Spacing optimization of horizontal wells in Pu 34 tight oil reservoir of Daqing oilfield

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Abstract. The geological conditions of Fuyu tight reservoirs in Pu34 well area of Daqing Oilfield are complex. The drainage area of horizontal wells with hydraulic fracturing under different well distribution methods is not clear, and the reasonable well spacing is difficult to determine. Based on the study of the geological characteristics and engineering parameters of the Pu34 well area, this paper establishes the multi-medium geological models of different scales for fluvial sediments in Fuyu reservoir, and studied the reasonable well spacing under different well distribution modes by numerical simulation. The results shown that the development effect of well distribution along the channel direction is better than that along the cutting channel direction. The optimum well spacing along the channel direction is 1800m, and the optimum well spacing along the cutting channel direction is 500m. This research provides a basis for the arrangement of horizontal wells in Fuyu tight oil reservoirs of Daqing Oilfield.

1. Introduction
Pu 34 well area is located at the southernmost end of Putaohua structure in Daqing Oilfield. The area of horizontal well test area is 14.5 km², and the petroleum geological reserves are large. Putaohua and Fuyu reservoirs are mainly developed in the well area. The lithology of Fuyu reservoir is siltstone. Reservoir distribution is discontinuous with an average effective porosity of 12.5% and permeability of 1.3 mD [1-3]. The reservoir is a typical tight reservoir with poor physical properties.

The tight oil of Fuyu Formation in block Pu 34 is a set of fluvial deposits, and the reservoir geology is complex [4-6]. Tight reservoir needs volume fracturing to realize benefit development, and there are multiple porous media of different scales in the reservoir after fracturing, the mechanism of seepage in porous media of different scales is complex, including starting pressure gradient, imbibition and so on [7-9]. It is difficult to evaluate the adaptability of reservoir to well pattern after large-scale hydraulic fracturing, and the reasonable well spacing is not clear. At present, there are a lot of studies on Optimization of horizontal well spacing, but most of them are for conventional homogeneous reservoirs [10-20]. It is impossible to accurately calculate the impact of macro and micro heterogeneity of unconventional tight reservoirs on Optimization of horizontal well spacing. Taking Pu 34 well area as an example, this paper innovatively establishes multi-media models of different scales of fluvial facies in tight reservoirs by using the self-developed unconventional numerical simulation software which can not only accurately characterize the distribution of pore in different...
scales, but also simulate the complex seepage mechanism in different scales of pore and fracture [21]. The rational well spacing optimization of horizontal wells in Pu 34 well area was also carried out.

2. Establishment of geological model

Tight reservoirs have different scales and multiple media, such as nano-micron pore and artificial fracture. The medium distribution is discontinuous, the geometric and attribute characteristics of the medium are discontinuous, the seepage mechanism and flow pattern of different media are different, and the different distribution rules of multiple media will affect the coupling seepage flow and mining performance. Therefore, it is necessary to establish multi-medium geological models of different scales in the well area on the basis of geological knowledge.

The macroscopic and microscopic heterogeneity of tight reservoirs in Pu 34 well area is strong. According to the results of laboratory core experiments, the reservoirs can be classified into three types macroscopically. The type I of reservoirs has the best physical properties, the porosity is > 12%, the type II reservoirs have medium physical properties, the porosity is 10-12%, and the type III reservoirs have relatively poor physical properties, and the porosity is 8-10%. High pressure mercury injection experiments were carried out for cores of different types of reservoirs, and the pore number distribution patterns of different scales of different types of reservoirs were established based on the experimental results, as shown in the Table 1.

| Reservoir type | Proportion of small pore (%) | Proportion of micropore (%) | Proportion of micro-nanopore (%) | Proportion of nanopore (%) | Average porosity (%) |
|----------------|-----------------------------|-----------------------------|---------------------------------|---------------------------|---------------------|
| Type I         | 50                          | 32                          | 11                              | 7                         | 13.86               |
| Type II        | 30                          | 32                          | 21                              | 17                        | 11.26               |
| Type III       | 15                          | 25                          | 40                              | 20                        | 9.3                 |
| Non-reservoir  | 0                           | 3                           | 5                               | 92                        | 2.6                 |

The tight reservoirs in Pu 34 well area are mainly fluvial deposits. According to the inversion results of seismic sand body attributes in well area (Figure 1) and the geological knowledge of sedimentary in well area, the spatial distribution characteristics of sand body in well area can be judged. The distribution ratio and physical properties of different types of reservoirs can be determined by the analysis of core laboratory test in the well area (Figure 2). Combining with the pore distribution patterns of different scales in different types of reservoirs, the well group geological models under two well distribution modes along the river direction and cutting the river direction are established respectively, which can be seen in Figure 3 and Figure 4. The direction of artificial fracture is mainly controlled by in-situ stress. When the direction of maximum horizontal principal stress is perpendicular to the direction of river course, the layout of horizontal wells is shown in Figure 3. When the direction of maximum horizontal principal stress is parallel to the direction of river course, the arrangement of horizontal wells is shown in Figure 4.

As shown in the figure, the two geological models have the same size and geological parameters. The length and width of the geological models are 2.8 km and 1.4 km respectively. The middle part of the geological model has the best physical properties. It is the type I reservoir, which gradually deteriorates to both sides, followed by the type II and type III reservoirs. The length of horizontal well is set according to the parameters of actual well, which is 1500m. Artificial fracture parameters
are 500m in length according to the size and distribution characteristics of the artificial fracture monitored by underground microseismic. Other parameters of the model are shown in the Table 2.

### Table 2. Parameters of geological model.

| Parameter        | Width of Reservoir type I (m) | Width of Reservoir type II (m) | Width of Reservoir type III (m) | Fracture conductivity (D.cm) |
|------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Value            | 300                           | 100                           | 50                            | 15                            |

3. **Development effect of horizontal wells under different well distribution patterns**

Based on the geological model of cutting the river direction and two well groups along the river direction, the numerical simulation was carried out, and the unconventional tight reservoir numerical simulator developed independently was used for calculation [15]. The relative permeability curves in different scales of pore are measured by laboratory experiments, and the selection criteria of fluid dynamics and dynamic equations in different scales of pore are based on the experimental results of core seepage in well area. The well spacing along the river direction is set to 1800 m, and the well
spacing cut along the river direction is set to 900m. The development effect of the two well patterns calculated is shown in the Figure 5.

![Figure 5. Horizontal well production curves under different well distribution modes.](image1)

The calculation results show that the drilling rate of high quality reservoirs along the channel is higher and the development effect of oil wells is better affected by the size of sand body. The average channel width of Pu 34 well area is 1000m, and the reservoir with the best physical properties accounts for 30%. The length of horizontal well is 1500m, and the drilling rate of high quality reservoir in horizontal well cutting channel direction is low. The distribution of reservoir pressure under two kinds of well arrangement are shown in the Figure 6 and Figure 7. The production of horizontal wells along the river is 28.5% higher than that of cutting the river.

4. Optimum well spacing under different well distribution patterns

4.1. Well spacing optimization along river direction
When the horizontal stress difference is large, the direction of artificial fracture is controlled by the in-situ stress. When the direction of maximum horizontal principal stress is perpendicular to the direction of the river, wells need to be distributed along the direction of the river. The well spacing of horizontal wells is 1600 m, 1700 m, 1800 m and 1900 m respectively to carry out numerical simulation calculation. The calculation results are shown in the Figure 8.
According to the simulation results, with the increase of well spacing, the production of horizontal wells increases, but when the well spacing increases to more than 1700m, the production of horizontal wells basically does not change. Figure 9-12 show the pressure distribution under different well spacing conditions. It can be found that there is no interference between two horizontal wells when the well spacing is greater than 1700m. Therefore, the optimal well spacing along the river should be 1700m.
4.2. Well spacing optimization cutting river direction
When the direction of maximum horizontal principal stress is parallel to the direction of river course, horizontal wells need to be arranged along the direction of cutting River course. The well spacing of horizontal wells is set to 450 m, 500 m, 600 m and 700 m respectively to carry out numerical simulation. The calculation results are shown in the Figure 13.

**Figure 13.** Production of horizontal wells with different spacing cutting the channel direction.

**Figure 14.** Pressure distribution with well spacing of 450m cutting the channel direction.

**Figure 15.** Pressure distribution with well spacing of 500m cutting the channel direction.

**Figure 16.** Pressure distribution with well spacing of 600m cutting the channel direction.

**Figure 17.** Pressure distribution with well spacing of 700m cutting the channel direction.
The results show that the production variation of horizontal wells with different well spacing is similar to that along the river channel under the condition of cutting well distribution. Figure 14-17 are pressure distribution charts under different well spacing when cutting channel well distribution. It can be seen that when the well spacing increases to more than 500m, the output of horizontal wells basically does not change, so the optimum well spacing is 500m.

5. Conclusions
(1) On the basis of seismic sand body attribute inversion and core physical property statistical analysis, and combined with regional sedimentary geology, this paper establishes multi-medium well group geological model of Pu 34 well area in Daqing Oilfield.

(2) Under the geological conditions of fluvial sediments of tight oil in Pu 34 well area, well distribution along the river channel is better than horizontal well distribution along the cut channel. Under the current drilling and fracturing conditions, the production difference is 28.5%.

(3) The optimal well spacing of horizontal wells in Pu34 tight reservoir of Daqing Oilfield is 1800 m under the condition of well distribution along the river direction and 500 m under the condition of well distribution along the cutting River direction.

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