Study on the dosage of temporary plugging Agent for steering fracturing

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Abstract. The Triassic Baikouquan Formation in the Junggar Basin has developed a large number of dense sandstore conglomerate reservoirs, which belong to ultra-low permeability and ultra-low permeability refractory reservoirs. In recent years, the productivity of single well is improved by selecting potential production wells for multi-stage steering fracturing. In order to realize the forced steering of fractures, it is very important to study the sealing pressure of temporary plugging agent. According to the actual needs of Baikouquan steering fracture, the net pressure model of steering fracture is established. The net pressure value in the seam is calculated according to the change of ground stress after steering, then calculated the minimum temporary plugging agent sealing pressure needed for a single fracture. Based on the net pressure model, the corresponding software is developed and applied to the field. The practical application effect is good, which provides economical and effective technical technical support for the continuous and stable production of low permeability oil field.

1. Introduction

Mahu tight gravel reservoir in Junggar Basin is rich in resources and has great potential for production on a large scale[1,2]. However, in the process of development, there are some technical problems, such as high cost of fracturing investment, fast decline of output after pressure, low degree of recovery and so on[3]. In recent years, multi-stage steering fracturing technology has made a breakthrough in Mahu Lake. By injecting temporary plugging agent to plug the old seam, increasing the net pressure in the fracture, forcing the fracture steering to form new fractures, communicating with a larger oil discharge area, thus increasing the oil well production. A large number of wells have achieved remarkable results through field tests, but they have also exposed some problems, such as fracture steering has not been realized, resulting in the effect of increasing production in some wells is not well.

It is considered that the insufficient dosage of temporary plugging agent is one of the main reasons for the failure of fracture steering[4]. The amount of temporary plugging agent has an important influence on the sealing performance and temporary blocking strength. If the amount of temporary blocking agent is more, it will increase the difficulty and time of operation, and increase the cost of operation. If the amount of temporary plugging agent is not enough, the effective sealing and temporary blocking strength can not be formed, and the steering fracturing measures will fail. In order to solve this problem, further optimization of reconstruction design of Mahu tight gravel reservoir and continuously improve the comprehensive benefit of tight gravel reservoir development, this study is based on the field data, carries out the research on the amount of temporary blocking steering, forms the economical and
effective matching technology, and carries on the field application to speed up the construction rhythm of Mahu area.

2. Mechanical conditions and angles of fracture steering
By increasing the net pressure in the fracture, the multistage steering fracturing forces the fracture to turn to form a new branch fracture, and finally forms a complex network fracture. In this paper, the mechanical conditions and angles of fracture steering are studied.

According to the Warpinski and Teufel fracture criteria[5,6], when the natural fracture occurs:

\[ p > \sigma_n \]  

(1)

According to the two-dimensional linear elastic theory, Shear stress and normal stress can be expressed as:

\[ \tau = \frac{\sigma_H - \sigma_h}{2} \sin 2\theta \]  

(2)

\[ \sigma_n = \frac{\sigma_H - \sigma_h}{2} - \frac{\sigma_H - \sigma_h}{2} \cos 2\theta \]  

(3)

where, \(0 < \theta < \frac{\pi}{2}\).

When a large amount of fracturing fluid enters the fracture, the pore pressure near the wall of the natural fracture is:

\[ p(x,t) = \sigma_h + p_{net}(x,t) \]  

(4)

According to the above research, the mechanical conditions of fracture steering extension are as follows:

\[ p_{net}(x,t) > \frac{\sigma_H - \sigma_h}{2} (1 - \cos 2\theta) \]  

(5)

where, \(p_{net}(x,t)\) is Net pressure in seam, MPa. \(\sigma_H\) is Maximum horizontal principal stress, MPa. \(\sigma_h\) is Maximum horizontal principal stress, MPa. \(\theta\) is the angle of fracture occurrence and steering.

According to Erdogan maximum circumferential stress theory[7], the fracture extends in the direction of the maximum circumferential tensile stress. Calculate the first derivative of polar coordinate expression of circumferential stress field of fracture tip, and its value is equal to 0, then the steering angle with respect to the current joint surface is obtained:

\[ \theta = \arccos \left[ \frac{3K_H^2 + K_I^2\sqrt{K_{II}^2 + 8K_H^2}}{K_I^2 + 9K_H^2} \right] \]  

(6)

where, \(K_I\) is fracture toughness of rock type I, MPa•m\(^{0.5}\); \(K_{II}\) is fracture toughness of rock type II, MPa•m\(^{0.5}\).

3. Dosage of temporary blocking agent
The main purpose of steering fracturing is to carry out fracture steering, start new layers and communicate new unused oil areas, so as to achieve the effect of increasing production. This technology is different from conventional repeated fracturing, with the main goal of producing new fractures. The dosage of steering agent is very important, which determines the type of control effect and the success or failure of construction.
According to the different migration position of the temporary plugging agent, the temporary plugging fracturing technology can be divided into the temporary plugging technology in the seam and the temporary plugging technology in the seam. The dosage of temporary blocking agent was studied for intra-seam steering and seam steering, respectively.

3.1. Dosage of temporary sealing agent for inseam
The branch seam is temporarily blocked in the seam. In the laboratory test of temporary blocking agent, it is found that the breakthrough pressure increases with the increase of temporary blocking agent slug length, and the breakthrough pressure gradient increases with the increase of temporary blocking agent concentration (Figure 1).

![Figure 1. Relationship between breakthrough pressure gradient and temporary blocking agent concentration](image)

It can be seen from Figure 1 that the breakthrough pressure gradient of different concentrations of temporary blocking agent is different, and with the increase of concentration, the breakthrough pressure gradient increases obviously.

In the process of temporary plugging and steering fracturing, the principle of construction is to use temporary plugging agent to seal the reformed fracture, to realize bottom hole holding pressure, and then to open the "dessert" area. The fracture pressure of the newly compressed reservoir area is greater than that of the modified area, so the bottom hole pressure needed to be achieved in the construction process is higher, and a thicker temporary plugging agent section seal length is needed to realize that the sealing position will not be broken through when pressing the "dessert" area. According to the results of indoor strength test and the geometric characteristics of fractures, the total amount of temporary plugging agent needed for a single fracture can be calculated.

Formula for calculating the amount of temporary plugging agent for a single fracture:

\[
m = k \rho LHW
\]

\[
L = \frac{(P_{\text{net}} + \sigma_h)}{p}
\]

where, \(m\) is dosage of temporary blocking agent, kg; \(k\) is reference coefficient; \(\rho\) is density of temporary blocking agent, kg/m³; \(L\) is temporary blocking length, m; \(H\) is fracture height, m; \(W\) is fracture width, m; \(P_{\text{net}}\) is net pressure in seam, MPa; \(p\) is breakthrough pressure gradient, MPa/m.

Therefore, the formula for calculating the total amount of temporary plugging agent required is:

\[
M = k \rho \sum_{i=1}^{n} \left[ \frac{(P_{\text{net}} + \sigma_h)}{p_i} \right] \sum_{i=1}^{n} H_i W_i
\]
where, M is total amount of temporary plugging agent used in construction, kg; n is number of cracks that have been pressed open.

In the process of fracturing, the net pressure in the fracture is the key to the extension of the fracture. Through the sealing of the temporary plugging agent, the fracture steering is increased when the net pressure in the fracture is above the critical value of steering. Therefore, the temporary plugging pressure of a single fracture is as follows:

$$P_p = P_{net} = \frac{mp}{K\rho HW} - \sigma_h$$

(10)

The blocking of the temporary plugging agent is effective when the plugging pressure of the temporary plugging agent is greater than the critical value of the inner net pressure. Therefore, the plugging pressure of the minimum temporary plugging agent for single fracture shall be met:

$$P_{p_{min}} = \frac{mp}{K\rho HW} - \sigma_h = \frac{(\sigma_{H} + \sigma_h)}{2} (1 - \cos 2\theta)$$

(11)

### 3.2. Formatting author names

The seams are temporarily blocked to create many fractures. The thickness of filter cake and the height of fracture are mainly considered in the dosage of temporary plugging agent, and the dosage of temporary plugging agent will be adjusted according to the actual situation. For the calculation of the amount of temporary sealing agent for seams, see the formula:

$$V_f = \pi H (d_1^2 - d^2)$$

(12)

where, $\Delta d$ is filter cake thickness, m; $d$ is Casing outer diameter, m; $H$ is support height, m

$$M = V_f \cdot \rho_1 \cdot 56\% + V_f \cdot \rho_2$$

(13)

where, $M$ is quality of temporary blocking agent, Kg; $V_f$ is filter cake volume, m$^3$; $\rho_1$ is apparent density of temporary blocking agent, Kg/m$^3$; $\rho_2$ is volume density of temporary blocking agent, Kg/m$^3$.

### 4. Application and analysis

The Baikouquan reservoir is a monoclinic inclined from northwest to southeast, with a dip angle of 2°~3°and an increase of 11°near the western fault. Baikouquan formation is a set of foothills alluvial sediments formed on Permian paleo-aolian crust with a sedimentary thickness of 52.5 m and an average of 161.4 m. The average thickness of gravel is 118.5 m, the ratio of gravel to gravel is 73.4%, the reservoir is continuously distributed, and the average effective thickness is 36.9m. The original formation pressure of H area in Baikouquan reservoir is 25.7MPa, the saturation pressure is 12.4MPa, the ground saturation pressure difference is 13.3MPa, the saturation degree is only 48%, the temperature in the middle of the reservoir is 62℃, and the geothermal gradient is 49.8m/℃. It belongs to the unsaturated reservoir of normal temperature and pressure system.

According to the geological characteristics of the target area, the corresponding software is developed. Taking well X as an example, according to the migration and distribution of temporary plugging agent, well X is the intra-fracture steering. The well depth is 2050.5m, the effective thickness is 17.5 m, the field construction displacement is 3.5m$^3$/min, the construction pressure is 29.4MPa~37MPa, and the total liquid content is 452.3m$^3$. According to the calculation of the minimum dosage of temporary plugging agent is 199.31kg, considering the migration distribution and settlement of temporary plugging agent, the actual temporary plugging agent is slightly larger than the critical value. After adding temporary plugging agent 205Kg, the construction pressure increases by 3.5 MPA, and the
temporary blocking effect is obvious, which can force the fracture to turn forced and achieve the expected effect. X well fracture steering is shown in Table 1 and Figure 2.

Table 1. Fracture steering in well X

| Original maximum principal stress (MPa) | Original minimum principal stress (MPa) | Maximum principal stress at steering point (MPa) | Minimum principal stress at steering point (MPa) | Minimum dosage of temporary blocking agent (Kg) |
|----------------------------------------|----------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 32.3                                   | 26.8                                   | 30.84                                         | 28.94                                         | 199.31                                        |

(a) Minimum ground stress of ordinary fractures  
(b) Maximum ground stress of ordinary fractures

Figure 2. Ground stress of ordinary fractures in well X

Table 2. Dosage of temporary plugging agent in well X

| Discharge (m³/min) | Transfusing measure (m³/m) | Steering number | Temporary blocking material particle size (mesh) | Total amount (Kg) | Effective percentage (%) |
|--------------------|----------------------------|-----------------|-----------------------------------------------|-------------------|--------------------------|
| 3.0—3.5            | 20—40                      | 2               | 20—60                                         | 420               | 100                      |

As shown in Figure 3, the average oil production of well X is 2 t/d before steering fracturing. After steering fracturing, the highest oil production is 21.7 t/d, the average stable oil production is 12.68 t/d. After steering fracturing, the effect is obvious, the oil production is greatly improved, and the steering fracturing construction is successful. This study has been applied to 14 wells in the field. The field application results show that the success rate of fracture steering is 86%.

According to the calculation formula of temporary plugging agent and many field application data, it is proved that the dosage of temporary plugging agent is related to reservoir type (fracture development or tight sandstone), difference of horizontal stress between two directions, fracture height and particle size of temporary plugging agent. The amount of temporary plugging agent in each layer of each well
is based on the field experience combined with the reservoir thickness and the particle size of the temporary plugging agent (seam is 3-5mm, inseam is 20 mesh).

Table 3. Standard for design parameters of temporary blocking steering

| Temporary blocking type                  | Single seam temporary blocking agent dosage (Kg) |
|------------------------------------------|--------------------------------------------------|
| temporary blocking for inseam            | 180-240                                          |
| temporary blocking for seam              | 240-320                                          |

5. Conclusion
The mechanical conditions and angles of crack steering are analyzed, and different formulas of temporary plugging agent dosage are obtained according to different temporary blocking types. The dosage of temporary plugging agent was applied in the field. After adding temporary plugging agent in well X, the construction pressure increased by 3.5MPa. The average stable oil production after pressure was 12.68t/d. It has played a good temporary blocking steering effect and provided effective technical support for the sustained and stable production of low permeability oil fields.

References
[1] Zhijun Q, Lihua C, Yuwen L, et al. Paleo-Sedimentary Setting of The Lower Permian Fengcheng Alkali Lake in Mahu Sag, Junggar Basin[J]. Xinjiang Petroleum Geology, 2016.
[2] Lun-Yu L, Guang-Hui H, Xv L, et al. Preparation and Performance Evaluation of Water Soluble Temporary Plugging Agent for Fracturing[J]. Liaoning Chemical Industry, 2016.
[3] Lixi L, Jing H, Xiangjun L, et al. Effect of Natural Fracture on Formation and Propagation of Induced Fracture Around Borehole in Shale Reservoir[J]. Geological Science and Technology Information, 2014, 19(3):327–352.
[4] Tianyu L, Jingjun P, Yugang L, et al. Research and Application of Volume Fracturing Mechanism on Volcanic Gas Reservoir in Xinjiang Oil Field[J]. Sino-Global Energy, 2013.
[5] Dingwei W, Qun L, Yun X, et al. Network fracturing techniques and its application in the field[J]. Acta Petrolei Sinica, 2011, 32(2): 280-284.
[6] Tang S, Zhang H. Hydraulic fracture prediction theory based on the maximum tangential strain criterion[J]. Chin. J. Rock Mech. Eng, 2016, 35: 2710.
[7] Weiping Z, Dali G, Xiaohui Z, et al. Impact of coal-bed stress sensibility on CBM output prediction[J]. Coal Geology of China, 2010, 22(4): 28-30.