Optimization of horizontal well fracturing mode in Gaotaizi tight reservoirs of L26 well block in Daqing Oilfield

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Abstract. The tight reservoir of the Gaotaizi oil layer in the L26 well area of Daqing Oilfield is a typical sand sheet deposit, with complex geological conditions. It is difficult to evaluate the production of horizontal wells in tight reservoirs with different well layout and fracturing operation scales, and the reasonable fracturing mode is unclear. Based on the study of reservoir characteristics and fracturing parameters in the area, multi-scale and multi-media well group models of sand sheet facies deposition in the Gaotaizi reservoir were established, and the reasonable well spacing under the mode of parallel and staggered fracture distribution was studied by numerical simulation. The results show that the production of horizontal wells with staggered fractures is slightly higher than that with parallel fractures. The well spacing of wells with parallel fractures is 600m, and the optimal well spacing under staggered fracturing is 500m. The results provide a basis for the optimal design of tight oil horizontal wells in the Gaotaizi reservoir of Daqing.

1. Introduction

Longhupao oilfield is located in the central depression of Songliao Basin, in which the L26 well block covers an area of 21.56km2 and has large oil geological reserves. The main reservoir lithology of Gao3 formation is composed of mudstone, mud bearing and calcium bearing siltstone, with continuous reservoir distribution, low effective thickness, average effective porosity of 13.9%, average permeability of 1.23md, good crude oil property (1.45cp), which is a typical tight reservoir [1-3].

The tight oil of Gaotaizi formation in the L26 well area is a set of sand sheet deposition, and the geological conditions of reservoir are very complex [4-5]. The reservoir develops different scale percolation media of micron, micro-nano, and nano, the evaluation of reservoir condition and fracturing mode adaptability under large-scale hydraulic fracturing is difficult, and the reasonable development technology policy is unclear. At present, there are a lot of researches on the optimization of horizontal well spacing and fracture parameters in the world, but most of the research is only applicable to the conventional homogeneous reservoir, their numerical simulator usually considers the matrix reservoir as a homogeneous medium or equivalently treats the seepage medium of the whole reservoir as the same[6-13], which can not adapt to the optimal design of well layout and fracture parameters in the complex multi-media condition of the unconventional tight reservoir. Based on the independent numerical simulation model and software of tight reservoir [13], taking L26 well area as the target block, this paper innovatively established the multi-scale multi-media model of different
fracturing modes of sand sheet facies of tight reservoirs, and carried out the research on the reasonable well spacing optimization of tight oil in L26 well area.

2. Geological models of sheet sand sedimentary facies

Different from conventional reservoirs, micro-heterogeneity in tight reservoirs has a great influence on the development of reservoirs. In tight reservoirs, multi-media with different scales, such as micron, micro-nano, nano scales of pores and artificial fractures, are not continuously distributed. There are significant differences in the geometry and properties of these media, and the seepage mechanism of fluids in different scale pore/fracture media various. So the influence of complex multi-media must be considered in the numerical simulation of tight reservoirs.

The reservoir in L26 well area has very strong macroscopic and microscopic heterogeneity. Based on the interpretation results of logging data and the analysis results of the indoor core experiments, according to the differences in physical properties, the reservoir can be divided into three types. Among them, the porosity of class I reservoir is more than 12 and the permeability is more than 0.5md; the porosity of class II reservoir is 10-12 and the permeability is 0.2-0.5md; the porosity of class III reservoir is 8-10 and the permeability is more than 0.08md. Based on the analysis of the high-pressure mercury injection test results of the cores of different types of reservoirs, the pore scale is divided, and the quantitative distribution of pores with different sizes in three reservoir types is established, as shown in Table 1 and Figure 1.

| Reservoir type  | Proportion of small pore (%) | Proportion of micropore (%) | Proportion of micro-nanopore (%) | Proportion of nanopore (%) | Average porosity (%) |
|----------------|-----------------------------|----------------------------|----------------------------------|---------------------------|----------------------|
| Type I         | 21                          | 35                         | 28                               | 16                        | 14.7                 |
| Type II        | 12                          | 21                         | 34                               | 33                        | 11.5                 |
| Type III       | 2                           | 11                         | 32                               | 55                        | 9.6                  |
| Non-reservoir  | 0                           | 3                          | 5                                | 92                        | 4.2                  |

The tight oil of Gaotaizi formation in the L26 well block is mainly sand sheet facies, as shown in Figure 2. According to seismic data, reservoir geological analysis and understanding of sand bodies in well area, the plane distribution patterns of different types of sand bodies are determined; the distribution proportion of three types of reservoirs and physical conditions of various reservoirs are determined by the interpretation results of logging data and the results of indoor core experiment analysis. Combined with the multi-scale pore distribution patterns of three types of reservoirs, the multi-media well group models of different scales under the two fracturing modes of parallel fracture and staggered fracture are established. These two geological models are shown in the Figure 3 and Figure 4.
The geological model is 4km long and 3km wide. The middle area of the model is the center of the sand body with the best physical properties, which is the first type of reservoir. It gradually becomes the edge of the sand body outwards, and its physical properties become poor, which is the second and third type of reservoir in turn. In the model, the length of the horizontal well is set based on the drilling parameters of the actual horizontal well, the well length is 1500m, and the artificial fracture parameters were set based on the results of downhole micro-seismic monitoring, and the fracture length is 400m.

3. Comparison of production under different fracturing methods
Based on the sheet sand geological model, the numerical simulation of two kinds of fracture modes, i.e. staggered fracture and parallel fracture, is carried out, and the self-developed multi-medium numerical simulator for the tight reservoir is used [14].

The percolation curves in different scale pores used in the simulation are from laboratory experimental data. The dynamic equations of percolation in different scale pores are based on the experimental results of core percolation in different types of reservoirs in the L26 well block. The spacing of the fractures on the same horizontal well is 100m. When the fractures are staggered, the horizontal wells are staggered 50m in front and back, and the spacing of two horizontal wells is 700m. The development effect of horizontal wells under the two kinds of fracturing modes is shown in Figure 5, and the pressure distribution of these two models are shown in the Figure 6 and Figure 7.

From the numerical simulation results, it can be seen that the distribution of L26 reservoir is continuous on the plane, the physical properties of the reservoir are good, the drilling rate of the reservoir is the same under the two kinds of fracture arrangement, and the fracture scale of a single well is the same. Production difference is mainly affected by inter-well interference, which is controlled by physical properties. Under the condition of the staggered distribution of fractures, the interference between fractures in the development of two horizontal wells is relatively small. Under the condition that the spacing between horizontal wells is 700m, the production of horizontal wells with the staggered distribution of fractures is slightly higher than that of parallel distribution of fractures.
Figure 6. Reservoir pressure variation under parallel fracturing of horizontal wells.

Figure 7. Reservoir pressure variation under staggered fracturing of horizontal wells.

4. Reasonable well spacing optimization under different fracturing methods

4.1. Optimization of well spacing in parallel fracturing
Parallel fracturing is the most common way of well distribution. According to the geological conditions of the reservoir and the result of artificial fracture evaluation in the L26 well area, the well spacing optimization calculation of the well group with parallel fracture distribution is carried out. The spacing of horizontal wells in the model is set at 450m, 500m, 600m and 700m respectively to carry out the simulation. The simulated production results are shown in Figure 8. The pressure distribution of these models are shown in the Figures 9 to 12.

Figure 8. Comparison of well production with different spacing of parallel fracturing.

Figure 9. Reservoir pressure variation with well spacing of 450m of parallel fracturing.

Figure 10. Reservoir pressure variation with well spacing of 500m of parallel fracturing.
According to the simulation results, under the same geological conditions, the development effect of horizontal wells improves with the increase of well spacing. However, when the well spacing reaches 600 m, the increase of production is no longer obvious. This is because there is no production interference between the two horizontal wells, so the optimal well spacing under the condition of parallel fracture fracturing of horizontal wells should be 600m.

4.2. Well spacing optimization of staggered fracturing
With the staggered fracturing, it is helpful to use the induced stress of fracture to form a better fracturing effect and increase the volume of reconstruction. In the same sand sheet multi-media model, the spacing of horizontal wells in the model is set at 400m, 500m, 600m and 700m respectively to carry out the simulation. The simulated production results are shown in Figure 13. The pressure distribution of these models are shown in the Figures 14 to 17.

![Figure 11. Reservoir pressure variation with well spacing of 600m of parallel fracturing.](image1)

![Figure 12. Reservoir pressure variation with well spacing of 700m of parallel fracturing.](image2)

![Figure 14. Reservoir pressure variation with well spacing of 400m of staggered fracturing.](image3)

![Figure 15. Reservoir pressure variation with well spacing of 500m of staggered fracturing.](image4)
Comparing the two simulation results, it can be found that the variation of development effect of horizontal wells with different well spacing is basically the same as that of parallel fracturing under the mode of staggered fracturing. When the spacing of horizontal wells reaches 500m, the change of horizontal well production is very small, so the reasonable well spacing of butt fracturing horizontal well is 500m.

5. Conclusions
(1) This paper established sand sheet geological models with different scales of multiple media in the L26 well area of Daqing Oilfield which takes into account the differences of reservoir pore physical properties, fluid, and flow mechanism in different scales, and it is closer to the actual physical situation.
(2) With the geological condition of tight reservoir sheet sand deposition in the L26 well area of Daqing, the drilling rate of horizontal wells is higher in high-quality oil layer along the wellbore direction. Under the condition of 700m well spacing, the difference of oil well production between the two conditions is small, and the production of horizontal well with a staggered fracture is slightly high.
(3) Under the condition of parallel fracturing, the optimal well spacing is 600m for the horizontal wells with tight oil in the Gaotaizi reservoir of L26 well block, and 500m for the wells with staggered fracturing.

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