Study on seepage characteristics of tight sandstone reservoir

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Abstract. Seepage characteristics of reservoir rocks are important factors affecting the effect of tight oil and gas production. Therefore the pore structure of tight sandstone from Dong 6 well in 4 block of the central Dzungaria Basin were studied by mercury injection experiment, and the seepage characteristics of tight sandstone were comprehensively studied by stress sensitivity experiment. The results show that: the pore throat distribution of the tight sandstone in the study area is not uniform, but the sorting property is good. The pore throat which promotes the permeability is mainly distributed near the threshold pressure of mercury injection experiment. The stress sensitivity of tight sandstone is affected by stress state and pore structure. Stress sensitivity is negatively correlated with confining pressure, and permeability loss is negatively correlated with pore throat radius.

1. Introduction

In the process of oil and gas exploitation and development, with the continuous production of oil and gas, the pore pressure of rock decreases and the effective stress increases, which results in the change of some properties of reservoir rocks [1-3]. The phenomenon that permeability changes with stress is stress sensitivity. Tight sandstone reservoir is characterized by complex genesis, low porosity, low permeability, complex pore structure, fine throat and secondary pore development [4]. The change of pore structure of rocks will cause the change of reservoir permeability, thus affect the productivity of oil and gas wells [5]. Based on the pore structure of tight sandstone, the seepage characteristics of tight sandstone reservoir are studied through stress sensitivity experiments.

2. Pore structure of tight sandstone

2.1. Mercury injection experiment

Mercury can't wet general solid, external pressure is needed to make mercury enter the pore of rock. The larger the external pressure is, the smaller the pore radius of mercury can enter. The pore size and distribution of rock can be obtained by mercury injection experiment.

Three samples of The tight sandstone reservoir from Dong 6 well in 4 blocks of central Junggar Basin is selected as the study area. Each core is 100 mm in length and 50 mm in diameter. The amount of Mercury entering the pore under different external pressures is measured in the experiment, the
capillary pressure curve, the histogram of pore throat distribution and the basic characteristic parameters of pore throat are obtained.

According to the capillary pressure curve of mercury injection, the contribution of different pore throat grades to permeability is calculated by the following formula:

\[
k_i = \frac{S_{i+1} + S_i}{100} \times \left( \frac{1}{p_i} + \frac{1}{p_{i+1}} \right)
\]

\[
\bar{k} = \sum k_i
\]

Where, \( p_i \) represents the mercury injection pressure, \( S_i \) represents the Saturation of rock sample, \( k_i \) represents the contribution value of pore throat to permeability in different intervals, \( \bar{k} \) represents the contribution value of total pore throat. Formula (1) indicates that when pressure increases from \( p_i \) to \( p_{i+1} \), the saturation of mercury in rocks increases from \( S_i \) to \( S_{i+1} \), and the contribution of pore throat to permeability in this interval is \( k_i \).

### 2.2 Analysis of experimental results

According to the experimental results, the capillary pressure curve and the histogram of pore throat distribution of tight sandstone are shown in Figure 1.

![Figure 1. Mercury injection experiment curve](image)

Figure 1 shows that the pore throat is mainly single-peak distribution, which shows that its sorting property is good, and the pore throat distribution range is relatively small. The basic characteristic parameters of pore throat are shown in Table 1.

| Threshold pressure/MPa | Maximum pore throat radius/µm | Median pressure/MPa | Median pore throat radius/µm | Mean Coefficient | Sorting coefficient |
|------------------------|-------------------------------|---------------------|----------------------------|------------------|--------------------|
| 0.320                  | 2.16                          | 3.57                | 0.21                       | 0.19             | 0.19               |
Threshold pressure is the corresponding pressure when Mercury first enters the core, and median pressure is the capillary pressure corresponding to 50% saturation on the curve. These two parameters can reflect the concentration degree and radius of pore throat. The lower the threshold pressure, the lower the median pressure, the higher the permeability of rock. The larger the mean coefficient is, the more uniform the pore throat distribution is, and its value is in the range of 0 ~ 1. The smaller the sorting coefficient is, the better the sorting property of the pore is.

The mercury injection experiment results show that the pore throat distribution of the tight sandstone in the study area is not uniform, but the sorting property is good. The pore throat radius is the main factor affecting the seepage of tight sandstone, and the pore throat which promotes the permeability is mainly distributed near the threshold pressure.

3. Stress sensitivity experiment of tight sandstone

3.1. Stress sensitivity experiment

Five rock samples are selected from the study area. The length and diameter of each rock sample are 50 mm and 25 mm respectively. HDQT-40 multifunctional displacement device and TY-5 core gripper are used in the experiment. The schematic diagram of the experimental device is shown in Figure 2.

![Experimental device diagram](image)

The confining pressure was changed and the permeability under different effective stress was measured. Nitrogen is used to provide the inlet pressure to the core. The gas flow rate is read by the soap-membrane flowmeter, and the permeability under this condition is calculated by formula (3).

$$K = \frac{2Q_0\mu L}{Ap_1(p_1 - p_0)}$$  \hspace{2cm} (3)

Where, $K$ represents permeability, $p_1$ represents inlet pressure, $p_0$ represents atmospheric pressure, $\mu$ represents gas viscosity, $Q_0$ represents volume flow rate of gas.

Considering the Klinkenberg effect of rocks, the Klinkenberg permeability is obtained after correction by formula (4).

$$K_a = K_\infty(1 + \frac{b}{p})$$  \hspace{2cm} (4)

Where, $K_a$ represents measured permeability, $K_\infty$ represents Klinkenberg permeability, $p$ represents average pressure of measuring point, $b$ represents Klinkenberg coefficient.
The stress sensitivity curve is drawn by using the Klinkenberg permeability, and the change of permeability with stress was analyzed.

### 3.2. Analysis of experimental results

According to the measured permeability, the Klinkenberg permeability under different confining pressures is calculated and the stress sensitivity curve is drawn, as shown in Figure 3.

![Stress sensitivity curve](image1)

Figure 3 shows that the permeability changes obviously with confining pressure before confining pressure is 20 MPa, and the change is stable after confining pressure is 20 MPa. That is to say, in the early stage of confining pressure growth (the initial stage of effective stress growth), the loss of permeability is more obvious, and with the increase of confining pressure, the loss of permeability becomes more and more stable.

This shows that the seepage in the micro-cracks plays a major role under lower confining pressure. When confining pressure is high, the micro-cracks are compacted or even closed, and the permeability decreases. On the other hand, the resistance of the rock to external forces increases, which makes the internal pore more difficult to compress and eventually causes the change of the permeability to be more stable.

The curve of permeability final loss rate and initial permeability of five rock samples is shown in Fig. 4.

![Permeability final loss curve](image2)

Figure 4 shows that the smaller the initial permeability, the greater the final loss rate after confining pressure increases, that is, the stronger the stress sensitivity. Combined with the mercury injection experiment results, it is found that the final loss rate of permeability is negatively correlated with the throat radius. The smaller the throat radius is, the larger the loss rate of throat radius when confining pressure increases, which makes the channel of fluid flow in rock sample decrease more obviously. Therefore, the permeability loss rate is larger and the stress sensitivity is stronger under this condition.
4. Conclusion

1) The pore throat distribution of the tight sandstone in the study area is not uniform, but the sorting property is good. The pore throat radius is the main factor affecting the seepage of tight sandstone under the same stress condition, and the pore throat which promotes the permeability is mainly distributed near the threshold pressure.

2) When confining pressure is low, the seepage of tight sandstone is mainly in microcracks. The permeability changes obviously with confining pressure, the stress sensitivity is strong. When confining pressure is high, the change of permeability is stable and the stress sensitivity is weak.

3) The loss rate of permeability of tight sandstone is negatively correlated with its throat radius. Under the same stress condition, the smaller the throat radius is, the greater the loss rate of permeability is, and the stronger the stress sensitivity is; On the contrary, the larger the throat radius is, the weaker the stress sensitivity is.

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