Application of highly deviated well injection technology in Huabei Oilfield

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Abstract. With the deepening of oilfield development, the amount of highly deviated (≥30°) layered water injection wells have increased year by year. In order to solve the technical bottlenecks such as poor sealing of the columns and short effective period of dispensing. The self-supporting step-by-step releasable packers with the outer diameter of 114mm and the highly deviated well ball seat are developed. The packer integrates the function of centering-righting, ball centering, spiral righting and stepping unblocking and the ball seat has self-locking function and able to meet the requirements of pipe string used in highly deviated wells within 60°. Through the field application, a highly deviated well-dispensing process technology suitable for the characteristics of Huabei Oilfield has been formed, it has a strong popularization and application value.

1. Introduction

There are 214 sandstone reservoirs in Huabei Oilfield, among which 208 are complex fault blocks and stratigraphic-lithologic reservoirs, accounting for 97.2% of the of the total number of sandstone reservoirs. Moreover, most of the sandstone reservoirs in Huabei Oilfield are low permeability reservoirs. In 2011, the casing damage and casing deformation injection wells in Huabei Oilfield accounted for 11.1% of the total number of sandstone injection wells. Since adopting water injection, difficulties such as complicated reservoir conditions and deterioration of well conditions have been overcome. In addition, a dispensing technology system based on hollow separate-injection and supplemented by eccentric separate-injection has been formed. By 2011, the injection rate of Huabei Oilfield is only 16.9%, which is far from the average level of the PetroChina Co Ltd. Data analysis shows that 30%-40% of the water drive controlled reserves in water-driven sandstone reservoirs in Huabei Oilfield have not been effectively utilized, relevant technique needs to be developed urgently [1, 2].
Huabei Oilfield investigated advanced domestic fine dispensing technology, combined it with the reservoir characteristics and wellbore conditions, finally established two sub-injection demonstration zones in Al and Tongkou to carry out pilot experiment. After the construction of the demonstration area, the injection level of Huabei Oilfield has been significantly improved. However, due to the influence of high temperature (≥100°C) and highly deviated (≥30°) well conditions, the wells that haven’t achieved fine separation still account for 49.5% of the wells that should have, and the number is increasing year after year, its dispensing process directly affects the improvement of fine dispensing level. In view of the technical difficulties like poor sealing performance and short effective period of highly deviated wells, Huabei Oilfield has carried out independent research and development focusing on sealing of the pipe string and optimization design of the tools to continuously met the process requirement of fine water injection.

2. Tubing string and process principle

2.1. Tubing string

The highly deviated well-dispensing pipe column mainly adopts the bridge type concentric injection process, which is mainly composed of Y341 packer series, bridge concentric water distributor, anti-card anchoring device, etc. Meanwhile, it adopts bridge concentric high efficiency adjusting-testing technology to accomplish test and allocate.

As Figure 1(a) shows, the two-stage two-segment highly deviated dispensing tubing string consists of tubing hanger + oil pipe + anti-card anchoring device + safety joint + self-centralizing step by step releasable packer + concentric water distributor + ball centralizer + Y341-114 packer + ball centralizer + concentric water distributor + highly deviated well ball seat + screen + plug.

And as Figure 1(b) shows, the multi-stage highly deviated dispensing tubing string, taking three-stage three-segment tubing string as an example, the tubing string is made up of tubing hanger + oil pipe + self-centralizing step by step releasable packer + concentric water distributor + self-centralizing step by step releasable packer + concentric water distributor + ball centralizer + Y341-114 packer + ball centralizer + concentric water distributor + highly deviated well ball seat + screen + plug.

Figure 1. The schematic diagram of the tubing string.

2.2. Process principle

The self-righting step-by-step releasable packer, Y341-114 water injection packer, concentric water distributor and highly deviated well ball seat are used together, the distribution core of the concentric
water distributor is closed before going down the wells, the ball is thrown when the pipe string lowers to the position. The tubing presses the packer, the ball seat locking mechanism locks, leading to the steel ball confined in a certain space. Then, using high-efficiency test and adjustment technology to test and allocate the string [3-5]. When replacing the pipe string, unload the pipe column directly to release the packer and lift the pipe string.

2.3. Technical characteristics

(1) The centering and centralizing mechanism is designed and developed, ensuring that the highly deviated well packer is centrally located, improving the sealing and service life of the column.

(2) Adopting ball centering mechanism to reduce the frictional resistance in the process of lifting and lowering the pipe string.

(3) Adopting the step-by-step unsealing technology, which is beneficial to reducing the unsealing load when lifting the pipe string.

(4) The positioning and adjusting joints of the instrument downhole are both concentric position. The inclination of the wells has little effect on the success of docking, thus it can be adapted to the stratified water allocation needs of highly deviated wells.

2.4. Technical specifications

Maximum outer diameter of the pipe column: 114mm, working pressure difference: ≤35MPa, working temperature: ≤150°C, setting pressure: 18MPa, unsealing load of the packer: 10t, adapting casing: 5 1/2 inches casing.

3. Optimization design of the sealing of the pipe

3.1. Optimization design of the washing valve structure

Usually, the washing valves of the Y341 packer use metal surface seal (hard seal). This kind of washing valves have problems that sealing cannot be achieved when sands and mechanical impurities are stuck in, which is easy to result in leakage; meanwhile, after some of the high pressure layers of injection wells are washed, the flushing valve could not be closed can also cause the packer to fail. The Figure 2 shows the structure of the common washing valve.

![Figure 2](image)

**Figure 2.** The structure of the common washing valve.

For the above problems, the structure of the flushing valve has been improved, the seal of the washing valve and the valve seat has been changed from surface seal to line seal in order to overcome the problems of sand inclusion and loosing closing. In addition, the automatic return mechanism of flushing valve is designed to solve the trouble that the washing valve cannot be automatically returned and strictly sealed after opening and ensures the washing valve can be safely opened and closed. The Figure 3 is the 3D model of the optimized washing valve.
3.2. *Design of anti-convex mechanism of rubbers*

(1) Compression test and finite element analysis of rubbers

Compression deformation of rubbers is a key factor affecting the sealing ability of the column. The finite element analysis (Figure 4) and compression test (Figure 5) of rubbers shows that when reaching the setting load, the ends and shoulder of the rubbers is obviously bulged. In order to extend the life of rubbers, it is necessary to design anti-convex mechanism [6-9].

**Figure 3.** The 3D model of the optimized washing valve.

**Figure 4.** Compression test of rubbers.

**Figure 5.** Compression distance distribution cloud map of rubbers under 8 KN and 60 KN.
(2) Principle of anti-convex mechanism of rubbers

The anti-convex mechanism is mainly composed of a certain degree of copper ring and a specially designed rubber. The outer diameter of the mechanism is \(\phi 114\) mm. When the packer is set, the rubber extrudes the copper ring to deform, so that the copper ring is supported on the inner wall of the casing. This can effectively prevent the shoulder of the rubber tube from protruding, and improve the sealing and pressure difference performance of the rubber.

(3) Laboratory test of anti-convex mechanism of rubbers

Laboratory tests verified that the anti-convex mechanism designed can effectively prevent the shoulder of the rubber from protruding and improve the pressure difference performance. Figure 6 is the photo of the laboratory test. The test results are shown in Table 1.

![Figure 6: The photos of the laboratory test.](image)

| Material | External diameter (mm) | Temperature (°C) | Tension (Mpa) | Number of times | Result description |
|----------|------------------------|------------------|---------------|----------------|-------------------|
| HNBR     | 114                    | 130              | 40            | 4              | The upper pressure is not stable and the lower rubber cylinder is damaged. |
|          | 114                    | 130              | 40            | 4              | With the anti-convex mechanism, the test is qualified. And the residual change is 5%. |
|          | 114                    | 150              | 35            | 4              | The test is qualified, but the degree of the residual change is high |
|          | 114                    | 150              | 50            | 4              | With the anti-convex mechanism, the test is qualified. And the residual change is 3%. |
3.3. Design of centering-righting mechanism of packers
Due to the influence of the well inclination, the rubber is unevenly stressed when the highly deviated well-dispensing process pipe string is set, which affects the sealing of the column. In order to improve the stress status of the rubber, the centering and righting mechanism is designed and developed.

(1) Centering righting structure
The centering-righting mechanism is mainly composed of shoulder pad, elastic split, wedge and anti-convex bowl. Elastic split is threaded with shoulder guard, and the elastic split is cut into 12 equal parts by wire. The Figure 7 is the 3D model of the centering righting structure.

(2) Principle of the centering-righting mechanism
When the packer is set, the piston pushes the outer cylinder upward, the outer cylinder pushes the rubber, the spacer ring and the wedge upward, so that the elastic split valve is opened and supported on the inner wall of the casing to ensure that the packer is set centered and righted. The piston goes up and continues to squeeze the rubber, the anti-convex bowl is opened and closely attached to the elastic split, which can effectively protect the packer shoulder protrusion and improve the sealing performance of the packer.

(3) Characteristics of the centering righting mechanism
The main features of the centering righting mechanism are: 1) The elastic shoulder guard is supported on the casing wall when sealing, which effectively improves the sealing effect of the rubber and realizes centralization; 2) It can be forcefully recovered (600kg) when unsealing, which ensures the string is safely unsealed.

4. Design of dispensing packers and matching tools
4.1. Design of self-righting step by step releasable packers
(1) Design principles
For the deviated well injection string, the general design of pipe column used in highly deviated wells is centralizers both at the top and bottom of the step by step releasable packer, which causes the tool string to be too long and the passing performance downhole to be poor, on the other hand, the packer is not center sealed and easy to fail [10-12]. In order to ensure the downhole passing performance of the tool string in highly deviated injection wells and the successful deblocking of
multi-stage packers, a new type of short packer which integrates centralizing and gradually deblocking function was developed.

(2) Structure of the self-righting step by step releasable packer
As is shown in Figure 8. The self-righting step by step releasable packer is mainly composed of upper joint, ball centering mechanism, backwashing mechanism, centering righting mechanism, sealing mechanism, setting mechanism and screw righting mechanism.

(3) Working principle
The self-righting step-by-step releasable packers is a type of packer for unpacking and unsealing the hydraulic seal. When the tubing is pressed, the piston of the setting and unsealing mechanism pushes the outer cylinder upwards, the outer cylinder pushes the rubber of the sealing mechanism upwards. The elastic splitting of the centering righting mechanism is opened and supported on the inner wall of the casing. The piston continues to ascend, the rubber of the sealing mechanism is squeezed to compress and deform, completing the setting of the packer. When unsealing, the pipe string is lifted, the releasable shear studs of the setting and releasing mechanism is cut, the outer cylinder is recovered and the rubber moves downward, realizing the unsealing of the packer.

(4) Features of the tools
The main features of the self-righting step by step releasable packers are: 1)The backwash valve adopts line seal and automatic return mechanism to overcome sand trapping and loose closure; 2)The packer is highly integrated with centralizer, ensuring the passing performance of the tool string ; the upper and lower ends adopt steel ball righting and spiral righting respectively , which reduces the resistance during the tools running down in wells[13]; 3) The tools have the ability of rigid centering-righting and are able to bear high pressure difference after setting; 4)The tools have gradually-releasing function, which is beneficial to multi-stage series use, and able to adapt to the requirements of deep wells and large span between packers[14, 15]. Table 2 is the parameters of self-righting step by step releasable packer.

| Total length (mm) | Maximum outer diameter (mm) | Minimum drift (mm) | adaption casing (in) | Working temperature (°C) | Working differential pressure (MPa) | Sealing differential pressure (MPa) | Force of unsealing (KN) |
|------------------|-----------------------------|-------------------|---------------------|--------------------------|------------------------------------|-------------------------------|------------------------|
| 1367             | 114                         | 50                | 5½                 | ≤125                     | ≤35                                | 18                           | 80-100                 |
| 1367             | 114                         | 50                | 5½                 | ≤150                     | ≤35                                | 18                           | 80-100                 |

4.2. Design of highly deviated well ball seat
In view of the problem that it is difficult to drop the rod to the position in highly deviated wells, and easy to wash the steel ball out, the ball-threwed automatic closing seat for highly deviated has been developed. Its characteristics are: 1) the large dip angle design ensures stable sealing in case of high inclination (≤60°); 2) the ball seat can be automatically closed and locked when setting, which eliminates the risk of washing the steel balls to the ground during well washing. Figure 9 is the 3D model of the highly deviated well ball seat and the Table 3 is the parameters of it.
Figure 9. Highly deviated well ball seat.

Table 3. Parameters of highly deviated well ball seat.

| Total length (mm) | Maximum outer diameter (mm) | Adapting steel ball (mm) | Locking pressure difference (MPa) | Working temperature (°C) |
|-------------------|----------------------------|--------------------------|----------------------------------|--------------------------|
| 689               | 100                        | 42                       | 10                               | ≤125                     |
| 689               | 100                        | 42                       | 10                               | ≤150                     |

4.3. Improvement of the pipe column righting process

In order to guarantee the protection of the rubbers when the pipe string goes down to the well, reducing the wear of the dispensing tools, ensuring the pipe column is centered, improving the safety and sealing reliability of the pipe column, the righting process technology of inclined well pipe column is improved, it is characterized by: 1) the screw centralizer (Figure 10) uses carbon fiber reinforced polymers with small friction coefficient, which is mainly used for the central setting of the pipe column; 2) the ball centralizer (Figure 11) can rotate, converting slide friction into rolling friction, reducing the downhole friction of the tool strings.

Figure 10. Screw centralizer.  
Figure 11. Ball centralizer.

5. Field application

This technology has applied a total of 958 wells in Huabei Oilfield. The average effective period of layered water injection pipe string is 24 months and the longest is 42 months. The success rate is 100%, the sealing check qualified rate is 91% and the measuring-adjusting success rate is 86%. Beyond that, the split rate has increased from 22.7% to 42.6%, the maximum well deviation reaches 59.3°, the maximum well depth reaches 3590m, while the highest well temperature achieves 127°C. Tong Kou Oilfield is a key block of new capacity in Huabei Oilfield in recent years. 297 layers of 92 wells were sub-injected in Tongkou Oilfield, with an average of 3.2 layers per well. The water drive rate has been ascended from 53.9% to 78.0%. The differences between layers were significantly improved. In addition, the proportion of non-absorbent layers and strong water-absorbing layers decreased gradually. The efficiency of corresponding oil well is 79.5%, the monthly water-containing rising rate is reduced from 2.9% to -1.7%, the natural decline rate is reduced from 10.8% to -2.5%, all data above slowed down significantly.

Take the following Y63-181 well as an example. In order to enhance water-flooding recovery, the well adopts two-stages two-segment bridge concentric injection technology and high efficiency adjusting-testing technology to test and allocate the flow. The artificial bottom of the well: 3030.45m, the production well section: 2607.0m-2681.8m, the maximum well inclination: 59.3°. On October 2019, dispensing process was carried out. The pipe column structure is (from bottom to top): plug + screen + ball seat + tubing + concentric water distributor II + tubing + ball centralizer + Y341-114.
packer 2 (2618m) + ball centralizer + tubing + concentric water distributor I + tubing + self-centralizing gradually releasable packer 1 (2595m) + tubing + safety joint + tubing anchor (2585m) + short section for depth correction + tubing to wellhead.

On October 22, 2019, the seating seal was implemented: lift the pipe column 0.65m, and the suspension weight was 24t. Press 8MPa for 5min, the suspension weight decreased to 23t; press 12MPa for 5min; then continue to press 15MPa for 5min, lower the pipe string to the wellhead, the suspension weight reduced to 17t, the pressure is 6t; press 17MPa for 10min, the casing has no overflow and the seating seal is succeeded.

On October 25, 2019, the seal was tested by a direct-reading check-sealing instrument. First, the instrument is lowered under the second-stage water distributor and raised above the water distributor at the target layer. Open its positioning claws and sit on the concentric positioning step. In the case of normal water injection, the seal is directly read the sealant of the sealer and the "open-close-open" operation is performed at the wellhead, each time interval is 3 minutes. The seal state of the packer is recorded in real time, and then lift the instrument up to the upper stage water distributor, repeat the above procedure until the uppermost packer is tested.

6. Conclusions
(1) The separate injection technology in highly deviated wells solves the problem that the highly deviated wells (<60°) can not be effectively stratified water-flooded. Form a set of water-flooding technology suitable for highly deviated wells in Huabei Oilfield, which has the effect of stimulation and water control.
(2) The self-righting step by step releasable packer designed is short and integrates the functions of centering righting, ball righting, spiral righting and gradually releasing, which is beneficial for it to pass smoothly in highly deviated wells. It can bear high temperature up to 150°C while its pressure difference reaches 35MPa. In addition, its sealing performance is good and the unsealing performance is reliable.
(3) The highly deviated well ball seat developed can meet the requirements of layered water injection for highly deviated wells (<60°), it has self-locking function, which ensures the steel ball is not back-washed during back-washing.
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References
[1] Wang Jianhua, Sun Dong, Li Heyi, et al. 2011 Research on technology of fine stratified injection and its application Well Testing 04 41-44
[2] Yang Yanhui, Cui Kai, Wang Xiaofen, et al. 2009 Development policies optimization for controlling water of sandstone reservoirs in Huabei Oilfield Oil Drilling & Production Technology 31(S1) 101-105+109
[3] Lan Ganghua, Li Hongchun, Han Jin, et al. 2005 Separate layer water injection string for φ 101.6 mm wells China Petroleum Machinery 10 33-35
[4] Gu Xiao, Ding Jianhua and Wang Chengfang 2002 Separate layer water injection technology of special well Oil Drilling & Production Technology 51 82-83
[5] Teng Haibin 2014 Popularization and application of high efficiency and real-time measurement and control technology for water injection well Inner Mongolia Petrochemical Industry 40(17) 99-102
[6] Wu Kaisong, Zhai Zhimao, Gu Jianfei, et al. 2008 Optimization of Packer Rubber’s Geometrical Parameters Oil Field Equipment 37(10) 68-71
[7] Li Wei, Song Wei, Lei Hongxiang, et al. 2017 Design and analysis of new anti-extrusion device for packer rubber Chinese Journal of Engineering Design 24(03) 359-364
[8] Guo Zhaohui, Yang Dekai and Ma Lanrong 2011 Current research status for key technologies of forign liner top packer Oil Field Equipment 07 19-23
[9] Peng Taixiang and Shi Jianshe 2019 Research of integrated long-team separate layer injection string China Petroleum Machinery 47(08) 107-111
[10] Luan Zhongwei, Chen Ping, Wang Xuehong, et al. 2007 Separate zone waterflooding technology for small-size diameter Petroleum Geology and Engineering 02 69-71+9
[11] Fan Qing, Chen Yonghong and Wei Wei 2014 Failure analysis of packer rubber cylinder Well Testing 23(05) 48-50+77
[12] Zhang Xiongwen 2012 Failure analysis and improvement measures of oil well packer Inner Mongolia Petrochemical Industry 36(04) 44
[13] Liu Yufei, Wang Jinzhong, Zhang Jianzhong, et al. 2018 Long-lasting sealing and safe tripping technology for separate layer injection string in highly deviated well China Petroleum Machinery 46(08) 69-74
[14] Wang Jiliang and Yi Weikai 2017 Design of releasable staged fracturing string for cased hole China Petroleum Machinery 45(05) 107-110
[15] Xia Jian, Wang Zhongxiu, Yang Chunlin, et al. 2015 Research and application of layered water injection pipe string anchored by bottom support Oil Drilling & Production Technology 37(05) 89-91