Application of wireline intelligent separate-layer water injection technology in Huabei Oilfield

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Abstract. In order to increase the separate-layer water injection effect of heterogeneous sandstone reservoir in Huabei Oilfield, improve the qualified rate of water injection and reduce the workload of sealing, testing and adjustment, the wireline intelligent separate-layer water injection technology was used. This technology can remotely read the downhole water injection flow, temperature, pressure which was collected by the intelligent water distributor in real time on the ground. And it also can adjust the nozzle size of the intelligent water distributor in real time to make the sealing test and adjustment work easily. Up to now, there are 180 wells were implemented by wireline intelligent separate-layer water injection technology in Huabei Oilfield. This paper introduces the characteristics, key tools and construction auxiliary devices of the wireline intelligent separate-layer water injection technology. And it also evaluates the effect of the 33 wells which were implemented in the past year. The effective probability of 33 well groups is 92%, and that of corresponding wells is 83.8%. The cumulative oil increment is more than 277830 bbl and it has saved the cost of sealing test and adjustment work by 33.12 million yuan. The effect is remarkable on cost decreasing and benefit increasing. The wireline intelligent separate-layer water injection technology can improve the water flooding oil recovery effectively and it is helpful to the accurate development of oil reservoir. This technology has great value of application and popularization.

1. Introduction
Currently, Huabei Oilfield mainly developed in sandstone blocks, most of which are heterogeneous multi-layered reservoirs in continental sediments. With the oilfield is developed into the middle-late stage, the water cut increases, while the contradictions between layers have become increasingly prominent [1, 2]. The recovery rate is low due to the effect by inter-layer interference. General water injection cannot meet the needs of production, so the layered water injection technology has been developed rapidly. Since 2012, the number of injection wells in Huabei Oilfield has been increasing year by year, and the degree of subdivision has been gradually improved. The injection effect also has been greatly improved thanks to the introduction of bridge eccentric, bridge concentric, high-efficiency testing and adjusting separate injection technology [3-5]. But at the same time, there are also problems such as long measurement and adjustment cycle, rapid decline of the inspection and distribution pass rate, and the inability of instantaneous measurement and adjustment method can’t achieve the long-term continuous monitoring of important parameters such as stratified flow rate and injection pressure. On the other hand, it also can’t meet the data demand for reservoir analysis and
evaluation [6-8]. As the measurement and adjustment workload has increased year by year. It has reached 3,040 well times by now, which requires a lot of manpower and material resources.

In view of the above situation, Huabei Oilfield has gradually explored and implemented wire-line intelligent separate-layer water injection technology since 2014. This technology can realize real-time monitoring and automatic measurement and adjustment of parameters such as injection volume, injection pressure and temperature of the whole process to ensure the distribution pass rate and reduce the workload of testing and adjusting. It can also provide a large amount of data support for reservoir analysis and evaluation [9]. The wire-line intelligent separate-layer water injection technology is conducive to the precise development of oil reservoirs and has broad application value.

2. Wire-line intelligent separate-layer water injection technology

The wireline intelligent separate-layer water injection technology is mainly composed of cabled intelligent water distributor, cable-through packer, downhole supporting tools, ground control instrument and remote data transmission system. The schematic diagram of the process principle is shown in Figure 1.

| Number | Comparison index | Wireline intelligent separate-layer water injection | Conventional separate-layer water injection |
|--------|-----------------|---------------------------------------------------|---------------------------------------------|
| 1      | Construction work | Work with cable, long work cycle, cannot realize operation under pressure. | Conventional operation, can realize operation under pressure. |
| 2      | Sealing test and adjustment | Real-time test and adjustment, direct reading of the results. | Download seal and test equipment (once every 3 months) |
| 3      | Adjust injection allocation | The central control room sends instructions remotely, and the water dispenser adjusts itself. | Download the measuring instrument to adjust the opening of the water nozzle. |
| 4      | Dynamic monitoring | Real-time monitoring | Timing point measurement |
| 5      | Cost input | High cost of measures, almost no investment in the later period, high comprehensive benefit. | Low cost of measures, high cost of later inspection. |

Each water injection interval has an intelligent water distributor. The distributors can monitor parameters such as flow, temperature, water injection pressure and formation pressure for a long time, it can also automatically control the opening of the water nozzle to control the water injection volume within the allowable error. And each layer is separated by a cable-through packer to prevent
interference between layers. Each intelligent water distributor and cable-through packer is equipped with cable joints and is connected by cables, the cables above the tool section need to be punched with a cable protection card at the coupling every time an oil pipe is run into the well. Finally, the cable is penetrated by the wellhead sealing tee set at the casing gate and connected to the ground control cabinet. The ground control cabinet can communicate with the remote control room to detect or reset the water injection volume of each layer, check the pressure and temperature of the water injection layer, and detect the sealability of the packer.

Table 1 shows the comparison between wire-line intelligent separate-layer water injection technology and conventional separate injection technology. The advantages of the former are obvious.

3. Key tools and auxiliary device for construction

3.1. Intelligent water distributor

The cabled intelligent water distributor is mainly composed of upper joint, flow channel, integrated adjustable water nozzle, differential pressure flowmeter, sealing nipple, control circuit and lower joint. Each part is relatively independent, and is connected by signal and control lines for power supply and information transmission. The structure of the intelligent water distributor is shown in Figure 2. Its outer diameter is 114mm, and the internal flow diameter is 46mm, the body withstand voltage can reach up to 80Mpa.

Figure 2. Structural diagram of the wireline intelligent water distributor.

Figure 3(a) is a schematic diagram of the structure of the integrated adjustable water nozzle. Its symmetrical structure can balance the pressure and ensure successful opening and closing of the faucet under high pressure difference. It adopts grooved water inlet design to prevent the faucet from sanding; at the same time, the multi-sealing ring structure guarantees that the water nozzle is completely sealed in high-pressure environment. The water nozzle selects imported high-temperature motor and reducer group, with an outer diameter of 30mm, a rated torque of 6N·m, and a maximum operating temperature of 150°C, so its performance is reliable. The drive mechanism is designed with a travel switch, which can cut off the power supply of the motor after the water nozzle is completely opened and closed. At the same time, current limiting and short-circuit protection measures are designed to ensure the reliability of the motor's long-term operation. Figure 3(b) is a schematic diagram of the structure of the differential pressure flowmeter. The flowmeter uses orifice pressure differential flowmeter, a throttling device which is equipped with an orifice plate is installed on the fluid pipeline. The hole’s diameter is smaller than the inner diameter of the pipeline. When the fluid flows through the orifice plate, the cross-sectional area shrinks due to the smaller diameter, the steady flow state is disrupted, thus the velocity changes, the speed increases, the static pressure of the fluid decreases accordingly, as a result, a differential pressure is generated before and after the orifice [10]. The size of the differential pressure is proportional to the square of the flow rate. This flowmeter has the characteristics of high measurement accuracy, corrosion resistance, low drift and stable performance, which ensures the accuracy of downhole water distribution flow. Figure 3(c) is a schematic diagram of the structure of the sealing nipple. It adopts the design of dual pressure gauges inside and outside the tube, which can continuously monitor the pressure before and behind the mouth, in order to realize the self-inspection and sealing function.
3.2. Cable-through packer
Thanks to the introduction of bridge eccentric, bridge concentric, high-efficiency testing and adjusting separate injection technology, Huabei Oilfield has accumulated rich experience and formed a series of high temperature and highly deviated packers with independent intellectual property rights since started fine injection. The packer has a pressure differential capacity of 35MPa and a temperature resistance of 150°C. On this basis, in view of the situation that the cable needs to pass through the packer, the researchers innovatively developed high temperature and high-pressure resistance cable-through packer sealing joints and quick connection technology, and formed the cable intelligent separate injection series cable packer. Figure 4 is a schematic diagram of cable crossing. Cables between tools are connected through cable joints. The cable joints are connected to the passing joints of the cable packer. The cables inside the packer enters the packer through passing joints, goes out from the crossing joints and cable joints on the other side, and continues to transmit to the next level from the annulus.

Figure 4. Structural diagram of the cable penetration.

Figure 5 is the schematic diagram of the cable sealing joint. As is shown in the figure, the joint adopts three-stage sealing method to realize the sealing connection of cable crossing. The first stage seal is extruded rubber ring seal. Under the squeeze of the pressure cap, the rubber ring can seal the gap between the crossing cable and the cable connector to prevent the high-pressure liquid in the tool from entering into the cable joints along the cable during down-hole working conditions. The second stage seal is the rubber ring seal which matches the cable joints and the crossing joints. It can seal the hole of the crossing joints to ensure that the internal liquid will not leak. The third level seal adopts Swagelok metal seal, which can lock the connecting cable outside the tool to prevent the high-pressure liquid in the annulus from entering the cable joints along the cable and ensure reliable sealing of the cable joints.

Figure 5. Structural diagram of the cable sealing joint.
3.3. Auxiliary devices for construction

In the process of construction, packers and water distributors are connected by cables, and the cables above the tool section go down into the well together with the tubing outside the pipe. Aiming at the problems caused by cable construction, the author has developed a series of auxiliary devices for construction.

During the construction process, the cable is lowered into the well with the tubing at the wellhead. For each tubing run, the cable in the well must be straightened and a cable fastening protection card must be placed at the tubing coupling to make it as close as possible to the tubing wall. Figure 6 shows the 3D model of cable protection card. The protective card is casted by stainless steel, which can wrap the cable inside the protective card at the coupling, avoiding extrusion damage to the cable caused by the steps of the coupling during the process of going down the well, and providing reliable fixed protection for the cable.

![Figure 6. 3D model of the cable fastening protection card.](image)

When raising and lowering the tubing, the elevator at the well head is very easy to rotate or swing under the drive of the pipe string, and the cable is easy to be damaged or even broken by the elevator. In the early stage of construction and application of the wire-line intelligent separate-layer water injection technology, this situation occurred from time to time, which not only delays the working hours, but also causes an increase in costs. For this reason, the author has developed the wellhead cable extrusion preventer, its 3D model is shown in Figure 7. The cable extrusion preventer is connected to the injection wellhead through a flange, the extrusion preventer stand and the plate of the extrusion preventer are connected by bolts and nuts. The cable passes through the gap between the limit wheel sets, and is piped down into the well by passing the guide wheel under the sliding handle. During the whole running process, the cable is below the lower plane of the elevator, no matter how the elevator rotates and swings at the wellhead, it will not cause any damage to the cable. The limit wheel set can limit the movement of the cable in its gap without deflection; the guide wheel can prevent the cable from being scratched because of directly rubbing against the edge of the well head. When the sliding handle is in the upper position, it limits the horizontal position of the cable together with the guide wheel, so that it will not be higher than the upper plane of the cable extrusion preventer, when the sliding handle is in the lower position, it makes room for the cable, which is convenient for tightening the cable guard and straightening the cable from the well. After using this device, the cable is no longer damaged by the elevator.

![Figure 7. 3D model of the cable extrusion preventer.](image)
The existing wellhead devices of water injection wells cannot be closed during the construction interval because the cable is always in the well head during the construction, which will bring significant safety hazards and will also restrict the widespread application of the wireline intelligent separate-layer water injection technology. It is not conducive to the stable production and increase of oil field. In response to this situation, the author has innovatively developed a over-cable wellhead sealing device, as is shown in Figure 8.

When the well needs to be sealed during the interval of construction, the rectangular sealing ring, supporting ring and threaded ring shall be installed on the tubing hanger body in turn to ensure that the respective grooves are in line with the notched holes of the rectangular sealing ring. The tubing hanger is connected to the upper end of the pipe string in the well, the cut of the rectangular sealing ring is opened, the armored cable is embedded along the grooves and ensures that the cable goes into the holes of the rectangular sealing ring. When routine temporary well sealing is needed, just loose the rectangular sealing ring, tighten the threaded ring, lower the tubing hanger until the seat is hung on the chamfered surface in the raising nipple, and then tighten the jacking wire. The device not only passes through the cable but also seals the cable, which solves the problem of intermittent well sealing with wire-line intelligent separate-layer water injection technology.

![3D model of the over-cable wellhead sealing device.](image)

1-Tubing hanger body, 2-Raising nipple, 3-Rectangular sealing ring, 4-Supporting ring, 5-Threaded ring, 6-Cable

Figure 8. 3D model of the over-cable wellhead sealing device.

4. Application and effect analysis

4.1. General application
Since 2014, Huabei Oilfield has gradually explored and implemented the wireline intelligent separate-layer water injection technology, and the workload has increased year by year. In early 2017, the company decided to establish an intelligent separate injection demonstration area in Y63 block of TK oilfield for large-scale promotion. Up to now, Huabei Oilfield has implemented a total of 180 wireline intelligent separate-layer water injection wells, with the maximum separate injection stage of five stages and five sections, the maximum depth of 3477.35m and the maximum deviation of 55.25°. The author has made follow-up evaluation on 33 wireline intelligent separate-layer water injection wells in the past year, and the success rate is 100%, the effective probability of 33 well groups is 92%, and that of corresponding wells is 83.8%, the cumulative oil increase is more than 277830 bbl, and the annual cost of inspection, sealing, testing and adjustment has been saved by 33.12 million yuan, the water driving degree of TK oilfield has increased from 75% to 78%; the annual natural decline rate has decreased from 20.1% to 13.1%; the water cut increase rate has decreased from 3.21% to 2.00%.
4.2. Application examples

Taking well Y63-145 as an example, the depth of the well is 3056.6m, and three-stage and three-layer intelligent separate injection with cable is adopted for construction. The pipe string configuration is shown in Figure 9. After the string and cable are lowered to the design position, the magnetic positioning and depth correction are carried out. According to the depth correction results, the string is adjusted to ensure that the packer clamping point is away from the casing coupling and the upper and lower edges of the water injection layer. Before sealing, the wellhead cable shall pass through the cable tee set at the wellhead casing gate. Lift the string 0.35 m, pressurize the tubing 5, 10 and 15 MPa, each pressure lasts for 5 minutes, and observe the string hanging weight and casing overflow status at all times, keep the pressure well, the hanging weight drops about 1ton, and the casing continuous overflow disappears, lower the wellhead pressure of string seat 2-3 tons, continue to pressurize 20MPa, stabilize the pressure for 5 minutes, and complete the packer setting after slow pressure relief. After the wellhead is sealed, the wellhead and water injection pipelines are installed and the cables are reserved, the control cabinet installation and data remote transmission construction are carried out. After the sealing is completed, it can communicate with the underground intelligent water distributor through the ground control cabinet on site, open the water nozzle of the water distributor, and even complete the sealing inspection on site with the cooperation of the cement truck. It can be seen that the advantages of the wireline intelligent separate-layer water injection technology are very significant compared with the ordinary stratified water injection technology.

![Figure 9. Pipe string matching diagram.](image)

After the completion of the well construction and the start of water injection, the sealing test and adjustment show that the injection allocation meets the requirements and the packer is well sealed. Figure 10 shows the real-time monitoring curve of the whole process of production parameters such as downhole injection volume, injection pressure, temperature, etc. for 6 months. When the injection volume fluctuates greatly, the intelligent water distributor can automatically adjust the size of water nozzle in real time to make the flow meet the set injection volume and ensure the qualified rate of water injection at all times. When the geology needs to adjust the injection allocation, it only needs to send the command in the remote central control room to complete the communication with the ground control cabinet and the water distributor of the corresponding section underground, and then the injection amount of the section underground can be changed. The adjustment process can be completed in a few minutes, which is almost zero cost compared with the conventional separate injection using manpower and material resources to adjust the nozzle size to meet the injection allocation. The huge data obtained from real-time monitoring also provides reliable data support for
reservoir analysis. Table 2 shows the comparison of production data before and after the effectiveness of well group Y63-145. It can be seen from the table that after adopting the wireline intelligent separate injection technology, 4 of the 6 oil wells in the well group are effective, and the daily oil increase of the well group is up to 73.22 bbl without much change in the daily fluid production, with remarkable oil increase effect.

Table 2. Composition of the production data.

| Well number | Connected well | Effective well | Before the effectiveness | After the effectiveness | Daily oil increase (bbl) | Percentage increase (%) |
|-------------|----------------|----------------|-------------------------|------------------------|-------------------------|-------------------------|
| Y63-215     | 6              | 4              | 301.49                  | 304.43                 | 73.22                   | 174.6                   |

5. Conclusions

(1) The wireline intelligent separate injection technology can realize the real-time monitoring and automatic measurement and adjustment of the whole process of the water injection layer of the water injection well. The production parameters include injection volume, injection pressure, temperature, etc., and can realize the self-sealing function. It not only ensures the qualified rate of water injection in separate injection wells, reduces the workload of sealing test and adjustment, but also provides a lot of data support for reservoir analysis and evaluation, which has obvious advantages over conventional separate injection technology.

(2) In recent one year, 33 wells in Huabei Oilfield have used wireline intelligent separate injection technology. The supporting intelligent technologies, including water distributor, cable packer and construction auxiliary devices, have withstood the severe test of high temperature deep deviated wells, with a construction success rate of 100%. The effective probability of 33 well groups is 92%, and that of corresponding wells is 83.8%. The cumulative oil production has increased by more than 277830 bbl, saving 33.12 million yuan in the cost of inspection, sealing, testing and commissioning. The water drive production degree of the whole block has increased by 4%. The annual natural decline rate decreased by nearly 35%, and the water cut increase rate decreased by nearly 38%, cost reduction and efficiency increase are significant.

(3) The application of wireline intelligent separate injection technology in Huabei Oilfield has achieved good results, but at the same time, there is also the problem of long period of operation with cable, which restricts the popularization and application of the technology to a certain extent. In the next step, the author will carry out experimental research on non-contact docking, wet docking and whole well wireless communication technology in the pipeline on the basis of wireline intelligent separate injection technology.
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