Research and Application of High-Efficient Vertical Well Multi-stage Fracturing Technology Without Moving String in Daqing Oilfield

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Abstract. Daqing oilfield is a giant, heterogeneous, multilayer sandstone oilfield with 80–120 small layers, interlayer permeability difference of over 60 times. The development of the oilfield has aimed at relatively thinner and less permeable layers to maintain the stable production. It is commonly believed that fracturing is an effective way to recover oil from thin, low porosity and low permeability sands. The fine control of fracturing stimulation can effectively improve the recovery effect.

The conventional multi-stage fracturing technology without moving string is not suitable for the needs of the current separate layer fine fracturing stimulation and increasing scale of sand loading volume. However, the damage to the reservoir is increasing with the large workload of several trips of field operation, and the existing operation staffs and equipment are difficult to meet the stimulation demand with the disadvantages of long rig time, low efficiency, and high cost. Therefore, the multi-stage sliding sleeve fracturing technology without moving string by launching steel balls rated up to differential pressure of 70 MPa at 120 °C is developed.

The key tools, such as sliding sleeve pressure transmitting & sand jet packer and hydraulic hold-down button with large inner diameter, were developed, and the innovatively integral design of small gradient sliding sleeve, pressure transmitting sand jet and packer has solved some technical difficulties of sticking release by washing off sand, tools design strength with large inner diameter and the safe reliability. The stages of fracturing without moving the string have

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leaped from 4 to 12, which greatly improve the rig efficiency, reduce the worker's labor and lower the risk of well operation. Field runs and lab testing have confirmed that multi-stage fracturing technology without moving string is a viable option in recovering oil from thin, low porosity and low permeability reservoirs in the vertical wells.

The technology has been applied to over 700 wells in Daqing oilfield with the success rate of 99.4%, which indicates a step up for the effective stimulation of thinner and less permeable formations and fine exploration development by water flooding in the periphery of Daqing Oilfield.

Keywords: Daqing oilfield · High efficiency · No moving string · Multi-stage · Research and application

1 Introduction

Daqing oilfield is a giant, heterogeneous, multilayer sandstone oilfield with 80–120 small layers, interlayer permeability difference of over 60 times, whose exploitation strategy is to inject water to keep the reservoirs' pressure. The major oil reservoirs' physical properties are quite different from the secondary ones. After long-terms 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 undeveloped hard-to-recover reserves in the peripheral blocks of Daqing Oilfield are mainly distributed in the Putaohua, Fuyang and Haita comprehensive reserves, which belong to low permeability or ultra-low permeability reservoirs with many thin layers in the vertical direction and low natural productivity. The fine control of fracturing stimulation for these reservoirs can effectively improve the recovery effect.

At present, the main fracturing technology in Daqing oilfield is dual-packer multi-stage fracturing technology by pulling up the string stage by stage to fulfill the multi-stage operation. The damage to the reservoir is increasing with the large workload of several trips of field operation, and the existing operation staffs and equipment are difficult to meet the stimulation demand with the disadvantages of long rig time, low efficiency, and high cost. The conventional multi-stage fracturing technology without moving string is not suitable for the needs of the current separate layer fine fracturing stimulation and increasing scale of sand loading volume. Therefore, the high-efficient multi-stage sliding sleeve fracturing technology without moving string by launching steel balls in vertical wells is developed, which provides effective stimulation method of thinner and less permeable formations and fine exploration development by water flooding in the periphery of Daqing Oilfield.

2 Research of Pipe String [1, 2]

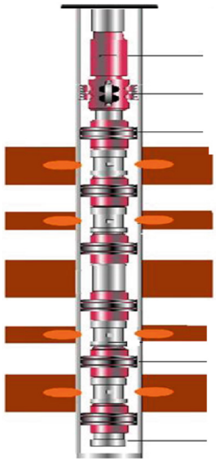
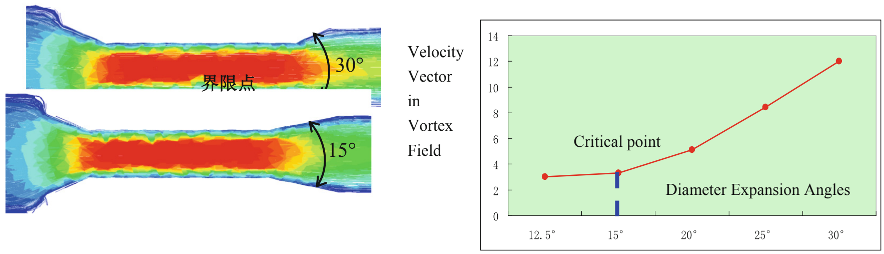


Fig. 1. Vertical well multi-stage frac pipe without moving string

The pipe string consists of safety joint, hydraulic hold-down button, K344/Y344-115 packer, sliding sleeve type pressure transmitting & sand jet packer, etc. (see Fig. 1) The multi-stage fracturing operation can be fulfilled without moving string by multi-stage ball launch to open the sliding sleeves. Pull out the frac pipe after the operation. The string is designed with reverse circulation passage, having the function of sticking release by washing off sand or pull out the pipe after releasing the safety joint.

3 Study on Abrasion Mechanism for Frac Pipe String [3, 4]

During vertical well multi-stage frac without moving string operation, with the increase of sand loading volume scale, the wear of sliding sleeve ball seat is severed. The sliding sleeve gradient needs to be reduced due to the increasing frac stages, which aggravates the contradiction between the sliding sleeve design with small gradient and its wear resistance. In order to solve the problems of abrasion failure of multi-stage & large-scale frac string, FLUENT software is used to simulate the internal flow pattern of frac string under the condition of large-scale fracturing according to the theory of fluid mechanics, and the distribution law of liquid-solid two-phase in the string under different parameters is analyzed to determine the abrasion mechanism of the string. The flow of frac fluid in the string is simplified to a two-dimensional model. The simulation calculation at the diameter variable point is carried out because of the pipe diameter expansion and the complex structure of frac string (see Fig. 2), and the experiments of different materials at different erosion velocities are carried out as well.



Velocity Contrast for Different Diameter Expansion Angles

Velocity Vector Map of Vortex Field with Variable Diameter Angle

Fig. 2. Flow pattern at diameter variable point of frac string under circulation rate of 4 m^3/min

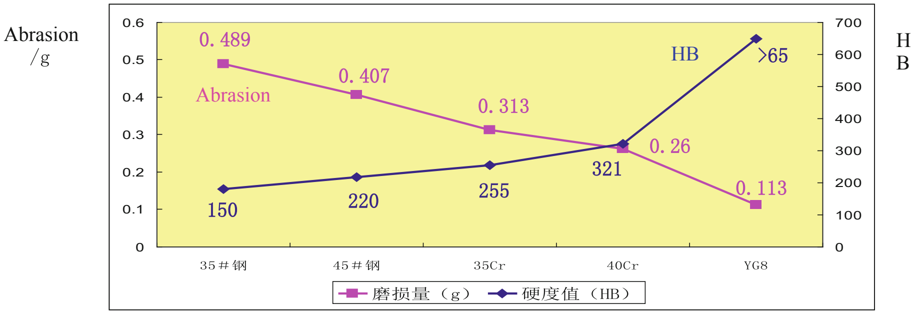


Fig. 3. Relation curves of hardness and abrasion for five different materials

Theoretical research and experiments show that the vortex field caused by abrupt diameter change is the main reason to cause the abrasion. The wear abrasion increases sharply when the angle of diameter change is more than 15°. The red area in Fig. 2 is the high velocity area, which is caused by the diameter change of the frac string. The vortex field is also generated, both the sand ratio and velocity in the vortex field increase. In addition, the main factors affecting the wear resistance design should consider the tool materials and heat treatment hardness. The higher the material hardness, the stronger the erosion resistance (Fig. 3).

4 Development of Frac Tools

4.1 Sliding Sleeve Pressure Transmitting and Sand Jet Packer

Integral Structure Design of Sliding Sleeve Pressure Transmitting and Sand Jet Packer. Pressure Transmitting & Sand blaster, packer and small gradient sliding sleeves are integrated together to shorten the tools length, which minimizes the distance between the packing element and the nozzle of sand blaster and effectively reduces the risk of sand-sticking accident caused by too long sand deposit. The sand blaster can also be used as reverse circulation sand washoff mechanism after the sliding sleeve is opened, which can effectively prevent sand-sticking, release sticking, and improve the safety of the string (Fig. 4).

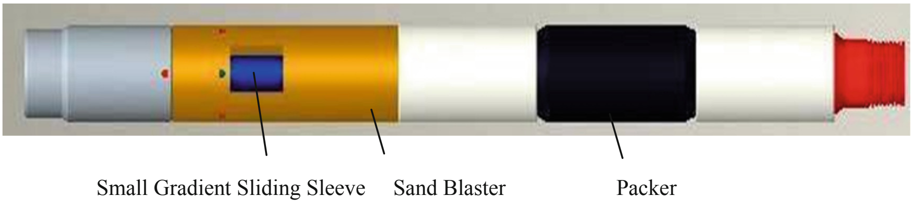


Fig. 4. Diagram of sliding sleeve pressure transmitting & sand jet packer

Development of Small Gradient Sliding Sleeve. In order to increase the frac stages in a single frac string, the design of sliding sleeve with small gradient (gradient is the difference between outer diameter of sealing ball and inner diameter of ball seat) is determined, which integrates the setting throttle nozzle and ball seat together [5]. It is necessary to improve the wear resistance of the sliding sleeve and to realize the sealing between the sealing ball and the sliding sleeve, so as to ensure that the sliding sleeve is opened normally to fulfill frac operation. Because the frac proppants flowing through the sliding sleeves increases step by step from bottom to top, the design principle of small gradient with variable diameter is determined (see Fig. 5). The gradient increases gradually from 2 mm to 3.5 mm when considering the allowable inner diameter of the pipe string, which not only increases the wear resistance of the tools and the sand loading scale, but also improves the success rate of opening the sliding sleeve, as well as ensures the increasing frac stages. What's more, the structure optimization and material selection of sliding sleeve with small gradient are carried out. The sliding sleeve adopts split design (see Fig. 6), which has the advantages of easy assembly and cost saving.

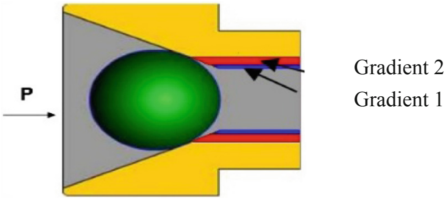


Fig. 5. Difference between OD of sealing ball and ID of ball seat

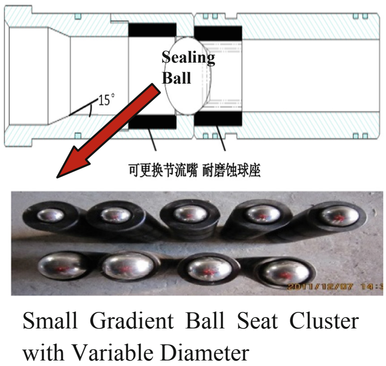


Fig. 6. Structure and photo of small gradient sliding sleeves

Development of Short Packing Element with Large Inner Diameter. In order to shorten the packer length and improve the retrievable performance of packing element, the short packing element with large inner diameter was developed. Firstly, Ansys finite element method is used to analyze the structure of short packing element with large inner diameter (see Figs. 7, 8 and 9). It is found that there is stress concentration on the shoulder of packing element. After optimization design, the arrangement angle of steel wire and cord is carried out for exploratory design and experiment to achieve the uniform stress. Secondly, the material of packing element is changed from NBR to HNBR by adding nano-additives. Thirdly, “steel wire + nylon cord” is replaced by “steel wire + aramid cord” with higher strength. The special treatment technology is studied to solve the problem of poor bonding performance between aramid and rubber, so that steel wire, rubber, latex and aramid cord can be integrated into one piece without “layering” when being vulcanized into packing element. The deformation rate of several different materials inside the packing element tends to be the same, which solves the problems of wire breakage for the packing element in the work condition. Through the research and development, the indoor oil immersion test is rated up to 120 °C and 70 MPa, which meets the requirement of frac operation.

Fig. 7. Short packing element with large ID

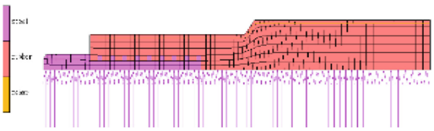


Fig. 8. Finite element discrete graph of axisymmetric for packing element

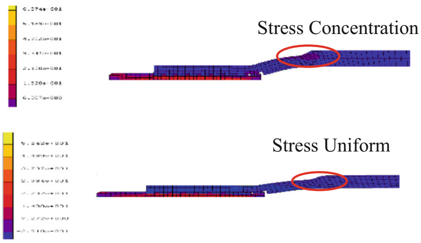


Fig. 9. Shoulder tensile stress during packing element expansion before and after structural optimization

4.2 Hydraulic Hold-Down Button with Large ID

Hydraulic hold-down button should have the dual function of good anchoring performance and reliable releasing ability to prevent string-stick happened after frac operation. The conventional hydraulic hold-down button has some inadaptability

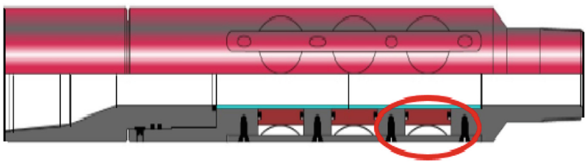


Fig. 10. Hydraulic hold-down button with large id and wear resistance

listed as follows. First, the inner diameter is only 46 mm that is smaller than the other frac tools. Due to the small ID at the top of the frac pipe string, it is impossible to achieve the integral structural design for the small gradient sliding sleeve type pressure transmitting & sand jet packer. Second, the energy consumed by the throttle loss created by the diameter change is the important factor to limit the increase of frac circulation displacement and the operation pressure under the condition of the same well depth and same type of frac fluid, which will bring unnecessary pressure loss for the frac operation. Third, poor abrasion resistance also restricts the large-scale frac operation.

Therefore, the claws of hydraulic hold-down button are designed as special sealing structure, whose inner diameter increases 30% to 60 mm, to reduce the fluid flow rate. The calculation shows that the flow rate is reduced by 1.7 times, and the wear resistance rate is reduced by 3 times. The design of the positioning mechanism of the claws avoids the hydraulic hold-down button crushing the central liner. At the same time, the abrasion resistance structure and cemented carbide liner are designed (See Fig. 10). Not only the inner diameter of the hydraulic hold-down button is expanded, but the wear resistance performance is greatly improved.

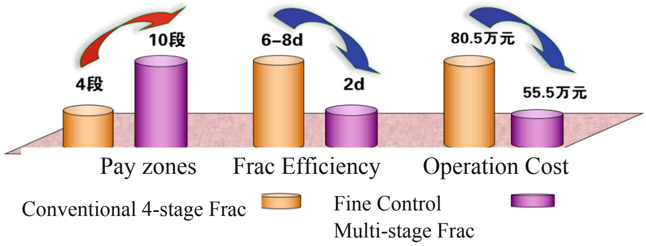


Fig. 11. Contrast between conventional and high-efficiency multi-stage frac technology without moving string

5 Field Application and Effect

The technology has been applied to over 700 wells in Daqing oilfield and the application is increasing year by year. The maximum flowback circulation rate is 8 m^3/min; the maximum sand loading volume is 398 m^3; and at most 12 stages can be stimulated in one trip with the success rate of 99.4%. Taking the Well X7-20 as an example, 28 small layers were drilled in the well, and 12 sections were optimized for fine fracturing to improve the stimulation proportion of small layers. The average daily oil production after fracturing with the technology is 4.7 times that of similar limited entry fracturing wells. The technology greatly improves the rig efficiency, reduces the worker's labor and lowers the risk of well operation because of no need to change another frac pipe string frequently or to save the time for waiting the frac vehicle in the field. The whole frac operation time reduces from 6–8 days to 2 days; the working efficiency improves more than 3 times; and the average single well operation cost reduces by 31% compared with the conventional technology. Field runs and lab testing have confirmed that multi-stage fracturing technology without moving string is a viable option in recovering oil from thin, low porosity and low permeability reservoirs in the vertical wells (see Fig. 11).

5.1 Conclusions and Understandings

The high-efficient multi-stage fracturing technology without moving string in vertical wells has the advantages of fine control of target pay zones, large sand loading scale, high rig efficiency, and low cost.

The fine exploiting development strategy supports the stable production in Daqing Oilfield. As one of the key technologies, the high-efficient multi-stage fracturing technology without moving string in vertical wells has become the dominant effective stimulation for the fine exploration in the well-developed old areas and for the effective development of thinner and less permeable hard-to-recover reserves in the periphery of Daqing Oilfield. The technology has been popularized on a large scale and its application proportion has increased year by year, which promotes the technological progress of vertical well fracturing technology.

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