Research and Application of Dual Packer Multistage Control Fracturing Technology in Horizontal Wells

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Abstract. There are some difficulties met in the horizontal well fracturing operation, such as difficult tripping the string smoothly in the well, large probability of sand stuck, high risk of operation and hard control in the field operation. In view of the problems mentioned above, the packing element of inflatable packer, the nozzle structure, phase and quantity of jet pores of pressure transmitting sandblaster were simulated with flow pattern optimization by using the ANSYS finite element analysis results and fluent flow pattern analysis software. The dual packer multistage control fracturing technology in horizontal wells was researched centring on repeated set inflatable packer with small diameter and flushable pressure transmitting sandblaster, which featured on highly targeted stimulation, high efficiency, sand stuck preventing and releasing function. The technological parameters of dual packer multistage control fracturing technology in horizontal wells are listed as follows: the temperature rating is 120 °C, the pressure rating is 80 MPa, the maximum sand loading volume in one trip is 245 m^3 and the maximum distance between two adjacent packers is 112 m. Up to 15 stages can be treated in one trip. The technology has been applied to 1978 intervals of 349 wells in Daqing oil field by now, with a success rate of 96.7%. The technology basically meets the fracturing stimulation needs of new and developed horizontal wells with different low permeability reservoir, which provides the strong technical support for exploiting the difficult recovered reserves in Daqing oil field.

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1 Introduction

Daqing periphery oil field is heterogeneous, multilayer sandstone oil field featured with low permeability, low abundance and thin reservoirs. It is commonly believed that horizontal well has larger contact area in the thinner reservoirs compared with the vertical wells. Moreover, fracturing is an effective method to increase conductivity near the wellbore and improve the horizontal wells' performance. There are some difficulties met in the horizontal well fracturing operation, such as difficult tripping the string smoothly in the well, large probability of sand stuck, high risk of operation and hard control in the field operation because of the special structure of horizontal well and reservoir characteristics. In the 1990s, Daqing oil field and Changqing oil field have carried out the exploratory tests of the Limited Entry Fracturing and the Sand Filling Plug Sectional Fracturing, respectively. In Daqing oil field, the accident of pipe stuck happened when the conventional inflatable dual packers were used to fracture the first horizontal well in the exploratory test in 2006. The fished pipe string through the overhaul workover operation showed that the seriously damaged packers were the main reasons to get the pipe string stuck [1]. The dual packer multistage control fracturing technology in horizontal wells was therefore researched centring on repeated set inflatable packer with small diameter and flushable pressure transmitting sandblaster.

2 String Composition of the Dual Packer Multistage Control Fracturing Technology

This pipe string is composed of safety joint, centralizer, hydraulic hold-down button, K344 inflatable packers, pressure transmitting sandblaster, centralizing end plug, etc (see Fig. 1).

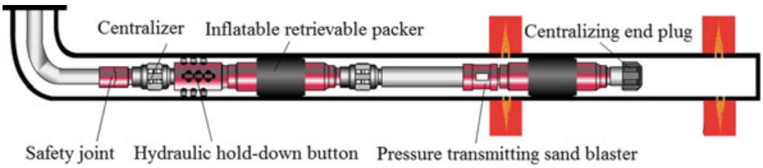

Fig. 1. Schematic drawing of multistage control Frac technology with dual-retrievable packers

3 Inflatable Packer with Small Diameter

3.1 Optimization of Steel Structure in Packer

In order to assure the safety of tripping the pipe string in the downhole, not only the outer diameter of the packer should be minimized, but also the packing element should be not scratched to reduce its residual deformation, which could guarantee the high efficiency and multistage fracturing when pulling up the pipe string. The movable steel structure is designed to reduce the residual deformation of the packing element, which improves the force condition of the packing element and provides the maximum free space for the expansion and contraction of packing element. The multiple fatigue tests for repeatedly setting and releasing the packer showed that the residual deformation of packing element decreased from 17 to 2.7%. It solved the problems of large residual deformation for the packing element, such as the phenomena of distortion and deformation beyond the steel structure happened on the assembly test, which improved the overall pressure of the packer and safety performance of tripping the pipe string.

3.2 Inflatable Packing Element with Small Diameter

The accident of pipe stuck happened when the conventional inflatable dual packers were used to fracture the first horizontal well in Daqing oil field. The traditional nylon cord was transformed into the combination of steel wire and the nylon cord when designing the packing element of the inflatable packer with small diameter. The outer diameter of the packing element was reduced from 113 to 105 mm, so the temperature resistance dropped to 70 °C and pressure rating was only 40 MPa, which could not meet the requirements of fracturing. Therefore, further studies were carried out as follows. First, the rubber element was modified from NBR to HNBR, and adding proper amount of nanoscale additives in HNBR. Second, the combination of steel wire and the nylon cord was upgraded to the combination of steel wire and aramid cord with higher strength. The problem of poor bonding property between aramid and rubber was solved by special treatment technology, so that steel wire, rubber, mucilage and aramid cord can be integrated into one piece with no slices when being vulcanized into the packing element. Moreover, exploratory design and test on the arrangement angle of steel wire and cord were carried out (see Fig. 2). The deformation rate of several different materials in the packing element tends to be consistent, so as to solve the steel wire or cord broken problems when the packing element is under working operation. Third, non-imprint mould and the matching vulcanization process were designed. The original imprint mould being replaced by non-imprint mould brings great difficulty to the vulcanization process. Therefore, the special mould pressing vulcanization process has been studied to solve the problem mentioned above, thus avoiding the cracking of the packing element in the longitudinal imprint line and improving the stability of the parameters of the packing element (see Fig. 3). Fourth, through the analysis of ANSYS finite element method on the stress distribution, the maximum stress position of flexible packing element is on the shoulder of element [2] (see Fig. 4). Shoulder protectors were designed for the packing element of the inflatable packer.

Fig. 2. Structure layout of steel wire and aramid cord

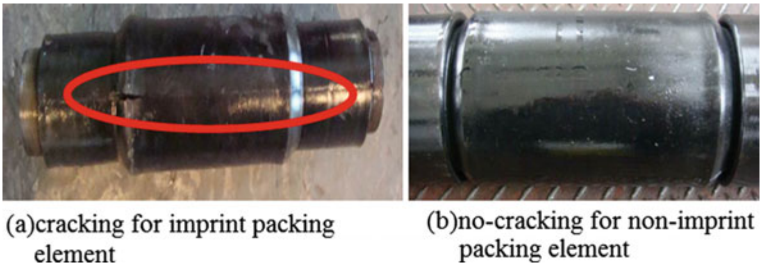

Fig. 3. Comparison between imprint and non-imprint packing element mould

Through the above improvement, a large amount of oil immersion test for inflatable packing element with small diameter was performed to make the packing element resist the temperature increasing from 70 to 120°C and pressure increasing from 40 to 80 MPa (see Table 1) [3]. The improved inflatable packing element with small diameter basically meets the needs of dual packer multistage control fracturing in horizontal wells of Daqing peripheral Putaohua and Fuyu reservoirs.

4 Pressure Transmitting Sandblaster

The function of pressure transmitting sandblaster is integrated with the pressure transmitting, sandblasting and throttle together, which is vital in the fracturing technology. First, the pressure transmitting passage is reasonably designed. The conventional pressure transmitting passage is located on the inner wall of the tool that is easily worn by the sand. Serious wear abrasion can affect pressure conduction. Even the unfiltered fracturing fluid flows into the lower packer, which will lead to the invalid zonal isolation of the lower formation or sand plug for the lower packer to make it

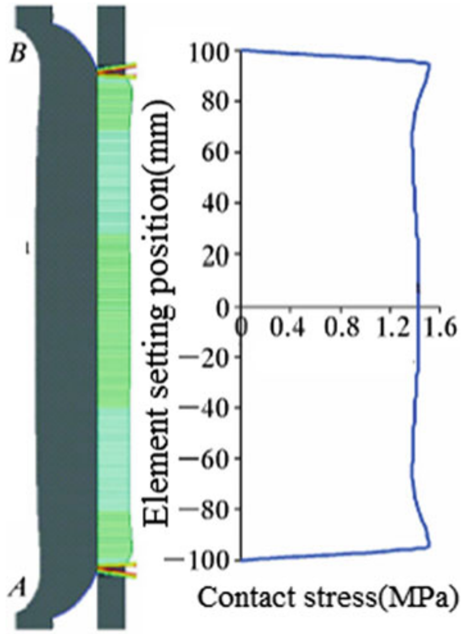

Fig. 4. Stress analysis diagram of inflatable packer

Table 1. Oil immersion test for inflatable packing element with small diameter

Oil immersion temperature (°C)	Oil immersion time (h)	Fatigue test (MPa × min × times)	OD before oil immersion (mm)	Max. OD after oil immersion (mm)	Maximum distortion (%)
120	4	80 × 5 × 5	105	107.8	2.67
120	16	80 × 5 × 10	105	108.1	2.95

difficult to release. Therefore, the structure design of the outer wall is optimized to enhance the sand loading volume and reliability. Second, the nozzle structure of sandblaster is optimized. The conventional nozzle shape of pressure transmitting sandblaster is long slot type. When the sand loading volume reaches 45 m^3, severe wear abrasion problem will happen. The flow pattern simulation analysis with the software of Fluent was applied on the nozzle with long slot type and multi-pore type individually. Meanwhile, the material of carbide liner is optimized. The results show that the flow pattern in the multi-pore type is much better than that in the long slot type. The sand carrier can flow through the pores evenly and avoids the serious wear abrasion phenomenon in some parts of the tool. Third, the outlet angle of jet nozzle is optimized and the diagram of the relationship between operation displacement and throttle differential pressure is set up to provide theoretical basis for the selection of nozzle with reasonable size (see Fig. 5). The diagram shows that the differential pressure of the nozzle is gradually increased with the decrease in the nozzle diameter under certain operation displacement, and the increasing trend is rather obvious. So the diameter of the nozzle has a great influence on the differential pressure. Pressure loss curve of the original structure is located between D = 23 mm and D = 25 mm of the optimized structure [4].

All the improvement and innovation, such as the pressure transmitting passage, the outlet angle of jet nozzle, the optimization of nozzle structure, the material selection of

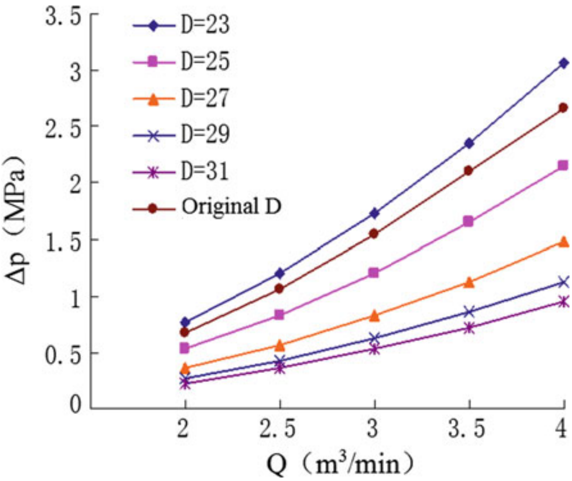

Fig. 5. The diagram of the relationship between operation displacement and throttle differential pressure

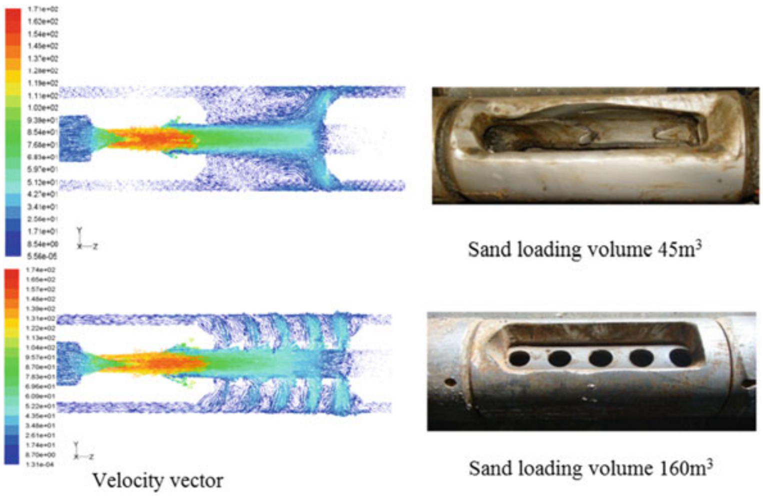

Fig. 6. Performance comparison chart before and after the improvement on the pressure transmitting sandblaster

liner and the diagram of the relationship between operation displacement and throttle differential pressure, make the sand loading volume increase from 45 to 160 m^3. The pressure transmitting sandblaster is only slightly worn (see Fig. 6), and it can still normally work even when the maximum sand loading volume being increased up to 245 m^3.

5 Sand Stuck Preventing, Sand Stuck Releasing Technique

For the Frac service, it is no denying that safe Frac operation is the most important thing. The dual packer multistage control fracturing technology is supposed to have functions of the sand stuck preventing, sand stuck releasing which can effectively reduce the risk of operation in the field. For the sand stuck preventing measure, the tools are designed as small diameter and short length. It has a low profile for greater running clearance to help reduce problems that may occur when running in horizontal wells. After fracturing the specific interval, reverse sand flushing can help clean the sand deposit between two adjacent packers to prevent the pipe string stuck when pulling up the string. For the sand stuck releasing measure, stage the steel ball from the well head to depart the safety joint from the other tools. The tubing above the safety joint can be picked up from the wellbore. There is a standard inner passage with 62 mm diameter for the fishing tools to mill or drill the stuck string.

6 Anchoring and Conductively Centralizing Technique

It is necessary to have the anchoring and conductively centralizing technique through the mechanical calculation of the pipe string in horizontal well (see Fig. 7) and the analysis of the flow pattern. They can prevent the string from moving upward or downward during the fracturing operation; flush the sand deposit by the reverse circulation; improve the sealing performance of packers; and provide the technical support for the multistage fracturing with long distance between two adjacent packers.

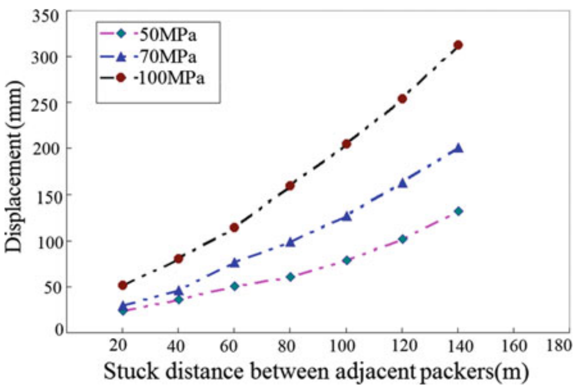

Fig. 7. Displacement contrast of lower packer under different pressure and different stuck distance between adjacent packers

7 Double-Channel Manometer Monitoring Technique

The manometer consists of four parts: sensor, memory, power supply and ground replay equipment. Among them, the first three parts are made up of downhole instruments. The electronic memory stores the data, and then, the sensor transmits the pressure/temperature induction frequency.

Before the fracturing operation, the storage temperature manometer is placed inside the manometer protecting carrier (see Fig. 8). Then, the manometer is run into the downhole with the fracturing pipe string to the measured depth and pulled out from the wellbore after fracturing operation, which likes an "electronic eye" to fully record the change of tubing and casing pressure during the fracturing operation. The recorded data in real time can judge the sealing performance of packers. In the fracturing operation, if the casing pressure of the lower manometer changes with the casing pressure of the upper manometer, it is proved that there are interlayer channelling problems or the packer is not sealed. On the contrary, if the casing pressure of the lower manometer does not change with the casing pressure of the upper manometer, it is proved that the packer is under the sealing performance [5]. When replaying the test data, the manometer is connected with the computer. The software converts test data into time, pressure and temperature files and then converts the data into a form or other curve formats (see Fig. 9).

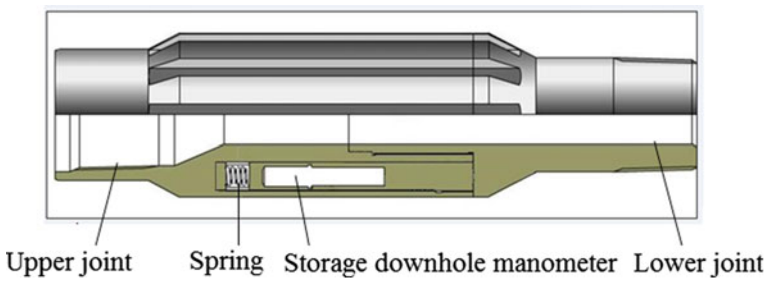

Fig. 8. Structure schematic drawing of manometer

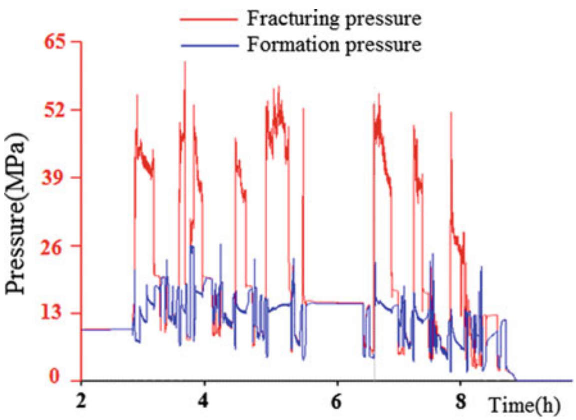

Fig. 9. Monitoring curve of downhole electronic manometer

8 Field Application and Effect

The dual packer multistage control fracturing technology in horizontal wells has been applied to 2004 intervals of 356 wells in the domestic oil fields of China by the end of 2015, among which 1978 intervals of 349 wells in Daqing oil field. Field applications ensure that it has become a mature technology and enjoys a technical success rate up to 96.7%. Taking Well ZF51-P × × as an example, at most to 15 stage fracturing could be executed in one trip [6] (see Fig. 10). The maximum working pressure was 60.2 MPa; the circulation rate during operation was 3.4 m^3/min; and the total sand loading volume was 110 m^3. Packers were set 32 times of 15 stage fracturing (including test fracturing), and the effective operation time was only 34 h. At the early stage after fracturing, the average daily oil production of individual well was 9.7 t, which was 5.5 times higher than that in vertical wells after using the dual packer multistage control fracturing technology according to the statistics of 174 horizontal wells. The technology has also been applied in Yumen, Changqing, Qinghai and other oil fields.

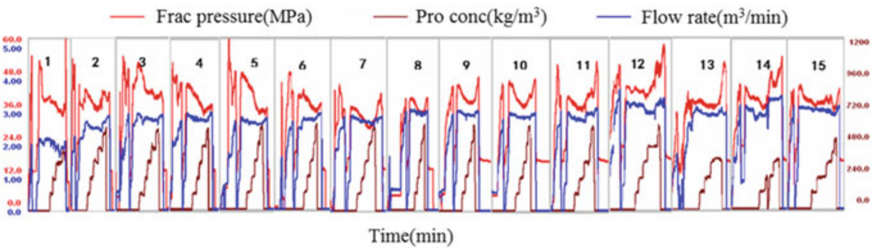

Fig. 10. Frac operation curve in well ZF51-P × ×

9 Conclusion

(1) The dual packer multistage control fracturing technology in horizontal wells successfully executes a wide range of horizontal well Frac service, which basically meets the fracturing stimulation needs of new and developed horizontal wells with different low permeability reservoir and provides the strong technical support for exploiting the difficult recovered reserves in Daqing oil field.

(2) The technology features highly targeted stimulation, high efficiency, sand stuck preventing and releasing function, which has become the dominant fracturing and completion technology in the field of horizontal well fracturing.

(3) It is suggested that the serialization of tools and the improvement of technical parameters should be carried out so that the technology can be applied in the field of clustered-type large-scale fracturing in horizontal wells.

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