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Research and Application of Long-life Water Injection Technology in High Water Cut Stage

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Abstract: The average service life of water injection strings in Shengli Oilfield is 3 years. In 2019, there were 20,060 workover operations, with workover costs reaching 6.297 billion yuan, and the oil production loss caused by workover occupancy amounted to 66,000 tons, which has seriously restricted the efficient development of the oilfield. Faced with the challenge of deteriorating overall development efficiency of water-flooded reservoirs in the high water cut stage of Shengli Oilfield, and based on meeting the full-life cycle functional requirements of separate-layer water injection strings for water wells, a multi-functional integrated separate-layer water injection string featuring "balance compensation + drillable bidirectional anchoring + multi-medium injection" was designed. It has been promoted and applied in 204 well times accumulatively, reducing 46 workover operations in total and saving 11.54 million yuan in expenses. This technology has prolonged the workover cycle of water wells and shown significant advantages in saving material input, reducing environmental pollution, and increasing effective production time. It has a very broad application prospect in oilfields both at home and abroad, and is of great significance for improving the sustainable and efficient development of water-flooded oilfields.

Keywords: High Water Cut; Long Service Life; Separate-layer Water Injection; Water Injection String.

1. Introduction

The old oilfields in the eastern part of Shengli Oilfield are mainly developed by water flooding. The water-flooded reservoirs include integral, fault block, low-permeability, and offshore ones, with a producing reserve of 3.509 billion tons, accounting for 74.9% of the oilfield area and 71.3% of annual oil production. They are the cornerstone of the stable development of the oilfield and an important base for the implementation of the "inventory efficiency and profit creation" strategy[1-5]. After more than 60 years of development, the water-flooded reservoirs in the eastern old oilfields have entered an extra-high water cut stage, with a comprehensive water cut of 92.4% and a recovery degree of 24.9%. With the deepening of water-flooded reservoir development and the re-understanding of fine reservoir description, new interlayer (intra-layer) contradictions have become more prominent. Under low oil prices, achieving low-cost reservoir development and low-cost process matching requires further improvement in the quality of separate-layer water injection[6-10].

In the later stage of high water cut, the water-oil ratio rises and development costs increase significantly. The oilfield has proposed to reduce the break-even point to below $50 per barrel during the "14th Five-Year Plan" period. However, the short service life of separate injection strings, high operation frequency, and high costs have become one of the restrictive factors for improving development efficiency in high water cut reservoirs. Water wells in the high water cut stage mainly face the following challenges: meeting the needs of water injection, profile control, and injection enhancement throughout the whole life cycle, extending the sealing life of packers in separate injection strings for high-temperature deep wells, and preventing sticking to avoid workover operations turning into major repairs in the later stage[11-12].

Foreign water injection strings mostly adopt bidirectional anchoring to improve the anti-creep ability of the string, which can better protect the packer rubber from being damaged by the expansion and contraction shear of the string. Split design is widely used, where the separate-layer string is released downhole, and the water injection tools and tubing are connected to the separate-layer string through insertion for sealed separate injection. Due to good water quality, foreign separate injection strings have no well-flushing channels. The service life of separate injection strings with permanent packers abroad can reach 8-10 years, and that with retrievable packers is 3-5 years, with temperature resistance of 150℃ and pressure resistance of 50MPa. Domestically, various process strings have been developed according to the complex reservoir types and working conditions of continental sediments, which can meet the separate injection requirements of various reservoir types such as integral, fault block, low-permeability, and offshore. In terms of high-temperature and high-pressure separate-layer water injection, Shengli, Zhongyuan, Jianghan, Tarim and other oilfields have carried out research and application of deep well high-temperature and high-pressure separate injection technology. Shengli Oilfield has developed a support-balanced separate injection string, which combines the advantages of anchored compensation strings and offshore balanced strings, optimizes the design of the support-balanced separate injection string, improves the stress on the string, and enhances the reliability of separate injection and inspection-replacement. It has a temperature resistance of 150℃, pressure resistance of 35MPa, and the validity period of the string is about 60% in three years. Jianghan Oilfield has developed an anchored compensation type ultra-high pressure water injection technology. The string is composed of Y241 type, Y341 type packers and string compensators, which can effectively anchor and centralize the string and realize string expansion compensation, meeting the needs of ultra-high pressure water injection above 35MPa, with an average validity period of about 300 days.

To address the above problems, a long-life separate injection string with "bidirectional anchoring + balanced stress + long-distance compensation" has been developed, supporting key technologies such as bidirectional anchoring and pressure balance compensation to eliminate the impact of string creep on packers and extend service life; the downhole tools are designed with "release and drillable" functions to effectively avoid string sticking and conversion to major repairs in later operations; and multi-functional injection methods such as "separate injection, acidizing, low-shear profile control, and static pressure measurement" are designed to meet the injection needs throughout the whole life cycle, eliminate unnecessary string moving operations, and extend service life.

2. Design of Long-life Multifunctional String

The focus of long-life string design is to find a balance between "long service life" and "major repair rate", that is, while achieving long service life, reduce or avoid the risk of major repairs during later inspection and replacement.

2.1. String Reliability Analysis

String creep leading to packer separation failure is one of the main factors for the short service life of the string. Therefore, it is necessary to calculate the string expansion and contraction in the free state of the tubing and the anchoring force in the constrained state under different load conditions such as pressure effect, temperature effect, and buoyancy effect during setting, water injection, well flushing and other working conditions. The assumed position of the packer is 3500m underground, and the assumed direction of the wellbore trajectory is vertically downward. According to the characteristics of the string structure, the quadrilateral shell element is selected as the element type for finite element simulation. The outer diameter of the tubing is 73mm, the inner diameter is 62mm, and the total number of elements is 400,000.

The force analysis of the pipe string under different working conditions is shown in the table below. Under the conditions of setting, injection stopping, lower layer water injection, well flushing, upper layer water injection, and simultaneous water injection with an 8MPa pressure difference, the creep stress of the 3500m separate-layer water injection pipe string ranges from -17.4t to 25.7t, and the creep amount based on the measured depth is 0.9m to 3.6m, with a creep activity range of 2.7m. For conventional suspended pipe strings under creep load conditions, the rubber cylinder is prone to tearing, and the packer unsealing mechanism is also easy to start, resulting in early unsealing.

Opinions on the reliability of the pipe string: The pipe string must be designed with anchoring and compensation. It is recommended that the pipe string adopt bidirectional anchoring with an anchoring force of more than 30t. The optimal compensation distance of the compensator is 2.7m. Considering processing and transportation, the compensation distance can be controlled at 2.0m, and the force generated by the excess distance shall be borne by the anchoring device.

Table 1. Force and Creep Analysis of Pipe String in Different States

state	measure depth	setting	injection stopping	lower layer water injection	well flushing	upper layer water injection	simultaneous water injection with an 8MPa pressure difference
creep amount, m	0.0	3.6	2.9	1.3	0.9	3.6	1.5
pipe string depth, m	3500	3503.6	3502.9	3501.3	3500.9	3503.6	3501.5
pipe string equivalent stress, t	0.0	44.2	25.5	51.1	8.1	48.2	41.7
creep stress, t		18.8	0.0	25.7	-17.4	22.7	16.2

2.2. String Structure Design

Based on the analysis in section 1.1, a multifunctional integrated separate-layer water injection string has been designed, which mainly consists of a long-distance balance compensator, drillable bidirectional anchor, high-temperature anti-aging packer, multi-medium injector, constant-pressure sand-settling well-flushing valve, etc. The balanced force and bidirectional anchoring technology realize long-life sealed separation of the separate-layer packers. The pressure balance and long-distance compensation technology eliminate pressure-induced self-elongation and prevent creep to extend service life. The dual-channel and multi-medium injection technology meets the injection functional requirements throughout the long-life cycle. The "lifting + drillable" dual-release technology achieves service life extension without major repairs and without increasing operation costs.

3. Design of Key Supporting Tools

It mainly includes anchored Y441, drillable Y341Z, drillable tubing anchor MZ, pressure balance compensator BCH, multi-functional water distributor, etc.

3.1. Drillable Y341Z Packer

The drillable packer type Y341Z is mainly composed of a setting mechanism, a sealing mechanism, a locking mechanism, a well-flushing mechanism, and an unsealing mechanism. The packer rubber sleeve is made of hydrogenated nitrile butadiene rubber, and the shoulder rubber sleeve is protected by a copper cover, resulting in excellent overall sealing and anti-aging performance; the upper and lower supporting parts of the packer rubber sleeve are drillable; the upper joint has a forward rotation releasing function.

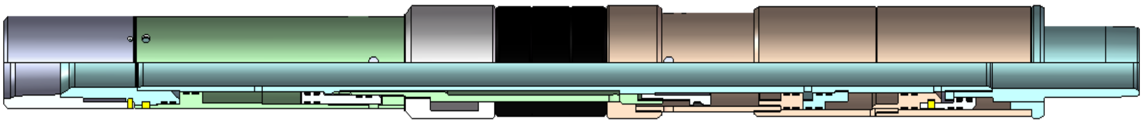


Figure 1. Structural Diagram of Drillable Packer

Working Principle: Setting. Positive pressure is applied inside the tubing, and the liquid pushes the starting piston upward through the pressure transmission hole of the central tube, shearing the setting shear pin, driving the sealing plug, upper piston, lower pressure ring, etc. to move upward together, compressing the rubber sleeve, and setting the packer; it is locked by the lock spring, and the rubber sleeve is not recovered. Well-flushing. The well-flushing fluid enters from the oil-casing annulus, pushes the well-flushing piston upward through the pressure transmission hole of the well-flushing cylinder sleeve, then passes through the Sandwiched cavity between the rubber sleeve shaft and the central tube - the pressure transmission hole on the locking sleeve, bypasses the rubber sleeve, and enters the oil-casing annulus at the lower end of the rubber sleeve. Unsealing. During later inspection and replacement, lift the pipe string to drive the upper joint, releasing joint, central tube, etc. to a certain tonnage (about 10 tons), shearing the unsealing shear pin; continue to lift, the central tube moves up to a certain distance, the lock spring is released, and the rubber sleeve is recovered by its own elastic force to realize unsealing. Releasing and drilling. When the pipe string cannot be lifted, the pipe string can be rotated forward to shear the releasing shear between the upper joint and the central tube, separating the upper joint from the central tube, and completing the releasing; lift out the upper pipe string, lower the casing milling barrel, which can drill and mill off the connecting part of the upper pressure ring, so that the upper pressure ring loses constraint, and the rubber sleeve is recovered by its own elastic force, realizing unsealing after releasing. Technical parameters: working pressure difference ≤ 35MPa; working temperature ≤ 150℃; releasing torque ≤ 2000N.

3.2. Development of Drillable Tubing Anchor

The drillable tubing anchor type MZ is mainly composed of a balancing mechanism, a bidirectional anchoring mechanism, a releasing mechanism, and a releasing mechanism. When resisting pressure difference, it can balance the force on the unsealing pin, reduce the unsealing force of the tubing anchor, and ensure that the tubing anchor is easy to unseal; bidirectional slip anchoring is used to prevent the pipe string from lifting and moving down, and the anchoring part is drillable; lifting the pipe string to unseal, forcing the cone to recover, making the tool easier to unseal; the upper joint has a forward rotation releasing function.

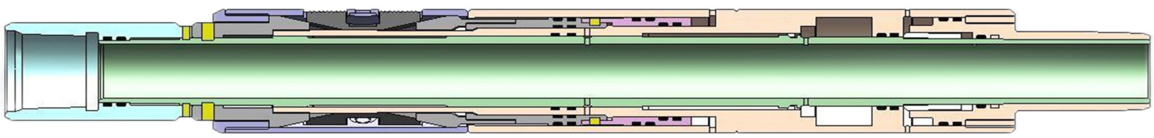


Figure 2. Releasable Drillable Tubing Anchor

Working Principle: Setting and clamping. Positive pressure is applied inside the tubing, and the liquid enters the piston cavity formed by the piston, auxiliary piston and upper cylinder through the liquid inlet channel of the central tube. Under the action of hydraulic pressure, a downward force is generated on the auxiliary piston to shear the setting shear pin, and the auxiliary piston moves downward. At the same time, the upper and lower lock blocks lose the restriction of the auxiliary piston, jump out of the locking sleeve and the central tube, the locking mechanism between the piston and the locking sleeve is opened, the piston, upper lock spring and lower cone move upward, the slips expand out of the casing to form anchoring, and the upper lock spring is locked on the locking sleeve to complete the setting and clamping. Unsealing. Lift the pipe string, the upper joint and the central tube move upward together, shear the unsealing shear, the central tube is separated from the lower joint, the upper step of the central tube hangs on the upper step of the upper cone, the threaded connection between the upper cone and the locking sleeve loses the restriction of the central tube, the upper cone is separated from the locking sleeve, the locking mechanism is opened, the upper cone moves upward, the slips lose the support of the cone, and are recovered under the action of spring force to complete the unsealing. Releasing and drilling. When the pipe string cannot be lifted, the pipe string can be rotated forward to shear the releasing shear between the upper joint and the central tube, separating the upper joint from the central tube, and completing the releasing; lift out the upper pipe string, lower the casing milling barrel, which can drill and mill off the bidirectional anchoring part, realizing unsealing after releasing. Technical parameters: working pressure difference ≤ 35MPa; working temperature ≤ 150℃; releasing torque ≤ 2000N·m; anchoring force ≥ 50t.

3.3. Development of Pressure Balance Compensator

The downhole balance compensating device is mainly composed of three parts: a balancing mechanism, a compensating mechanism and a control mechanism. The balancing mechanism is set so that the compensator is always in a balanced force state under the wellbore hydraulic conditions, and the compensating mechanism does not move with the change of internal pressure, but only moves with the relative movement of the upper and lower joints, which can meet the length extension requirements of the supporting pipe string caused by pressure effect and temperature effect.

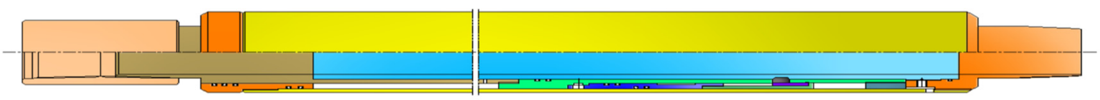


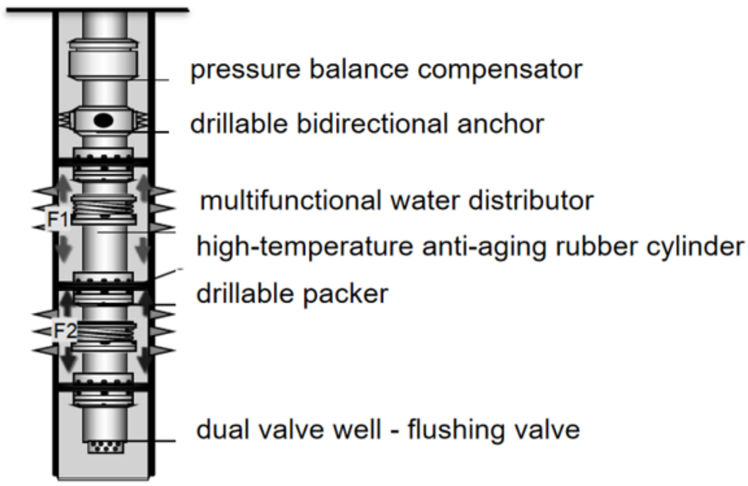
Figure 3. Structural Diagram of Pressure Balance Compensator

Working Principle: Activation. The tubing is pressurized to a certain value, and the piston shears the shear pin and moves down to a certain distance under the action of hydraulic pressure to release the lock block. At this time, the upper joint and telescopic tube can slide freely with the two parts of the retaining sleeve, outer cylinder and lower joint. Due to the setting of the balancing mechanism, there is no relative movement between the two parts under the action of internal pressure. Compensation. Under the action of pressure effect and temperature effect, the length of the pipe string expands and contracts, driving the relative movement of the upper and lower joints of the compensator; And further, driving the telescopic tube and the two parts of the retaining sleeve, outer cylinder and lower joint to slide freely, realizing the expansion compensation of the pipe string. Technical parameters: working pressure difference ≤ 35MPa; working temperature ≤ 150°C; compensation distance ≤ 1m.

4. Technical Application

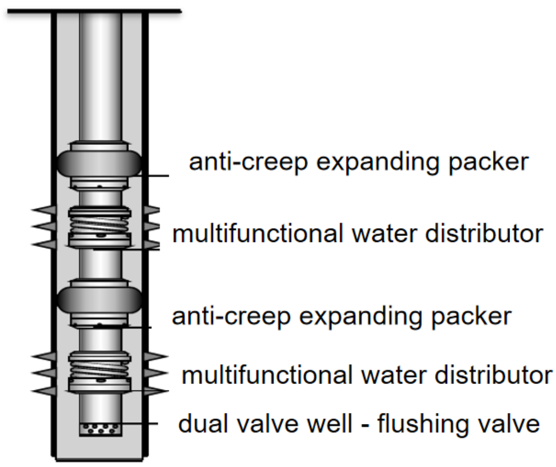
4.1. Supporting Modes for Long-effective Separate Injection String

Based on factors such as reservoir, well depth, temperature and pressure, a full-series and differentiated supporting mode of separate injection string has been formed, with the deep well mode centered on balance compensation + drillable bidirectional anchoring + anti-aging rubber cylinder and the medium-shallow well mode centered on pressure balance + soft anchoring anti-creep, which improves pertinence and reliability.



balanced separate - layer injection string
well depth≦4000m
interlayer pressure difference≦8MPa

Figure 4. Supporting Mode of Long-life Separate Injection String for Deep Wells



anti-creep expanding separate injection string
well depth≦2000m
integrated oilfield,shallow well,sand production

Figure 5. Supporting Mode of Long-life Separate Injection String for Medium-shallow Wells

4.2. Field Application

This technology has been applied in 204 wells in total in water-flooding reservoirs such as Binnan low-permeability and Gudong medium-high permeability reservoirs in Shengli Oilfield, with an average production cycle of 36 months and still effective. The implemented wells have reduced 46 operations in total, saving 11.54 million yuan. It has given full play to the technical advantages of prolonging the service life and improving the efficiency of water wells, effectively saved operation costs, reduced the time occupied by operations, lowered environmental pollution and safety risks, and provided technical support for the low-cost and high-quality development of the oilfield.

5. Conclusion and Insights

(1) A multifunctional long-life separate injection string integrating "bidirectional anchoring, balance compensation, releaseable and drillable, and split-flow injection" has been designed, forming a long-life water injection technology that meets the current needs.

(2) Specifications and standards for the application of the technology have been formulated, providing a guarantee for the large-scale application of the technology.

(3) This technology can effectively extend the operation cycle of water wells, showing significant advantages in saving material input, reducing environmental pollution and increasing effective production time, and providing technical support for cost reduction and efficiency improvement in water-flooding development.

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