Study and Application of Horizontal Well Enhanced Oil Recovery Technology on Huabei Oilfield Jin45 Fault Block

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Abstract. Huabei Oilfield Jin 45 fault block Es_2 is a middle porosity and low permeability reservoir with only 1.7% recovery, which has great potential. Horizontal well technology is an effective way to exploit old low permeability oil fields. It is proposed that the remaining oil enrichment area of Jin 45 fault block can be exploited efficiently by "horizontal well + staged fracturing", and the utilization degree of difficultly-recoverable reserves can be improved. In the actual development, how to enlarge the reformation volume, realize the full reformation of the horizontal section and avoid the rapid connection with the water injection well has become the main technical problems. Based on the integrated evaluation and analysis of "geology-reservoir-engineering" in Jin 45 fault block, the spatial distribution technology of non-equal-length fractures in horizontal wells is formed to achieve the optimal match between artificial fractures and well pattern. The integrated fracturing design technology of "reservoir-engineering" was put forward. The fracturing technology of "pumping bridge plug + multi-cluster perforation", combined with temporary plugging agent technology, has realized the fracturing of close cut volume fracture network. The horizontal well of Jin 45 fault block has formed a series of main reformation technology of "non-uniform fracture distribution + temporary plugging and diversion + multi-stage fracturing" By the end of 2020, three horizontal Wells have been fractured in the Jin 45 fault block, with a total of 46 clusters in 18 stages. The maximum daily oil production of a single well is over 40 tons, which is the highest of single horizontal well production in central Hebei region, providing a guarantee for the production capacity construction and recovery improvement of Jin 45 fault block, and providing technical support for the construction of relevant blocks in Huabei Oilfield.

Keywords: Horizontal well · Network fracturing · Multi-stage and multi-cluster · Capacity of remaining

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1 Introduction

The Huabei Oilfield Jin45 fault block is located between the middle and south troughs of Shulu Sag. It is a nose-shaped structural reservoir controlled by the nearly east-west striking Jingmound fault. The Es_2 member is one of the main oil-bearing layers in the fault block, with an oil-bearing area of 6.1 km^2 and geological reserves of 571.45 $\times$ 10^4t. Es_2 section of Jin 45 fault block was developed on trial in December 1997. As of November 2019, the accumulative oil production is 9.68 $\times$ 10^4t, but the recovery degree is only 1.7%, showing great potential for exploitation.

Horizontal well technology is an effective development method for the exploration of low permeability old oil fields. It has a large reservoir penetration, and can effectively increase the seepage area, reduce the production pressure difference, and improve the productivity of single well [1–5]. For implementation of Jin 45 block further development of remaining oil enrichment region, is proposed to realize benefit through + staged fracturing in horizontal well development, the use of horizontal well fracturing to improve the single well controlled reserves, injection pattern complement formation energy, fully tap potential injector-producer interwell remaining oil, implement block rolling production, the use of more difficult to reserve. However, it is a major technical problem to enlarge the reservoir volume, realize the full reconstruction of the horizontal section, and avoid the rapid connection with the injection well. Therefore, in view of the development plan of Jin 45 fault block, this paper, by fully combining the "geology-reservoir-engineering" evaluation, uses reservoir numerical simulation and engineering tests and other means to carry out research on the technology of enhancing oil recovery by horizontal well fracturing, so as to improve the scientific design of fault block horizontal well scheme and the effect of reservoir reconstruction.

2 The Characteristics of Jin 45 Fault Block

2.1 Reservoir Physical Property

Es_2 section of Jin 45 fault block belongs to medium porosity and low permeability reservoir, with average porosity of 16.2% and average permeability of 13.5mD (see Fig. 1). The reservoir pores are locally developed, and the face ratio is generally less than 1. The main reservoir pores are intergranular dissolved pores, and a few feldspar ingranular dissolved pores and mold pores. The formation pressure coefficient is 0.99 and the highest geothermal gradient is 2.79 °C/100 m. It belongs to the normal pressure and temperature system.

The heterogeneity between reservoir layers is mainly heterogeneous type and severe heterogeneous type. The average permeability range is 20.9, and the average coefficient of variation is 0.8, which can easily lead to large differences in water absorption and recovery conditions in the longitudinal direction. The intra-layer intrusion coefficient >3, the variation coefficient >0.6, the plane heterogeneity is strong. In the west and southeast of the fault block, the thickness of the oil layer is larger than that of the core part. The sand layer connectivity rate is 100%, and the oil layer connectivity rate is 98.2%. The fault block is favorable for the formation of direct injection and oil production reservoir network.

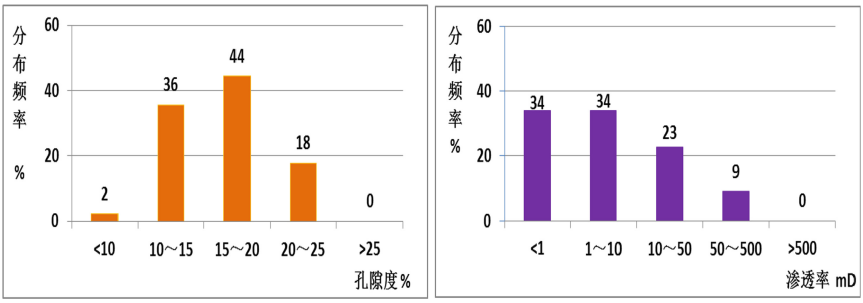

Fig. 1. Frequency curve of porosity and permeability distribution

2.2 Petrographic Character

The lithology of Es_2 section of Jin 45 fault block is unequal lithic feldspar sandstone, and the interstitials are mainly argillaceous heterobase, calcite and dolomite. The interstitials are weathered moderately, sorted poorly, rounded and subrounded, cemented in pores, and line-point contact between grains. The most common cementation is calcite and anhydrite argillaceous hybrid cement, and a small amount of quartz and feldspar are secondary increased. The quartz content of the reservoir is 40.92%, the artificial fracture is relatively easy to open, and the compressibility is good. The clay mineral content is 21.35%, and the clay mineral content is mainly chlorite and Aimonite mixed layer (content 15.61%) (see Table 1). Reservoir water sensitivity is medium to strong, weak to medium constant velocity sensitivity, salt sensitivity is strong, stress sensitivity is medium to weak. In the selection of fracturing fluid, attention should be paid to the compatibility with the formation to strengthen the protection of the reservoir.

Table 1. Mineral content of strata rock.

Mineral species	Average content, %
Quartz	40.92
Clay minerals	21.35
Plagioclase	20.86
Calcite	10.52
Potassium feldspar et al.	6.35

The extension pressure gradient of fault-block formation is about 0.019MPa/m, Young modulus is 38.78–112.79 (64.81), Poisson ratio is 0.16–0.26 (40.12), and brittleness index is 11.24%–76.15% (45.12%). In combination with the brittleness rating standard of Shahejie Formation reservoir in Jin45 fault block (see Table 2), The brittleness rating of the reservoir is medium to good, which is conducive to the formation of complex fracture network.

Table 2. Brittleness rating standard of Jin 45 fault block.

Brittleness rating	Friability index, %	Fracture shape
Difference	<40	Between two symmetry and more sewing
Medium	40–65	More seam and seam transition
Good	>65	Network

2.3 Dig Potential Difficulty and Countermeasure

Es_2 reservoir of Jin 45 fault block has poor permeability, so it needs to be fractured and put into production. At the same time, the natural energy is weak, the fluid supply condition of production well is poor, and water injection is needed to maintain pressure development. In previous years, vertical well reconstruction was the main method, but single well control reserves were limited, which restricted the development effect of measures. Using the technology of "horizontal well + staged fracturing", combined with the temporary plugging method in the fracture, it can moderately improve the fracture complexity, effectively increase the drainage area, improve the seepage capacity of the reservoir, maximize the use of controlled reserves, and improve the productivity of a single well. However, it faces the following difficulties:

1) The horizontal well sections of Jin 45 fault block are relatively long (750 m), and the cementing quality of part of the wellbore is poor, which increases the difficulty of staging fracturing. The perforation location and plug location are required to take into account both sweet spot and cementing quality.
2) With multiple clusters of perforations in the section, it is difficult to control each cluster of fractures to expand according to the design. It is proposed to adopt the method of less clusters (2–3 clusters) in the section, achieve uniform fracture expansion of each cluster through temporary plugging, comprehensively control the fracture height, fully build the main fracture, and achieve multi-scale fracture filling.
3) There is a perfect water injection well network system around the horizontal well, which requires both increasing the fracture control volume and waterproof channeling. In accordance with the existing injection and production well pattern, the artificial fracture parameters were optimized, and the scale of fracturing was appropriately reduced near the water injection well, and the scale of fracturing was increased far away from the water injection well to form the non-uniform fracture distribution mode.
4) Because it is a fault-block reservoir with complex in-situ stress distribution, the horizontal wellbore direction does not completely point to the direction of the minimum horizontal principal stress, and there is a certain Angle between fracturing fractures and wellbore, which affects the proppant and sand adding process. In the phase of pre-loading fluid, the holes and joints were polished with powder pottery to ensure the smooth sand adding. The sand carrying fluid type, proppant type and adding mode were comprehensively optimized to optimize the fracture sand embankment profile and improve the fracture filling degree.

3 Enhanced Oil Recovery Technology of Horizontal Well

3.1 Spatial Distribution Technology of Non-equal-Length Fractures in Horizontal Wells

In order to prevent water from one fracture and water channeling from multiple fractures, fracture distribution mode has become a key technical problem during the optimization design of horizontal well reconstruction by using the seven point method of direct injection and horizontal production. Combined with reservoir pattern, made the fault block jin 45 artificial crack cloth principle, namely: to avoid water increased, oil well segment, segment within the cluster, section between don't shake hands-handle, seam can shake hands-handle, formed "the length of horizontal well fracture space distribution technology, realization and the optimal matching of well pattern, avoid horizontal well production early water breakthrough, controlling water cut rising rapidly (see Fig. 2).

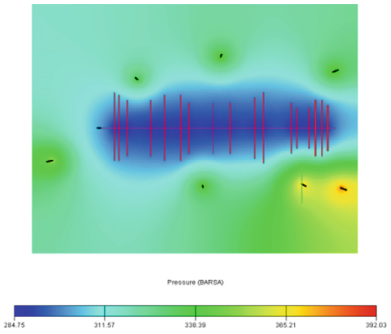

Fig. 2. Non-equal-length fractures of horizontal Wells are spatially distributed

3.2 Pumped Plug and Multi-cluster Perforation "Fracturing" Technology

Horizontal well fracturing technology are mainly pitch partial pressure fracturing process, double seal drag partial pressure, water injection multistage multiple fracturing technology, casing sliding sleeve multi-stage fracturing process [6–9], such as combination of Jin 45 block for Es_2 reservoir characteristics and horizontal well borehole trajectory, formed suitable for fault block Jin 45 Es_2 period of development benefit "pumping bridge plug + perforation clusters" technology. The technical principle is using hydraulic push, adopts the transmission cables in one trip to complete the bridge plug setting and a bunch of perforation and create channel conditions for staged fracturing transformation, is one of the horizontal well application relatively mature way of perforation completion, is "down to" + setting, perforation integration, high efficiency advantages, can cooperate with large displacement volume rapid implementation of the fracturing technology.

3.3 Temporary Plugging Agent

Racturing temporary plugging agent is a material used for temporary plugging of fractures. During construction, it selectively enters the high permeability layer or the original artificial fracture to form a bridge plug to improve the net pressure in the fracture, and then changes the orientation of fracture initiation to open micro-fractures or form new branch fractures [10–14].

Aiming at horizontal well of Jin 45 fault block, the temporary plugging technology of fracture mouth and the temporary plugging technology of fracture inside are formed. Based on the optimal principle of high plugging efficiency and effective in-seam/inter-seam temporary plugging, the water-soluble temporary plugging agent system was optimized. The water-soluble temporary plugging agent system has the technical advantages of high compressive strength, safety and reliability, high plugging efficiency, completely controllable degradation, and environmental friendness (see Table 3).

Table 3. Performance index of temporary plugging agent

Character	Index
Form	White, yellow to brown particles
Degradability	12–48 h
Density	1.0–1.3 g/cm^3
Particle size	0.5–7 mm
Suitable temperature	90–130 °C
Compressive strength	>40 MPa

The temporary plugging agent technology was applied in the construction of Well X, with stable displacement and obvious pressure rise (see Fig. 3). The old fractures were blocked and the new fractures were opened to ensure the effective opening of multiple clusters of perforations, and the temporary plugging effect was obvious.

4 Field Application

By the end of 2020.03 horizontal Wells have been fractured in the Jin 45 fault block, with a total of 46 clusters in 18 stages. The temporary plugging effect between layers is obvious. Through fracture monitoring, all of them have achieved the target of large-scale and volume reconstruction. At present, all three Wells have been put into production, with the highest daily oil production of each well exceeding 40 tons, which is the highest single horizontal well production in central Hebei region. At present, the average daily oil production of a single well is over 15 tons, low water cut is stable, stable production effect is good, and the accumulative oil increase is over 8400 tons.

Taking the fracturing of Well X as an example. The drilling depth of Well X was 4,027 m, the horizontal section was 744 m, the outer diameter of the casing was 139.7 mm,

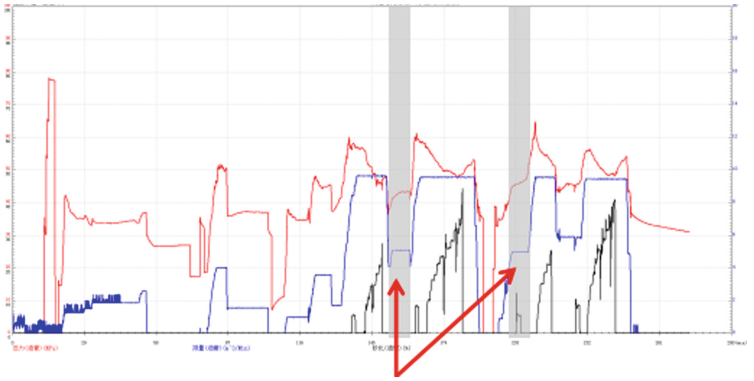

Fig. 3. Temporary plugging effect of fracturing on Well X

the wall thickness was 10.54 mm, and the engineering reconstruction was carried out in 7 sections and 17 clusters. The well was fractured with casing injection and temporary plugging volume fracturing in the interval. Six drillable bridge plugs were run with a flow rate of 10 m^3/min, a maximum pressure of 83 MPa, 7,726 m^3 of fluid and 572 m^3 of proppant (see Fig. 4).

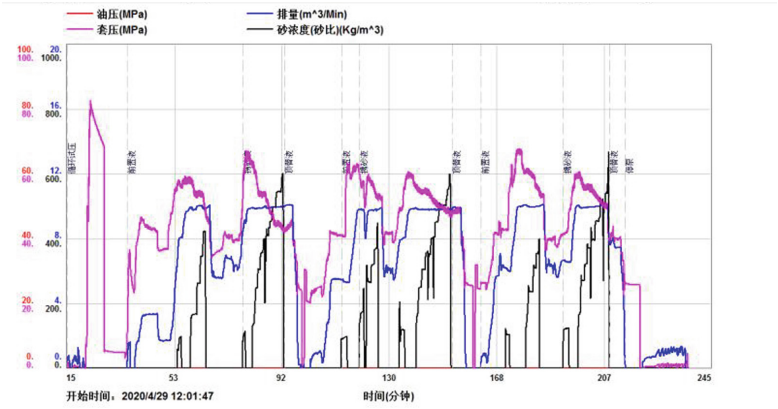

Fig. 4. Construction curve of the seventh section of J Well X

According to the fracturing construction cracks after pressure monitoring and evaluation plan demand, the deployment of Well X fracturing fracture monitoring project, using the ground energy dense array scanning the four-dimensional imaging fracturing fracture monitoring technology of the fracturing design and site construction scientific, reasonable and objective evaluation, fracture monitoring volume 3.32 million cubic meters, the transformation plan is completed the target (see Fig. 5).

Up to now, the well has been in production for 239 days with a maximum daily production of 47.7 tons of fluid and 40.44 tons of oil, with significant stimulation effects.

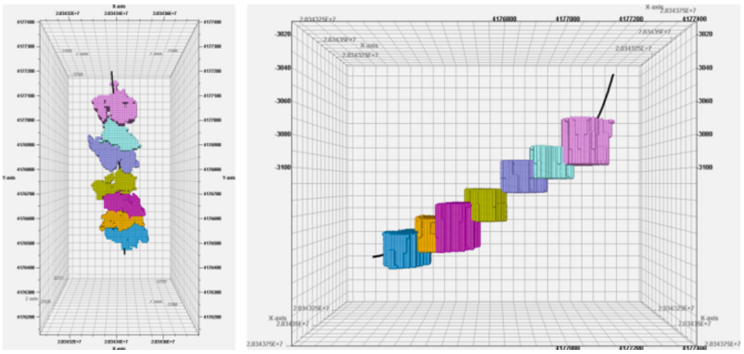

Fig. 5. Fracture monitoring imaging of Well X

At present, the daily output is 17.4 tons of liquid, 15.54 tons of oil and 10.7% of water content. The total oil production is 4,403 tons at present.

5 Conclusion

1) The recovery degree of Jin45 fault block in Huabei Oilfield is low, and the mature application of the technology of "horizontal well + staged fracturing" can realize the benefit development of the remaining oil enrichment area, improve the utilization degree of the hard-to-recover reserves, and realize the excavation of the old low permeability oil field. The maximum daily oil production of a single well is more than 40 tons, which effectively improves the recovery of fault blocks and provides technical support for the construction of other blocks in Huabei Oilfield.
2) The horizontal well of Jin 45 fault block has formed a series of main reformation technologies of "non-uniform fracture distribution + temporary plugging and diversion + multi-stage fracturing". Non-uniform distribution of the seam, improve the effect of plane use, to achieve water and oil, improve the crack control volume and waterproof channeling. The transient plugging and steering technology solves the problems such as large stress difference of fault block and the difficulty in each cluster of fractures to expand according to the design. The multi-stage fracturing technology, combined with pumping plug and in-stage close cutting, has achieved large volume fracturing rates.

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