Large-Scale Dual-Packer Drag Type Multi-stage Fracturing Technology for Horizontal Wells

Jin-you Wang[1,2], Che Wang[3], Li Ban[1,2], Hong-yan Zhang[1,2](✉), Lin Li[1,2], Xin-ying Cheng[1,2,3], Xiao-chuan Zhang[1,2,3], and Chun-hui Zhang[1,2,3]

[1] Production Engineering and Research Institute, Daqing Oilfield Company Ltd., Daqing, Heilongjiang, China
zhy6944@petrochina.com.cn

[2] Heilongjiang Provincial Key Laboratory of Oil and Gas Reservoir Stimulation, Daqing, Heilongjiang, China

[3] No. 6 Oil Production Plant of Daqing Oilfield Co., Ltd., Daqing, Heilongjiang, China

Abstract. Horizontal well technology is a technological revolution in oil industry, and it is one of the most important methods of marginal low permeable formation exploitation in Daqing Oilfield. It is commonly believed that large-scale & multi-stage fracturing is an effective way to recover oil from thin, low porosity and ultra-low permeability tight reservoirs. However, the conventional horizontal well dual-packer multi-stage technology is not suitable for the large scale fracturing application for the existence of such problems as serious wear & corrosion of the tools, easily damaged packers, tools poor performance and incompatible blowout control technology. The large-scale dual-packer drag type multi-stage fracturing technology for horizontal wells was developed by innovatively optimizing the design of key tools such as small-diameter k344 packer, large sand volume pressure-transmitting sand jet and pressure controlled blowout preventer. The technology has been applied to 432 wells in the field. Up to 18 stages of fracturing can be executed in one trip with the flowback circulation rate of 8 m^3/min and sand loading volume per trip of 516 m^3 during operation. At the early stage after fracturing, the average daily oil production of single well was 5.2 t, which was 2.4 t/d higher than that of wells after the conventional fracturing treatment. The large-scale dual-packer drag type multi-stage fracturing technology basically meets the requirements of volume fracturing stimulation for the new wells and repeated fracturing for the old wells, which achieves the fracturing stimulation goals with the advantages of strong adaptability, environmental protection, cost reduction and high efficiency. File runs and lab testing have confirmed that the large-scale dual-packer drag type multi-stage fracturing technology for horizontal wells is a viable option in recovering oil form the ultra-low permeability and hard-to-recover reservoirs.

Keywords: Low-permeability tight reservoir · Horizontal well · Large scale fracturing · Dual-packer dragging · Repeated fracturing

1 Introduction

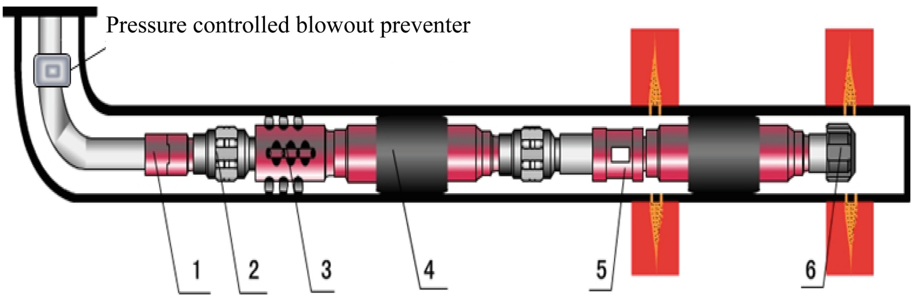
The undeveloped hard-to-recover reserves in the peripheral blocks of Daqing Oilfield mainly belong to low porosity, low permeability and low abundance reservoirs with many thin layers in the vertical direction and low natural productivity. After long-terms

J. Lin (Ed.): IFEDC 2021, SSGG, pp. 76–84, 2022.
https://doi.org/10.1007/978-981-19-2149-0_8

of water flooding, 95% of main pay zones have been in production and water flooded, and the development of the oilfield has to aim at relatively thinner and less permeable layers to maintain stable production. The effective thickness decreases by 25.7%; the porosity drops by 17.7%; the permeability falls by 50%; and the reserve abundance declines by 36.1%. For the ultra-low permeability reservoir, the conventional horizontal well fracturing has the limits of stimulating small swept volume, low production degree and short effective period [1]. It is commonly believed that fracturing can increase the contact area between fractures and reservoirs by improving the reservoirs exploitation longitudinally and realizing high strength laterally. The large-scale volume fracturing technology can increase the oil production of single well with ultra-low permeability reservoir [2, 3]. However, the conventional horizontal well dual-packer multi-stage technology for the new wells and old wells is not suitable for the large scale & high sand volume fracturing application for the existence of such problems as serious wear & corrosion of the tools, frac string broken accident, and high lifting load after fracturing operation [4]. Therefore, it is necessary to carry out the research on large-scale dual-packer drag type multi-stage fracturing technology for horizontal wells.

2 String Composition of Large-Scale Dual-Packer Drag Type Multi-stage Fracturing Technology

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



1. safety joint; 2. diversion centralizer; 3. hydraulic hold-down button;
4. K344-110 packer; 5. pressure transmitting sand jet; 6. centralizing end plug

Fig. 1. Schematic drawing of large-scale dual-packer drag type multi-stage fracturing technology

3 The Redress Kits and Technology Research

In order to assure the safety of tripping the horizontal frac pipe string in the downhole and large-scale fracturing operation, the design of fracturing tools should follow the principle of "small OD and large ID" (i.e. minimum outer diameter and maximum inner diameter). The structural design, material selection and heat treatment process of fracturing tools were carried out to meet the requirements of bearing high pressure, good wear & corrosion resistant performance.

3.1 K344-110 Inflatable Packer with Small Diameter

Optimization of Steel Structure in Small-Diameter K344-110 Packer. First, design the appropriate structure of the packing element to reduce the residual deformation. 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 when pulling up the pipe string and fulfill the multi-stage fracturing. The movable steel structure is designed to effectively solve the problems. Second, develop the packers with large inner diameter. In order to reduce the unnecessary pressure loss and improve the wear & corrosion resistant performance during the large-scale fracturing operation, the inner diameter of the packers can be maximized by reducing the wall thickness of the steel body. Hence, the connecting thread of the central pipe is designed from the conventional tapered thread to the T-shaped thread, and the material is preferred to be 40CrMnMo with the relevant heat treatment process. Third, design the sand filter and pressure transmitting channel. The sand filter and pressure transmitting mechanism of k344-114 packer for the conventional fracturing technology was designed at the joint of upper joint and central pipe. However, due to the limit of the size of k344-110 packer, it can only be designed at the central pipe by wire cutting to make sure the strength of packers (Fig. 2). The width of wire cutting seam should ensure the effective sand filtration and smooth pressure transmission. Fourth, improve the anti-corrosion resistance of inner channel. According to the corrosion law of two-phase flow in the channel [3, 4] and in order to ensure the stability of the internal flow field of the packers and reduce the corrosion of the internal channel, gradient varying size structure should be designed for the variant part of packers to avoid or slow down the local vortex current of fracturing fluid at the variant part and reduce the degree of wear & corrosion damage [5].

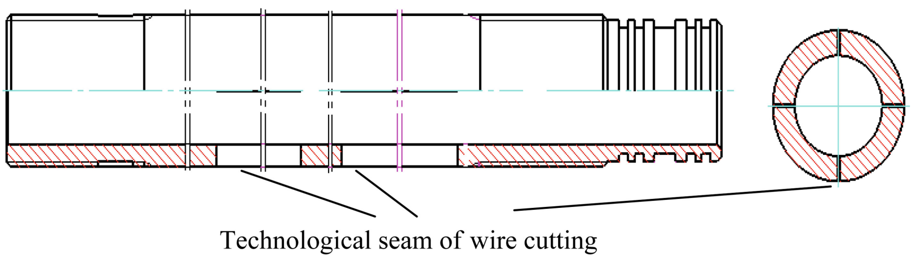


Fig. 2. Schematic drawing of sand filter and pressure transmitting channel

3.2 Development of Packing Element in Small-Diameter K344-110 Packer

K344-110 packer, as the core tool, plays an important role in the drag type multi-stage fracturing operation for horizontal wells. Its sealing performance is mainly determined by the parameters of packing element. Due to the poor performance of temperature resistance and pressure bearing in the packing element of small-diameter packer, and especially repeated setting and releasing during the operation, the excessive residual deformation will damage the packing element, resulting in poor sealing effect or difficult tripping the string smoothly in the well. Therefore, the research was carried out from the aspects of packing element structure design, processing and trial production, indoor oil immersion test and so on.

Fig. 3. Comparison with short packing element with large inner diameter and conventional packing element

Development of Short Packing Element with Large Inner Diameter. In order to meet the requirements of large-scale fracturing, it is necessary to design the short packing element with large inner diameter (Fig. 3). However, because the length of packing element was shortened by 38% and the inner diameter was expanded by 28%, the packing element only rated up to 35 MPa at 70 °C, which could not meet the requirements of fracturing. Therefore, it is urgent to carry out the further technical research. Through the structural analysis of the short packing element with large inner diameter, there is stress concentration on the shoulder of packing element during the expansion and contraction of repeated setting process in multi-stage fracturing. It leads to the damage of the packing element which is consistent with the previous experimental results. As a result, the shoulder of the rubber packing element was designed as circular arc transition structure in order to reduce the stress concentration. The arc radium is 10 mm according to the structural parameters.

Structure Optimization, Material Selection and Trial Production of Cord in Packing Element. First, the traditional nylon cord was transformed into the combination of steel wire and aramid cord when designing the packing element of the inflatable packer. However, water splashed on the surface of the packing element under the pressure differential of only 5 MPa in the initial pressure bearing experiment for the packing element It was found that the steel wire, rubber, aramid cord and mortar inside the packing element were separated from each other, and the steel wire at the end of the packing element and the fixing position of the vulcanization core was broken when cutting the packing element into halves. Without reducing the strength and elasticity of steel wire, special process was adopted to treat the surface of steel wire with higher hardness. In order to improve the adhesive properties of steel wire and aramid cord, the deformation rate of several different materials including steel wire, rubber, aramid cord and mortar in the packing element tends to be consistent, so as to solve the steel wire separating or cord broken problems when the packing element is under working condition. It is found that the deformation of packing element is the smallest and the tension of cord is 50 kN when the cord angle is optimized to be 15°. In this case, it not only ensures the uniform force, but also reduces the change of cord after locking. Moreover, the rubber element was modified from NBR to HNBR, and adding proper amount of nano-scale additives in HNBR [6].

Laboratory Oil Immersion Test of Packing Element. In order to meet the needs of large-scale stimulation for the ultra-low permeability and tight reservoir, the oil immersion test for KZ105-12-80 packing element was carried out in the laboratory under simulated well temperature of 120 °C and pressure of 80 MPa. The experimental results showed that the performance of the packing element before optimization was unstable under the pressure of 80 MPa and temperature of 120 °C; the shoulder was damaged and cracked; and the residual deformation rate was 8.9%. The test was unqualified. Experimental results are shown in Fig. 4 and Table 1.

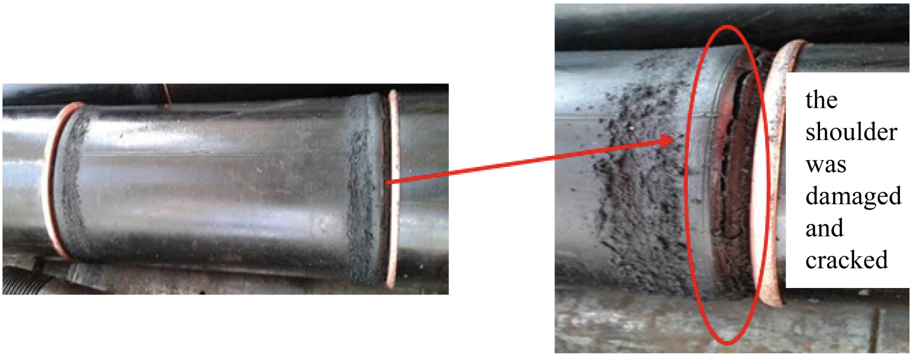


Fig. 4. Packing element was damaged and cracked under 80 MPa at 120 °C after oil immersion test

Table 1. Oil immersion test for KZ105-12-80 packing element before optimization

No.	Oil immersion temperature (°C)	OD of packing element (mm)	Fatigue experiment			Experimental result			Remarks
			Pressure (MPa)	Time (min)	Frequency	OD after bearing pressure (mm)	Residual deformation (%)	Conclusion	
1	120	103.4	80	5	8	109.91	6.3	Unqualified	Slight damage on shoulder
2	120	103.5	80	5	8	112.71	8.9	Unqualified	Shoulder damaged
3	120	103.5	80	5	3				Broken at 60MPa

Through the above improvement, oil immersion test for KZ105-12-80 packing element after optimization was performed to make the packing element resist the temperature increasing to 120 °C, pressure to 80 MPa and the maximum residual deformation of 2.96%. The oil immersion test (Fig. 5 and Table 2) meets the needs of large-scale fracturing stimulation for the ultra-low permeability tight reservoirs in the peripheral blocks of Daqing Oilfield.


Packing Element Before Oil immersion test


Packing Element after Oil immersion test

Fig. 5. Comparison of packing element before and after Oil immersion test under 80 MPa at 120 °C

Table 2. Oil immersion test for KZ105-12-80 packing element after optimization

No.	Oil immersion temperature (°C)	OD of packing element (mm)	Fatigue experiment			Experimental result			Remarks
			Pressure (MPa)	Time (min)	Frequency	OD after bearing pressure (mm)	Residual deformation (%)	Conclusion	
1	120	103.6	80	5	8	105.57	1.90	Qualified	Good appearance
2	120	103.4	80	5	8	105.45	1.98	Qualified	Good appearance
3	120	103.5	80	5	3	105.9	2.35		Good appearance

3.3 Pressure Transmitting Sand Jet

The function of pressure transmitting sand jet is integrated with the pressure transmitting, sand blasting and throttle together, which is vital in the fracturing technology. First, optimize the number, shape and spacing of holes in the pressure transmitting sand jet (Fig. 6), reduce the vortex area, balance the overflow, decrease the outlet flow velocity, and improve the anti-splash corrosion resistant ability [7]. Second, the internal structure was designed as "flow blocking", which forced the frac fluid carrying sand to flow through each hole evenly, and changed the local wear abrasion into uniform corrosion. Third, the pressure transmitting channel is located on the part far away from the easily wear-abrasive area (Fig. 7) to prevent the unfiltered fracturing fluid flow 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 difficult to release. Fourth, the inner liner, sandblasting mouth and outer wall of the main body of the pressure transmitting sand jet are designed to be a fully-covered armor-type anti-splash structure, whose material is selected as the anti-abrasive hard alloy. At the same time, the integral design is adopted to connect the main body and lower joint of the pressure transmitting sand jet together (Fig. 8), which effectively improves its wear & corrosion resistance and meets the needs of large-scale fracturing operation.

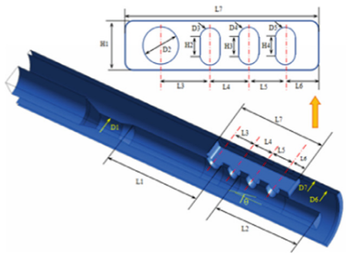


Fig. 6. Flow field structure model

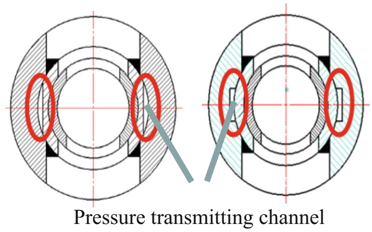
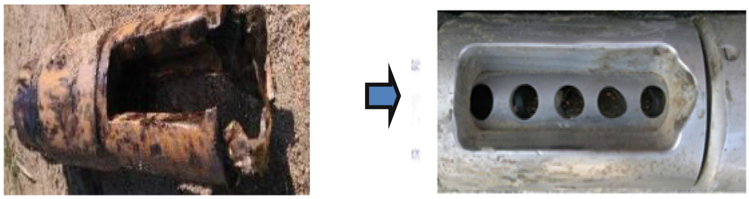


Fig. 7. Optimal design of pressure transmitting channel



Sandblasting mouth of conventional sand jet broken after adding 80m^3 sand

Sandblasting mouth after optimization slightly corroded when adding 516m^3 sand injection design

Fig. 8. Comparison before and after improvement on pressure transmitting sand jet

3.4 Pressure Controlled BOP (Blowout Preventer)

Conventional fracturing technical string does not have blowout prevention function, so it is unable to realize green environmental protection operation. The technology is faced with the dilemma of being eliminated according to the requirements of the new "environmental protection law". The pressure controlled blowout preventer (Fig. 9) was developed to research the key technologies of repetitive switch, sealing reliability and switch control mode. The work efficiency was increased by 57% without increasing the process, difficulty and cost.

The design of sealing structure of blowout preventer improves the reliability of repeated sealing First, the conventional L-type seal rubber was designed as the self-sealing core type, which had dual seal structure of both self-sealing and pressure differential sealing to fulfill the self compensation function. It could avoid the invalid seal caused by the expansion of the seal rubber. Second, the structural design and material

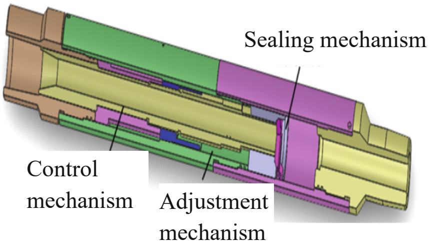


Fig. 9. Schematic drawing of BOP structure

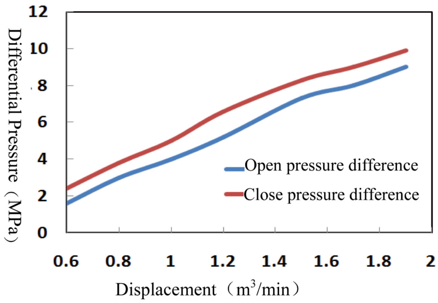


Fig. 10. Relationship chart between the switch pressure differential and the operation displacement

selection of the torsion spring were optimized. The torsion spring was designed from the traditional single barrel type to the double barrel type to make the stress more reasonable. At the same time, the high-quality alloy material was selected and endured the process of the aging anti-fatigue treatment, which improved the elastic and anti-fatigue properties by 30%. Third, the material of valve plate and its shaft were optimized, and the high-quality alloy steel torsion spring with the advantages of high strength and good toughness and light aluminum alloy valve were combined together. The blowout pressure rates up to 30 MPa, which met the requirements of repeated sealing for multi-stage fracturing.

The pressure adjustable mechanism makes the BOP controlled by pressure differential The structure of BOP controlled by pressure differential was designed, whose adjustment range was increased from 1–2 MPa to 1–30 MPa, so as to avoid the wrong operation on the switch, increase the adjustment range and adapt to different reservoir requirements. According to the fitting analysis of the measured results from the down-hole electronic monitor pressure gauge, the relationship chart between the switch pressure differential and the operation displacement was established (Fig. 10), which could provide the basis for determining the pressure differential to control switch in different reservoirs [8].

4 Field Application and Effect

The large-scale dual-packer drag type multi-stage fracturing technology for horizontal wells has been applied to 432 wells in the field. Up to 18 stages of fracturing can be executed in one trip with the flowback circulation rate of 8 m^3/min and sand loading volume per trip of 516 m^3 during operation. The success rate of single layer fracturing and pressure controlled blowout technology reach up to 100%. The average number of fractured layers combined with blowout control technology is increased from 2.8 intervals/day to 4.4 sections/day, and the work efficiency is increased by 57%. The technology not only meets the requirements of ever-increasing green environmental fracturing operation, but also improves the operation environment for workers and reduces the labor intensity.

5 Conclusion

The large-scale dual-packer drag type multi-stage fracturing technology for horizontal wells rated up to 80 MPa at120 °C with the flowback circulation rate of 8 m^3/min; the total sand loading volume was 516 m^3; and the controllable pressure differential of downhole blowout preventer was from 2 to 30 MPa. The technology provides an effective technical means for the development of low permeability reservoirs.

The technology has the advantages of high efficiency, multi-stage, environmental protection, large-scale fracturing operation in one trip, and the redress kits of fracturing blowout prevention technology, which solves the fracturing blowout prevention problems that has plagued the oilfield for many years, and improves the overall technology level.

It is suggested that the further research should be carried out on the dual-packer drag type separate layer fracturing technology for casing damaged wells whose inner well diameter is less than 104 mm, which will expand the application field.

References

1. Xianjun, W., Litao, S., Minghui, Z., Wanyou, Y.: Technical research and field test of degradable fiber fracturing. Petrol. Geol. Oilfield Dev. Daqing **32**(2), 141–144 (2013)
2. Jinyu, T.: Treatment of low-yield and low-efficiency wells through optimization measures. Oil-Gasfield Surface Eng. **32**(1), 38–39 (2013)
3. Warpinski, N.R., Mayerhofer, M.J., Vincent, M.C.: Stimulating Unconventional Reservoirs: Maximizing Network Growth While Optimizing Fracture Conductivity. SPE 114173. SPE Unconventional Reservoirs Conference, 10–12 Feb 2008. Keystone, Colorado, USA (2008)
4. Zhang, X., Wang, J., Wang, C., et al.: Study on the large-scale staged fracturing process string of vertical wells in Hailar Oilfield. Chem. Eng. Equip. **2016**(2), 98–100 (2016)
5. Gao, F.: Research on Fracture Technology of Volcanic Rock Gas Reservoirs in Xusehn Gas Field. Northeast Petroleum University (2011)
6. Wang, J., Wang, C., Yao, G., et al.: Research and application of dual packer multi-stage controlling fracturing technology in horizontal well. Oil Product. Eng. **1**, 26–29, 81–82 (2016)
7. Zhang, X., Wang, J., Li, L., et al.: Abrasion analysis optimization and field test of large-scale fracturing sandblaster in horizontal wells. International Petroleum and Petrochemical Technology Conference (2018)
8. Zhang, Y., Xuguowen, W.J.: application of two-channel electronic memory gauge in horizontal well fracturing. Oil Product. Eng. **2**, 64–68, 82 (2011)