressure is 25MPa, the success rate of construction reaches 100%, and the sealing accuracy rate is 100% after 5 wells are sealed underground.

2) It can monitor and adjust the stratified injection allocation in real time and intuitively, make the allocation more timely and convenient, ensure that the qualified rate of water injection reaches a higher level, realize efficient water injection, and provide effective technical guarantee for further subdivision and potential tapping.

3) The results show that the technology can not only monitor the data and adjust the flow rate in real time, but also complete the packer direct reading sealing test. The testing and adjusting technology is reliable and simple, greatly saving the workload after production. At the same time, it solves the technical problem that high-angle wells and horizontal wells cannot be measured and adjusted, and provides technical support for fine water injection in high-angle wells and horizontal wells.

Acknowledgments

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