The effect of engineering parameters on production capacity of a fractured horizontal well in tight oil reservoirs

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Abstract. Terrestrial tight oil in China has the characteristics of poor reservoir properties and strong heterogeneity. Large-scale volumetric fracturing of horizontal wells is one of the few solutions to achieve economic exploitation. Horizontal well productivity after fracturing is affected by many complex factors. Therefore, by using the numerical simulation method, the ellipsoidal fracture network containing the major fracture and the minor fracture is designed by the method of locally densifying grids to simulate the productivity of a single well of the tight reservoir of Changqing Oilfield and analyse the affecting factors on the productivity. The results show the horizontal well productivity increases with the length of the horizontal section, the number of fractured stages, the volume of SRV, and the complexity of the fracture network, but the increment gradually decreases. The orthogonal test method was used to rank the influencing degree of engineering parameters on productivity. It was found that the influencing degree of fractured horizontal well productivity in tight oil reservoirs was decreasing from SRV volume, fractured stages, the complexity of fracture network to the length of horizontal section.

1. Introduction
In recent years, tight oil has become a hot spot in the development of the oil and gas industry [1-6]. China's tight oil mainly in terrestrial reservoirs, with wide distribution area, poor physical properties, low production, and low EUR. It is necessary to adopt large-scale volumetric fracturing of horizontal wells for effective economic development. The research methods for the productivity of tight oil fracturing horizontal wells are mainly divided into electrolytic simulation, equivalent seepage resistance method, potential superposition principle and conformal transformation principle and numerical simulation analysis methods. The numerical simulation method overcomes the deficiencies of physical simulation [7-10] and analytical methods [11-15], and can perform productivity analysis of complex fractured wells [16-20]. In this paper, Eclipse numerical simulation software is used to simulate the single well production capacity of YP8 well in Changqing Oilfield. The yield curve with different engineering parameters of the fractured horizontal well and the cumulative production of 5a is obtained.
The effect of influencing factors such as the length of horizontal section, fractured stages, SRV volume and the complexity of fracture network on productivity law is analyzed. By using the orthogonal test method to rank the influencing factors, the main controlling factors are determined, and the basis for the optimization design of the engineering parameters of the fractured horizontal wells is provided.

2. The establishment of a model
In order to study the influencing law of engineering parameters on the horizontal production capacity of a fractured horizontal well in Changqing Oilfield, based on the real geological data, PVT parameters of the reservoir, oil test data and fracturing monitoring report of the single well YP8, as shown in Table 1, the black oil model in Eclipse is used for oil-water two phase to establish a single porosity and single permeability model. For complex fracture network, the rectangle network which contains major fracture and minor fractures is designed by local dignified grids. The production process of a volume fractured well with complex fracture network is simulated under defined pressure with this model.

| Parameters                  | Value     | Parameters                  | Value      |
|-----------------------------|-----------|-----------------------------|------------|
| Porosity (%)                | 8         | Oil volume factor           | 1.2931     |
| Permeability (mD)           | 0.17      | Oil compression coefficient (MPa⁻¹) | 1.401×10⁻³ |
| Effective thickness (m)     | 50        | Gas density (kg/m³)         | 1.426      |
| Original water saturation (%)| 55        | The reservoir depth (m)     | 2050       |
| Oil viscosity (mPa·s)        | 1.86      | Water density (kg/m³)       | 1000       |
| Oil density (kg/m³)         | 854       | Rock Compressibility (MPa⁻¹) | 0.0006     |
| Reservoir pressure (MPa)    | 22.55     |                             |            |

3. The simulation of development history
15 volume fractures of Yangping 8 well is simplified into orthogonal fractures. The Yangping 8 well is a flowing well. The production dynamic history fitting is based on the production data from December 2012 to May 2015. For a given pressure, the result of fitted yield is shown in Figure 1.

4. The influencing factors and their degree on productivity of the fractured well
4.1. The length of horizontal section of fractured well
When studying the effect of the length of horizontal section on productivity, other parameters such as fractured stages, fracture length, and fracture conductivity are maintained. The length of the horizontal section is set to 1000m, 1200m, 1500m, 1800m, 2000m for numerical simulation. The production law in 5a is analyzed.

The cumulative production of fractured wells with time and different horizontal section length are shown in the Figure 2 and Figure 3. With time, the daily oil production gradually decreased. With the
increase of the length of horizontal well section, the cumulative oil production increased. However, when the length of the horizontal well section is more than 1500 m, the increment of cumulative oil production gradually decreases. The result can tell that if we would like to achieve an economical and high-production fracturing outcome, the length of the horizontal section can be 1400m~1600m.

4.2. The number of fractured stages

When studying the effect of the number of fractured stages on productivity, other parameters such as the length of horizontal section, fracture length, and fracture conductivity are maintained. The number of the fractured stages is set to 10, 13, 14, 15, 17 and 20 for numerical simulation. The production law in 5a is analyzed.

The cumulative production of fractured wells with different number of fractured stages is shown in the Figure 4 and Figure 5. With time, the daily oil production gradually decreased. With the increase of the number of fractured stages, the cumulative oil production increased but the increase amplitude is not as big as in the Figure 2. However, when the number of fractured stages is more than 17, the increment of cumulative oil production gradually decreases. The result can tell that if we would like to achieve an economical and high-production fracturing outcome, the number of fractured stages should be controlled between 15 to 19.

4.3. SRV volume

In this paper, the rectangle fracture model was used, so in a given thickness of the reservoir, the SRV volume can be seen as the reflect of the length of fracture and the length of horizontal section.

When studying the effect of SRV volume on productivity, other parameters are maintained. The SRV volume is set to $750 \times 10^4 m^3$, $900 \times 10^4 m^3$, $1050 \times 10^4 m^3$, $1200 \times 10^4 m^3$, $1350 \times 10^4 m^3$ and $1440 \times 10^4 m^3$ for numerical simulation. The production law in 5a is analyzed. The cumulative production curves with different SRV volume are shown in the Figure 6 and Figure 7. According to the results, the optimum range of SRV volume is between $1050 \times 10^4 m^3$, $1200 \times 10^4 m^3$ and $1440 \times 10^4 m^3$. 

Figure 2. The curve of the cumulative production with time with different length of horizontal sections

Figure 3. The comparison of the cumulative production in 5a between different length of horizontal sections

Figure 4. The curve of the cumulative production with time with different number of fractured stages

Figure 5. The comparison of the cumulative production in 5a between different number of fractured stages

Figure 6. The curve of the cumulative production with time with different SRV volume

Figure 7. The comparison of the cumulative production in 5a between different SRV volume
4.4. The complexity of network
The complexity of fracture network is rated by the number of minor fractures induced by volume fracturing. When studying the effect of the complexity of fracture network on productivity, other parameters are maintained. The number of minor fractures is set to 0, 2, 4, 6 and 8 for numerical simulation. The production law in 5a is analyzed. The cumulative production curves with different number of minor fractures are shown in the Figure 8 and Figure 9. According to the results, the optimum number of minor fractures is between 4 to 8.

4.5. The analysis of influencing degree of different parameters
In order to study the main controlling factors affecting the post-fracturing production capacity of tight oil reservoirs, the orthogonal design experiment was carried out according to the factors in the development process described above.

Considering the length of horizontal well, the number of fractured stages, SRV volume, the number of minor fractures, orthogonal test is designed, and each factor is designed at three levels. The specific test arrangement is shown in Table 2. The Figure 10 shows that the change of SRV volume has the greatest impact on productivity, the length of horizontal section is the smallest, and the number of fractured stages is medium.

| Factor          | The length of horizontal section (m) | The number of fracture stages | SRV volume \( \times 10^4 \) m³ | The number of minor fractures | Cumulative production in 5a \( m^3 \) |
|-----------------|-------------------------------------|-------------------------------|----------------------------------|-------------------------------|----------------------------------|
| Test1           | 1400                                | 15                            | 105                              | 4                             | 13020                            |
| Test2           | 1400                                | 17                            | 120                              | 6                             | 15235                            |
| Test3           | 1400                                | 19                            | 144                              | 8                             | 16634                            |
| Test10  | 1400 | 15  | 120 | 6  | 13750 |
|---------|------|-----|-----|----|-------|
| Test11  | 1400 | 17  | 105 | 4  | 14900 |
| Test12  | 1400 | 19  | 120 | 6  | 13750 |
| Test13  | 1500 | 15  | 120 | 8  | 13744 |
| Test14  | 1500 | 17  | 144 | 4  | 16316 |
| Test15  | 1500 | 19  | 105 | 6  | 15982 |
| Test16  | 1600 | 15  | 144 | 6  | 15020 |
| Test17  | 1600 | 17  | 105 | 8  | 14017 |
| Test18  | 1600 | 19  | 120 | 4  | 16711 |

Figure 10. Influencing degree of different engineering parameters on productivity of the fractured horizontal well

5. Conclusion

(1) The productivity of fractured horizontal wells in tight reservoirs increases with the increase of the length of the horizontal section, the number of fractured stages, the volume of SRV and the number of minor fractures, but the growth rate becomes smaller. For a specific reservoir, each parameter has an optimal selecting range.

(2) For the YP8 well in Changqing Oilfield, the optimal horizontal section length is between 1400m–1600m, the optimal number of fractured stages between 15 to 19, the optimal SRV volume between 1050×10⁴m³ to 1440×10⁴m³, and the optimal number of minor fractures between 4 to 8.

(3) The orthogonal experiment method is used to analyze the influence degree of engineering parameters of the fractured horizontal well on the productivity. The results show that the SRV volume has the greatest influence, the fractured stages follow on, the number of minor fractures and the length of horizontal section are similar and lie behind.
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