Research of complex fracture acid fracturing technology in low permeability carbonate reservoir

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Abstract. Based on the analysis of the characteristics of the low-permeability carbonate reservoir, this paper has carried out studies on the adaptability of geological conditions, the adaptability of rock mechanics conditions and the characteristics of horizontal stress of the reservoir, etc., and demonstrated the feasibility of the acid fracturing of the low-permeability carbonate reservoir with complex fractures. In view of the poor connectivity of low-permeability carbonate reservoirs and the unsatisfactory effect of conventional acid fracturing, a "large scale + high pump rate" process idea of complex fracture acid fracturing technology was formed through the simulation of process parameters and optimization of construction pipe string, so as to expand the reservoir stimulation volume and improve the communication scope.

1. Introduction

China's carbonate rock reserves contain abundant reserves, accounting for about 40% of the total reserves. The new round of national oil and gas resource evaluation shows that China's Marine carbonate oil and gas resources amount to about 340×10⁸ t of oil equivalent, and lacust-phase carbonate oil and gas resources amount to about 45×10⁸ t of oil equivalent. At present, the average proven rate of these two types of carbonate oil and gas reservoirs is only about 11%, showing great potential for exploration and development. In recent years, with the deepening of exploration and development, there are more and more deep Marine carbonate reservoirs, such as Tarim Basin, Sichuan basin and so on have found a large number of such reservoirs. However, with the deepening of development, the permeability and porosity of some carbonate reservoirs become lower and lower, and the single well production is difficult to meet the expectations.

Many experts at home and abroad have carried out in-depth studies in various aspects on the acid fracturing technology of deep carbonate reservoirs [1-7], such as adopting non-uniform etching acid fracturing technology to improve the acid penetration distance and realize remote communication. Some scholars have also put forward the concept of volume acid fracturing, which makes use of natural fractures with relatively developed reservoirs and promotes the opening of natural fractures through measures such as temporary blocking and turning, so as to increase the reservoirs stimulation range of acid fracturing [8-10]. However, there is no specific research on low permeability carbonate reservoirs at home and abroad. In this paper, through large-scale research on acid fracturing technology of complex fractures, measures such as acid type optimization and construction string optimization are adopted to...
greatly increase the scope of transformation and the probability of communicating oil and gas enrichment area, so as to effectively improve the production capacity of single well.

2. Feasibility study on acid fracturing of complex fracture

2.1. Britleness index
The britleness of rock is one of the important rock mechanics characteristic parameters considered in fracture network fracturing. In addition to the distribution of in-situ stress, the britleness of rock is an important intrinsic factor influencing the formation of fracture network, and brittleness index is often used to characterize the volume fracturing of shale gas reservoirs. In this study, the brittleness index was calculated based on the characteristic parameters of the rock, and the average value of the calculated brittleness index was 63.46%. As the rock is brittle, fracturing may form a "fracture network". Therefore, the rock mechanics characteristics of low permeability carbonate reservoirs meet the requirements of fracture network fracturing.

2.2. Natural fracture characteristics
The imaging logging data analysis shows that the region is dominated by natural fractures with medium and high angles. The fractured zone explains the development of high conductivity fractures, and a small number of dissolved pores develop in some Wells, creating a prerequisite for the formation of fracture network. According to the theory of Rahman M, Ali Aghighi and Sheik S. Rahman, this type of reservoir has certain adaptability to acid pressure of seam network, and can be used to try the acid pressure process of complex seam.

2.3. Horizontal stress difference of reservoir
The horizontal principal stress difference of the reservoir is 13-15MPa, and there is basically no stress difference and no stress shielding layer in the longitudinal direction, which will lead to the excessive extension of the acid etched fracture in the longitudinal direction. Large horizontal stress difference is difficult to improve the sweep range of fractures in the transverse direction. Although the two-direction stress difference of the reservoir is high, natural fractures develop in some layers, and the stimulation of the volume fracture network can be realized through the technologies of high pump rate, low viscous and high viscous liquid combination, large-scale injection of fracturing fluid and sliding water.

3. Optimization of acid fracturing of complex fracture

3.1. Acid type selection
The adoption of highly viscous acid can impede the flow of acid in the dissolution pores, reduce the reaction rate of acid rocks, and delay the growth of acid-etching wormholes. In terms of the filtration loss reduction technology, the formation filtration resistance can be improved by improving the viscosity.
of the filtration fluid, such as the use of cross-linked acid, or the alternate injection of pre-fracturing fluid with acid.

As can be seen from Figure 2, with the increase of time, the filtration coefficient of gel acid (cross-linked acid) is the lowest, and the filtration loss reduction effect is the best. Therefore, large pump rate can be used to inject cross-linked acid with good slow speed and low filtration, greatly improving the effective action distance of acid solution.

3.2. Optimization of construction string
In order to fully reduce the construction friction and improve the effective bottom hole pressure in the construction process, the method of optimizing the construction string structure can be adopted. Large diameter tubing is adopted to minimize the length of small diameter tubing. If conditions permit, oil jacket annulus can be used for liquid injection. The method of "shallow tubing down" is adopted, that is, under the premise of good cementing quality, the lower part of the tubing is constructed with light casing.

The construction friction of the 3.5in fracturing string is 2-3 times that of the 3.5in+4in combination fracturing string. By using 140MPa wellhead + 4 inch and a half pipe string, compared with 3 inch and a half pipe string under shallow tubing, the displacement can be greatly improved. For reservoirs over 6000 meters, the pump rate can be increased from 3-4m3/min to 6-9m3/min, which can effectively improve the ability of seam making.
3.3. Perforation layer optimization

Combined with logging data and imaging logging data, perforation was conducted at 6039-6043 m (4 m), 6065-6069 m (4 m) and 6083-6088 m (5 m), and the number of perforations was 16 holes /m, which promoted the concentrated liquid absorption and balanced expansion of acid-etched fractures in the main target layer.

![Figure 4. Simulation of fracture morphology after perforation](image)

3.4. Liquid amount optimization

On the whole, both fracture length and fracture height increase with the increase of liquid volume (Fig. 5). However, after the liquid volume reaches 2000 m$^3$, the fracture length shows a trend of increasing and slowing down. However, at this time, the increase degree of seam height and average seam width increased significantly. Therefore, considering the increase amplitude of fracture length and fracture height and construction cost comprehensively, it is more appropriate to use about 1000 m$^3$ fracturing fluid.

![Figure 5. Construction scale optimization](image)

4. Field application

The reservoir of Well X1 is buried at a depth of 6,000 meters, and the bottom hole temperature is 140°C. A temperature resistant 140°C fracturing fluid and a cross-linked slow-release acid fluid system are used. The lithology is dark gray limestone and dark gray bioclastic limestone. The logging interpretation consists of 18.0 m/4 layers, among which the gas layer is 8.0 m/1 and the gas bearing layer is 10.0 m/3. It belongs to a low-porosity and low-permeability reservoir with a permeability of 0.006-0.102×10^{-3} MD and porosity of 1.5-2.3%. The imaging logging showed that there were 49 high conductivity fractures in this section, and a small number of dissolved pores were developed.
Therefore, the complex fracture acid fracturing process of "low viscose sliding water expansion + temporary blocking steering" can be adopted. First, low viscose acid is preloaded to remove pollution near the well. Then, large viscose crosslinked acid base solution is injected with increased pump rate to form the main channel of acid erosion fracture. Subsequently, acid-resistant slip water is injected into the natural fracture to replace the acid solution, and the viscosity difference (5-10 times) between acid-resistant slipwater and cross-linked acid is used to form non-uniform etching effect to improve the conductivity of complex acid-corroded fractures. Then, the sliding water is used to carry temporary plugging particles into the stratum to increase the net pressure in the fractures to achieve the effect of temporary plugging between the layers and the joints. The reconstructed area was enlarged by injecting crosslinked acid and slippery water again, and then the fracture network was etched by crosslinked acid to improve the overall fracture conductivity of this section.

5. Conclusion
The low permeability carbonate reservoir has poor physical properties, and the conventional acid pressure transformation range is limited. It requires large-scale deep acid fracturing or increased liquid volume to obtain industrial oil flow, so as to realize large-scale stimlution and greatly increase production.

The effective range of acid can be greatly improved by injecting a good slow speed and low filtration rate crosslinked acid at large pump rate. By optimizing the construction string, the pump rate can be increased from the conventional 3-4m³/min to more than 6m³/min, and the effective action distance of acid solution can be greatly increased.

In order to maximize the reservoir stimulation volume and increase the communication probability of the fracture body, the main fracture + complex fracture acid pressure is adopted to fully expand the existing natural fractures in the reservoir and maximize the reconstruction volume of acid fracturing.

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