Study on the Shut-in Time Law after Volume Fracturing of Glutenite Reservoir——Taking the Horizontal Well of Mahu 1 Well Area as an Example

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Abstract. Two horizontal wells have been put into operation in the Mahu 1 well area. The difference in geology and engineering between Mahu 1 well area and Ma 18 and Ma 131 well area is small, but the pressure and output drop rapidly after putting into production. Aiming at this problem, the micro-mechanism analysis is carried out, through the analogy with the neighboring area, and the reasonable shut in time is calculated through the derivation of theoretical infiltration rate formula. The results show that the reasonable closing time after horizontal well fracturing in the Mahu 1 well area is 18 days. Through the analysis of the mine test, the infiltration method and pressure drop method can accurately predict the reasonable shut-in time after fracturing, the research results have played a good guiding role in the production of horizontal well volume fracturing.

1. Introduction
Mahu sag is located in the northwest of Junggar Basin. The northwest slope of the sag is adjacent to Wuxia fault zone, Kebai fault zone and Zhongguai uplift from north to south. The southwest of the sag is adjacent to Shiyingtan uplift, Yingxi sag, Sangequan uplift, Xiayan uplift and Dabasong uplift from north to south. It is generally distributed in the north-east-south-west direction, with an area of about 6000km². Mahu sag is an important hydrocarbon-rich sag in Junggar Basin [1-4]. The controlled reserves of three main strata (Baikouquan formation, Shangwuerhe formation and Baijiantan formation) in Mahu 1 well area are more than 100 million tons [5], which will become an important area for capacity construction, storage and production increase of Xinjiang Oilfield in the next few years [6].

At present, two horizontal wells have been put into operation in Baikouquan formation of Mahu 1 well area, and the pressure and output decrease rapidly after putting into operation. The preliminary analysis shows that the phenomenon of rapid decline in pressure and production can be improved by shut-in well after fracturing, and the oil flowback rate can be reduced and the oil production period can be shortened. However, scholars at home and abroad mainly study the flowback law after fracturing of coalbed methane and shale gas reservoir, and consider that the prolongation of shut-in time can greatly reduce the flowback rate of fracturing fluid [7-10], while the flowback rate is affected by multiple factors, including the viscosity of gel breaker fluid, pressure coefficient and timing of flowback [11]. Generally speaking, the initial production of shale gas wells with low flowback rate is relatively high,
but the relationship between cumulative shale gas production and flowback rate is not clear, so the flowback rate should not be deliberately pursued [12]. At home and abroad, there are not enough studies on the micro mechanism of shut-in well and the necessity of shut-in well of glutenite reservoir. The purpose of this paper is to study the shut-in time after fracturing of horizontal wells, guide the production of the newly drilled well, and guide the overall deployment and production management of horizontal wells in the reservoir.

2. Necessity of shut-in well

According to the statistical results of shut-in well and production in area around Mahu, through comparison, it is found that the well conducting shut-in after fracturing has a short oil production period, a low oil flowback rate and a relatively high average daily oil production of single well; the well remaining opened after fracturing has a long oil production period, a high oil flowback rate and a relatively low average daily oil production of single well (Table 1). Taking well 1**1 which has been put into operation in Baikouquan formation of Mahu 1 well area as an example, the well has not been closed after fracturing, and the continuous sand production is serious after well opening. Oil can be seen in 26 days after well opening. The oil production period is long, and the oil flowback rate is high, reaching 15.2%. It can be seen that the shut-in well after fracturing can shorten the oil production period, reduce the flowback rate, and improve the initial and cumulative production.

| Well area | Shut-in days (d) | Pressure coefficient | Oil appear period | Initial stage | Accumulation |
|-----------|-----------------|----------------------|-------------------|---------------|--------------|
|           |                 |                      | Days             | Flowback rate (%) | Single well daily fluid (t) | Single well daily oil (t) | Single well daily oil (t) |
| Ma18      | 7.1             | 1.58~1.66            | 3.0              | 0.4           | 66.8         | 55            | 36.92 |
| Ma131     | 14.5            | 1.11~1.16/0.92~1.29  | 9.7              | 8.0           | 38.7         | 24.4          | 16.4   |
| Aihu2     | 6.0             | 1.26                 | 10.0             | 1.8           |              |               |        |
| FN4       | 22.3            | 1.1                  | 15.7             | 2.5           |              |               |        |
| MD2       | 001             | 15                   | 12.8             | 7             | 3.3          | 79.1          | 48.4   |
|           | 1**1            | 0                    | 1.59             | 26            | 15.2         | 73.7          | 25.7   | 22.7 |
|           | 1**4            | 2                    | 1.37             | 83            | 30           | 90.5          | 34.9   | 17.9 |

3. Micro-mechanism of shut-in well

From the macroscopic statistical law, it can be found that the shut-in well has indeed improved the productivity. From the microscopic point of view, the shut-in well process has three functions: pressure conduction, infiltration effect and gravitational differentiation, which affect the macroscopic production law.

3.1. Pressure conduction

Volume fracturing means that a large amount of fracturing fluid is put into the target layer in a short period of time. After fracturing, the fracturing fluid is mainly distributed in the artificial fracture network and the matrix near the fracture. Due to the low infiltration of the matrix, the fracturing fluid cannot be quickly and effectively transported to the deep matrix in a short period of time. A large amount of fracturing fluid accumulates in the newly formed fracture network in the reservoir reconstruction area, resulting in high pressure, while the far end of the matrix around the fracture network still maintains the original formation pressure. In the process of shut-in well, the fracturing fluid flows from the fracture network to the inner part of the matrix stratum. With the increase of shut-in time, the pressure in the matrix stratum in the reservoir reconstruction area increases gradually, and the pressure in the fracture decreases gradually. When the shut-in time is long enough, the pressure in
the reservoir reconstruction area is evenly distributed. When measuring the wellhead pressure, it will be found that the pressure of stopping pump after fracturing is often large. With shut-in time getting longer and longer, the wellhead pressure gradually decreases. Its essence is that the pressure in the process of shut-in well is transmitted from the fracture network to the matrix stratum (Figure 1, Table 2). If the well is opened directly instead of closing it at first after fracturing, the fracturing energy will be released from the wellhead instead of being transmitted to the matrix stratum sufficiently, which finally affects the productivity. When the pressure drops to a stable level, it means that the pressure tends to be balanced and the energy of the stratum is fully supplemented, reaching the time of well opening.

![Figure 1. Curve of ideal pressure drop after fracturing](image)

| Well  | Shut-in days | Pressure of the pump stopping (MPa) | Pressure of well opening (MPa) | The pressure drop (MPa) |
|-------|--------------|------------------------------------|-------------------------------|------------------------|
| 22**1 | 40           | 39                                 | 34.2                          | 4.8                    |
| 22**3 | 18           | 39                                 | 34.1                          | 4.9                    |
| 11**1 | 17           | 37                                 | 29                            | 8                      |
| 21**2 | 25           | 30                                 | 19.8                          | 10.2                   |
| 11**5 | 21           | 24                                 | 12.2                          | 11.8                   |
| 02*H  | 2            | 31                                 | 18.1                          | 12.9                   |

### 3.2. Infiltration effect
The main component of fracturing fluid is slickwater, which is mainly composed of water, drag reducer, anti-swelling agent and surfactant. When fracturing, it can make fractures and supplement energy for the stratum. After fracturing, it can improve the hydrophilic property of rock. Under the action of capillary force, the fracturing fluid in the fracture is sucked into the small pores in the matrix, and the crude oil in the matrix is discharged to the high permeability area of the fracture network to realize the replacement of oil and water of the fracture and the matrix (Figure 2). In fractures, the water saturation decreases; in matrix, the water saturation increases. This effect can significantly improve the initial oil production, and can have a positive impact on the cumulative oil production.
3.3. Gravitational differentiation

After oil-water replacement, with the passage of time, the buoyancy in the fracture network plays a leading role, and the oil and water will undergo the phenomenon of gravitational differentiation. The fracturing fluid will gradually gather in the lower part, and the crude oil will migrate and gather to the higher part of the fracture network, so as to realize the quick oil production at the wellhead after the shut-in well, and the initial oil production will increase when the initial liquid production does not increase [13].

4. Reasonable shut-in time

In the process of shut-in well, pressure conduction and fluid infiltration are the main factors, so the reasonable shut-in time can be calculated by the law of pressure change and the theoretical formula of infiltration effect.

4.1. Infiltration method

In the process of shut-in well, the fracturing fluid flows from the fracture into the matrix. Therefore, the reasonable shut-in time can take the time required of the fracturing fluid in the fracture to seep into the internal center of the matrix as the solution.

The average infiltration velocity is:

$$v = \frac{K_m \Delta p}{\mu \Delta L} \times 10^6$$  \hspace{1cm} (1)

Where: $v$ is the average infiltration velocity, m/s; $K_m$ is the matrix permeability, $10^{-3} \mu m^2$; $\mu$ is the viscosity of the fluid, mPa·s; $\Delta p$ is the driving differential pressure, MPa; $\Delta L$ is the distance from the fracture to the center of the matrix, m; $G$ is the starting gradient, MPa/m.

The formula of the time of fluid flowing from fracture network to matrix stratum is as follows:

$$t = \frac{\Delta L}{v}$$  \hspace{1cm} (2)

Where: $t$ is the infiltration time, s; $\Delta L$ is the distance from the fracture to the center of the matrix, m; $v$ is the average infiltration velocity.

From the above formulas, we can get:

$$t = \frac{\Delta L^2 \mu}{K_m (\Delta p - G \Delta L)} \times 10^6$$  \hspace{1cm} (3)
Taking platform 22 and platform 11 in Mahu 1 well area as examples, the reasonable shut-in time calculated by infiltration method is 10-25 days, which is similar to that calculated by pressure drop method.

4.2. Pressure drop method
By continuously measuring the wellhead pressure after fracturing, continuous daily pressure drop velocity data are obtained. The initial pressure is the pressure of stopping pump after fracturing, and the ending pressure is the predicted equilibrium pressure. According to formula (1), a reasonable shut-in time can be predicted.

\[
\text{shut in time} = \frac{\text{the pressure of stopping pump} - \text{the equilibrium pressure}}{\text{pressure drop speed}} \quad (4)
\]

Taking platform 22 and platform 22 in Mahu 1 well area as examples, the The difference between the pressure of stopping pump and the equilibrium pressure are about 5-8 MPa, the average pressure drop speed is 0.3 MPa/d, and the reasonable shut-in time calculated by pressure drop method is about 18 days. shut in time

4.3. Analogy method
The geological conditions and engineering parameters of Madong 2 well area and Mahu 1 well area are similar. According to previous studies, the reasonable shut-in time of Madong 2 well area is 20 days [14-15], which is basically consistent with the reasonable shut-in time calculated by pressure drop method and infiltration method. Finally, the reasonable shut-in time of Mahu 1 well area is determined to be 18 days.

5. Field test verification
After fracturing, the production test was carried out for the newly drilled horizontal wells in Mahu 1 well area according to the reasonable shut-in time predicted by calculation. The wells with the shut-in time more than 18 days have achieved good production results, with short oil production period, low flowback rate and high average cumulative daily oil production; the wells with the shut-in time less than 18 days have not achieved ideal production effect, with long oil production period, high flowback rate and low average cumulative daily oil production, because the pressure is released instead of completely being transmitted into the formation.

| Formation | Well | Planned shut-in days (d) | Actual shut-in days (d) | days from well open to oil appear (d) | Flowback rate when oil appear (%) | average cumulative daily oil output (t) |
|-----------|------|--------------------------|------------------------|----------------------------------------|------------------------------------|---------------------------------------|
| P3w2      | 22**1| 18                       | 40                     | 10                                     | 2.19                               | 40.8                                  |
|           | 22**2| 18                       | 2+37                   | 10                                     | 1.95                               | 23.8                                  |
|           | 22**3| 18                       | 18                     | 10                                     | 2.24                               | 22.1                                  |
|           | 02*H | 26                       | 2                      | 74                                     | 20.5                               | 10.12                                 |
| P3w1      | 11**1| 17                       | 17                     | 14                                     | 3.7                                | 33.62                                 |
|           | 11**2| 18                       | 18+7                   | 8                                      | 1.35                               | 25.92                                 |
|           | 11**3| 18                       | 12+6                   | 11                                     | 1.19                               | 21.39                                 |

6. Conclusion
(1) After fracturing, the decline of pressure and output of horizontal well after putting into production can be improved rapidly by shut-in well.
(2) In the process of shut-in well, the pressure is transmitted from the fracture to the matrix stratum, and the fluid also has the infiltration effect. Under the action of capillary force, the fracturing fluid is sucked into the small pores, and the crude oil is discharged to the high permeability area, so as to
realize the replacement of oil and water in the matrix and significantly improve the initial production capacity.

3) The reasonable shut-in time can be calculated by pressure drop method and infiltration method. The reasonable shut-in time of Mahu 1 well area is determined to be 18 days by referring to the relevant experience of adjacent area. The production test shows that 18 days of shut-in well has a good production effect.

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