Study on Fracturing Parameters Optimization of Horizontal Wells in Low Permeability Layers

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Abstract. Block A has poor and thin oil layers, and it is developed with horizontal wells to achieve Higher recovery. The horizontal initial production capacity 3-5 times the surrounding straight well initial production. However, as the development time goes on, some horizontal wells produce more water. This is mainly because of their well types. The horizontal wells have special layers and those layers are produced differently. In order to improve the production of different layers, we can use hydraulic fracturing to improve the production of horizontal wells. This paper uses numerical simulation technology to establish geological model of the block, to optimize the fracturing crack spacing, length, number of bars and other parameters, so we can maximize the effect of measures, while providing guidance for similar oil field level fracturing measures.

Keywords: thin oil layers; horizontal wells; fracking; parameter optimization.

1. Introduction
Block A reservoir thickness is thin, and single well only has 3.1m average effective thickness, among which the thinner layer thickness is about 1m. The sand bodies mainly are delta section plain - inner leading edge - outer facies, and have strong heterogeneity. The horizontal wells started overall development since 2012, and they have achieved higher yield and more efficient development with less wells. However, as the development time goes on, horizontal wells have produced more water than oil. So far, the average single-well horizontal segment is 533m long, and the average oil-bearing sandstone length is 259m, and the daily production is 2.3t, water-containing is 71.2%. Because of the horizontal well plane and vertical reserve loss, fracturing measures are an effective measure to improve the reserves of single well, but due to different reservoir conditions, horizontal well fracturing parameters need to be further optimized, so this paper takes Block A as a model to optimize the parameters of horizontal wells in order to guide follow-up horizontal well measures.

2. Establishment of a geological model of the horizontal well
According to the actual geological conditions of Block A, the design simulates the reservoir area range of 1180×580m², the reservoir depth is 1450m, single layer thickness is 0.8m, the original formation pressure is 14MPa, the oil saturation is 65%, and the porosity is 20%. For reservoir permeability, the permeability homogeneity and penetration non-homogeneity are simulated, in which the penetration rate of homogeneity model is 40mD and the permeability difference of non-homogeneity model is 30 to
100D. The horizontal well is located in the middle of the oil deposit and the horizontal segment length is 600m. When we are simulating cracks perpendicular to horizontal wells, we use the NWW Module of ECLIPSE, which can generate unstructured mesh by encryption, at the same time it can set parameters such as seam width, length, permeability and porosity of crack area, so as to better simulate the flow law of the near well area under fracturing conditions. In this case, the Carteson grid is selected for modeling, with 20m×20m×0.8m grid step and a total grids 59×29×1. During optimizing the angle between the crack and the horizontal well, the method we use is to construct the non-structural PEBI mesh because the near well model can't build the crack with a certain angle with the horizontal well, then we modify the permeability properties of the specific mesh according to the angle direction of the design crack and the horizontal well, so as to simulate the crack.

2.1. Physical parameter selection
The material parameters of the geological model are selected according to the PVT parameters of Block A. Crude oil density is 863 kg/m³, and water density is 1000 kg/m³, and the formation water compression coefficient is 4.4×10⁻⁴ MPa⁻¹ when the reference pressure is 13.62 MPa, and the water volume coefficient is 1.03579 m³/m³, the formation water viscosity is 0.8cP, the crude oil compression coefficient is 8.2×10⁻⁴ MPa⁻¹, the rock pore compression coefficient is 6.80×10⁻⁴ MPa⁻¹.

2.2. Relative permeability curve
The simulation uses a black oil model that does not take dissolved gas into account, so only the relative permeability of the two phases of oil and water is considered.

![Oil-water permeability curve of Block A](image)

3. The parameters of horizontal well fracturing cracks optimization
The simulation of crack parameters is mainly optimized for the spacing, length, number of bars, the spacing unevenness, the length unevenness and the angles between cracks and horizontal wells, and a total of 76 different scheme designs are used to arrive at the optimal crack parameters suitable for horizontal well fracturing. In the optimization, the seam width of fracking crack is 5mm, the crack penetration is 40000mD. For reservoir permeability, the permeability homogeneity and permeability non-homogeneity were simulated, in which the permeability of homogeneity model was 40mD, and the permeability of non-homogeneity model ranged from 30 to 100mD with the lateral non-homogeneity.

3.1. Fracking crack spacing optimization
The horizontal section length of the horizontal well was 600m with 5 cracks, and two half-lengths (120m, 150m) of the two cracks were selected to optimize the crack spacing. The crack spacing was selected as 60m, 80m, 100m, 120m, 140m.

3.1.1. Homogeneity model crack spacing optimization. For the homogeneity model with 5 cracks, crack half-length selected 120m and 150m, the horizontal well initial capacity of different crack spacing scheme can change with the crack spacing which can be seen in Figure 3-1 respectively.
According to these curves, it can be seen that for the homogeneity model, the crack spacing increases, and the initial production of horizontal wells increases and then decreases. Due to interference between adjacent cracks, the horizontal well production is maximized at the optimal crack spacing, and the horizontal well production decreases gradually as the spacing continues increase. Therefore, when horizontal well fracturing is designed, the reasonable value of the design crack spacing is 100m to 120m in order to improve the effect of the measures.

3.1.2. Non-homogeneity model crack spacing optimization. For the non-homogeneity model with 5 cracks, crack half-length selected 120m and 150m, and two kinds of horizontal well initial production capacity curve obtained by different crack are shown in Figure 3-2.

For the non-homogeneity model, under certain conditions of the number of crack strips and half length, the initial production capacity of horizontal wells changes with the spacing trend with the increase of crack spacing, and the initial production capacity of horizontal wells increases first and decreases later, and the optimal spacing is 100m to 120m.

3.2. The number of crack bars optimization
According to the results of crack spacing optimization, the reasonable crack spacing value is 100m to 120m. When the crack spacing is set as 120m, the fracking crack half-length is 100m, then the number of fracking cracks of the fracking horizontal well is optimized. Because the average horizontal segment length of this oil field is 600m, the scheme sets the cracks number of horizontal wells as 1, 2, 3, 4, 5, 6 and 7.
3.2.1. The number of cracks in the homogeneity model is optimized. For the homogeneity model, when the crack spacing is 100m and the crack half-length is 120m, the curve corresponding to the initial capacity of the horizontal well corresponding to the horizontal well in different crack number schemes varies with the number of crack strips, as shown in Figure 3-3.

![Figure 4](image_url)

Figure 4. The different number of crack bars and the initial production of horizontal wells in homogeneity model

If homogeneity model, crack spacing, half length are fixed values, the horizontal well initial production increases when the number of bars increase. When the number of crack bars is less than 5, the initial production capacity of horizontal wells soars out with the increase of the number of cracks is. When the number of cracks is greater than 5, the increase is reduced, which indicates that the optimal number of cracks is 5.

3.2.2. The number of cracks in the non-homogeneity model is optimized. For the non-homogeneity model, when the crack spacing is 100m and the crack half-length is 120m, the initial capacity of the horizontal well corresponding to the horizontal well in different crack strip schemes varies with the number of crack strips. Under the condition of crack spacing and half length, the change trend of horizontal well initial production capacity with spacing is similar to that of homogeneity model, with the increase of the number of crack bars, the initial production capacity of horizontal well is increasing, but when the number of cracks is greater than 5, the initial capacity of horizontal well is very close to 5 cracks, so the optimal number of cracks for non-homogeneity model is also 5.

![Figure 5](image_url)

Figure 5. The horizontal well initial production curve with different number of crack bars in non-homogeneity model

3.3. Fracking crack length optimization

We have optimized the crack spacing and strip number of horizontal well, for homogeneity and non-homogeneity model, the optimal crack spacing is 100m to 120m, the optimal number of cracks is 5.
Therefore, we choose 5 cracks and 100m crack spacing, design cracks half-length as 30m, 60m, 90m, 120m, 150m and 180m, in order to optimize the length of cracks.

3.3.1. Homogeneity model crack length optimization. For homogeneity models, when the fracking cracks is 5 and the crack spacing is 100m, the curve of the initial capacity of horizontal wells with the number of cracks in the half-length scheme of different cracks is shown in Figures 3-5. When the number of cracks and the spacing of cracks are fixed, the initial production capacity of the horizontal well increases with the half length, and when it reaches 120m, it tends to flatten out, so we determines the most reasonable half-length is 120m.

![Figure 6. The initial capacity curve of horizontal wells with different cracks and half lengths in homogeneity model](image)

3.3.2. Non-homogeneity model crack length optimization. For non-homogeneity models, when the fracking cracks is 5 and the crack spacing is 100m, the initial capacity of horizontal wells in different crack half-length schemes varies with the number of cracks, as shown in Figures 3-6. When the number of cracks and the cracks spacing are fixed, the initial production capacity of the horizontal well increases with the half length, and when it reaches 120m, it tends to flatten out ,so we determines the most reasonable half-length is 120m.

![Figure 7. The initial capacity curve of horizontal wells with different cracks and half lengths in non-homogeneity model](image)

3.4. Crack angle optimization
In order to evaluate the influence of the angle between the crack and the horizontal segment, four schemes of the angle between the crack and the horizontal segment wellhead are designed, which are 30, 45, 60 and 90 degrees. In the angle optimization scheme, the crack half-length is about 140m and the crack width is about 5mm, the fracturing crack spacing is 100m, and the crack permeability is 40000mD.
3.4.1. **Homogeneity model crack angle optimization.** The results of the initial production capacity of horizontal wells in different crack angle schemes of homogeneity models can be found in Table 3-3. For the homogeneity model, with the increase of the angle between the fracturing crack and the horizontal segment, the initial production capacity of the horizontal well is increasing, when the fracturing crack is perpendicular to the horizontal segment (90 degrees), the initial production capacity of the horizontal well is the highest. The reason for the analysis may be that if the angle between the crack and the horizontal segment is smaller, the vertical distance between the adjacent cracks is shorter, thus aggravating the interference between the adjacent cracks and reducing the capacity of the horizontal well.

The results of the initial capacity of horizontal wells in different crack angle schemes of non-homogeneity models can be found in Table 1. For non-homogeneity models, the initial production capacity of horizontal wells is increasing with the increase of the angle between fracturing cracks and horizontal segments. That is, when the fracturing crack is perpendicular to the horizontal segment (90 degrees), the initial production capacity is the highest. Therefore, both homogeneity model and non-homogeneity model should choose fracturing crack perpendicular to the horizontal segment when we design fracturing cracks.

| Crack angle, ° | Initial production capacity, m³/d | Crack angle, ° | Initial production capacity, m³/d |
|----------------|-----------------------------------|----------------|-----------------------------------|
| 30             | 39.99                             | 30             | 50.23                             |
| 45             | 41.85                             | 45             | 53.01                             |
| 60             | 42.03                             | 60             | 53.03                             |
| 90             | 43.92                             | 90             | 54.9                              |

4. **Conclusion**

1. The optimal crack spacing is between 100m-120m and the optimal number of cracks is 5, and the optimal crack half-length is 120m.
2. In the case of the fixed total crack length, the non-uniform combination of crack length can be considered in the horizontal well fracturing design, so as to further improve the fracturing effect, especially in the case that the crack length of the horizontal well root and finger ends is long and the length is short, the fracturing effect is best. For non-homogeneity reservoirs, the length of the design fracturing crack can be appropriately increased in the thin layer, and when a water injection well exists near the horizontal well, the crack length of the horizontal well is designed according to the position of the injection well.
3. Fracking design is to design and select the most reasonable crack spacing, if the total spacing is certain, and adjacent crack spacing can not be guaranteed as the most reasonable spacing, then we should increase the spacing between the two sides, in order to improve the production of fracturing wells.
4. Fracturing fracture with vertical chamber of horizontal section is the best.

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