Pore Structure Characteristics Analysis of Tight Reservoir

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Abstract. In the development of oil and gas reservoir, tight oil and gas reservoir refers to the oil and gas reservoir with liquid measured permeability of 0.1 milli-Darcy, and the pore structure characteristics of tight oil reservoir is an important factor affecting its development effect. In this paper, constant-rate mercury penetration, nuclear magnetic resonance and scanning electron microscopy are used to detect the rock samples of a tight oil reservoir in Daqing, and analyse the distribution of pores and throats in the reservoir. And it turns out: Tight sandstone pore throats in this block are distributed at 0.01μm-1μm. The average pore throat radius was 0.43μm. The pore radius ranged from 80μm to 180μm, with an average radius of 122.7μm and the average pore radius was 124μm. The analysis of experimental data shows that the permeability of tight sandstone is mainly determined by throat radius and has nothing to do with pore size. The results of the three test methods are basically consistent and can be verified with each other.

1. Introduction: characteristics of tight oil and gas reservoirs
With the development of petroleum exploration and exploitation technology, the tight oil reservoir has become the main part of the increase of petroleum storage and production in China[1-3]. The porosity of tight oil reservoir is less than 10%, the underground permeability is less than 0.1md, and the fluid is mainly medium and high maturity oil, which is concentrated in the dissolution zone or fracture zone. Pore structure mainly refers to the size, shape, distribution and connection of pore and throat. Pore characteristics determine macroscopic reservoir and permeability properties and are important factors affecting tight oil recovery. There are differences in pore throat radius between domestic and foreign tight reservoirs, but generally less than 1μm. For example, Travis Peak tight sandstone in North America has a pore throat radius of 45-220nm; The radius of pore throat of tight sandstone in Yanchang formation of Ordos basin is 60~900nm.

Total tight oil reserves exceed 151.4×10⁸t in China, but the development of tight oil reservoirs is still at the pilot stage[4]. Compared with marine-based tight reservoirs in the United States, China's continental tight oil reservoir is characterized by thin oil layer, poor continuity and more difficult development.

The research methods for tight reservoir pores[5]can be summarized into three categories: experimental data analysis technology, image analysis technology and digital core technology. The commonly used methods for experimental data method include constant-rate mercury penetration method[6-8], high-pressure mercury injection method, nuclear magnetic resonance method[9,10]and cryogenic nitrogen adsorption method. All kinds of test methods have their own advantages and
In this paper, 15 cores from a tight reservoir in Daqing were firstly analyzed by clay minerals and whole-rock X-ray diffraction. The chemical composition and clay content of the 15 cores were detected to be 13% on average, mainly chlorite, illite and smectite interlayer. The chemical composition of the whole rock is mainly quartz, plagioclase and calcite. Then the distribution of pore and pore throat in the reservoir was analyzed by means of rate-controlled, nuclear magnetic resonance and Scanning electron microscopy.

2. The pore size distribution of dense core by constant-rate mercury penetration

The technology of constant-rate mercury penetration is one of the most advanced techniques used to analyze the microscopic pore structure of rock. Unlike conventional mercury injection technology, which can only give the throat radius and the corresponding throat control volume distribution, it can give accurate pore, throat, pore throat ratio size and content distribution, suitable for ultra-low and ultra-low permeability reservoirs with very different pore throat properties, as well as tight oil reservoirs. The constant-rate mercury penetration technique has a limited test range and can only test apertures with a radius greater than 0.12μm[11].

The aspe-730 constant velocity mercury injection instrument was used in the experiment, and the constant velocity mercury injection experiment was conducted on 7 tight sandstone blocks at a constant speed of 0.0001ml/min. In this process, 485 mN/m surface tension and contact Angle of 140°stays the same. When mercury enters the small throat of sandstone, the pressure value of the whole capillary system will increase due to the holding pressure. When mercury finally enters the pore, the pressure release of the whole system will decrease. The pore throat data can be obtained by recording the pressure curve changes during the process. Table 1 shows the basic results of constant-rate mercury penetration test.

| Sample no. | K (10⁻³mD) | φ/% | rₜ/μm | rₚ/μm  |
|------------|------------|-----|--------|--------|
| 4          | 0.039      | 6.43| 0.308  | 134.0  |
| 6-1        | 0.043      | 14.7| 0.65   | 117.2  |
| 6-2        | 0.04       | 16.1| 0.217  | 122.7  |
| 7-2        | 0.055      | 15.8| 0.667  | 123.3  |
| 8-2        | 0.032      | 14.1| 0.200  | 131.8  |
| 13         | 0.041      | 7.48| 0.603  | 102.7  |
| 2-1        | 0.132      | 7.8 | 0.847  | 127.68 |
| **Average**| **0.054**  | **11.77**| **0.498**| **122.7**|

Table 1 shows that the average permeability of the core is 12.21×10⁻³mD, and the average porosity is 0.536%. The average throat radius was 0.498μm and the average pore radius was 122.7μm. Figure 1 and figure 2 show the distribution frequency of throat and pore radius measured by constant-rate mercury penetration. It can be seen from the distribution frequency diagram of core throat and pore radius that the throat radius is mainly distributed between 0.217μm and 1.153μm. The pore radius is mainly distributed in 102.7-164.7μm.
Figure 1. Throat radius frequency curves

Figure 2. Pores radius frequency curves

Figure 3 and Figure 4 show the variation of average throat radius and pore radius with permeability. As can be seen from Figure 3, with the increase of permeability, the radius of the average pore remains unchanged in the range of 110~140 μm, suggesting that the average pore size has little influence on the permeability. It can be found from Figure 4 that the average throat radius increases significantly with the increase of permeability, and the low permeability of these Daqing cores is mainly caused by the small throat.

Figure 3. Pores radius varies with permeability
Figure 4. Throats radius varies with permeability
3. The pore size distribution of dense core by Nuclear magnetic resonance method

Nuclear magnetic resonance is a natural phenomenon in which a certain nucleus absorbs electromagnetic radiation of a certain frequency existing in a strong magnetic field and appears to precession freely. In recent years, this technology has been widely used in the field of conventional and unconventional oil and gas research. Nuclear magnetic resonance technology [12] does not cause damage to the pore structure of the core, but is susceptible to the effects of magnetic materials in the core.

The experimental principle of NMR is that there are three different relaxation mechanisms for the fluid in the pores [13]: free relaxation, surface relaxation and diffusion relaxation. The T2 relaxation time reflects the chemical environment of the hydrogen proton in the sample, which is related to the binding force and freedom of the hydrogen proton, and the binding degree of the hydrogen proton is closely related to the internal structure of the sample. In addition to the effects of bulk relaxation and diffusion, the T2 distribution is related to pore size. In porous media, the longer the pore diameter is, the longer the water relaxation time is. The smaller the pore size is, the more bound the water in the pore is and the shorter the relaxation time is, that is, the position of the peak is related to the pore size, and the area of the peak is related to the corresponding pore size. When short TE is used and the pores are only water-containing, the surface relaxation plays a major role, that is, T2 is directly proportional to the pore size.

Microm12-025v NMR analyzer was used to detect the T2 spectrum of fluid in core pores. The test results are shown in figure 5.

The results of NMR pore size distribution show that the pore size distribution is bimodal, and the pore proportion of throat is much larger than that of pore, indicating that the pore size distribution of tight sandstone is dominated by throat. The average throat radius of a single core is shown in table 2, and the overall average throat radius is 0.438μm. Compared with the experimental results measured by constant velocity mercury injection, the nuclear magnetic resonance test results show that the throat radius is slightly smaller than the test results of constant-rate mercury penetration. Compared to the test range of constant-rate mercury penetration, NMR can measure the data of smaller pore size, so the result is more accurate.

![Figure 5. Throat radius distribution by NMR](image)

| Sample no. | \( R_t/\mu m \) |
|------------|-----------------|
| 2-1        | 0.60            |
| 3          | 0.72            |
| 4          | 0.56            |
| 6-1        | 0.25            |
| 8-2        | 0.36            |

Figure 5. Throat radius distribution by NMR
The pore size distribution of dense core by Scanning electron microscopy

The Scanning electron microscopy image can visually see the pores and fractures at the micro-nano-level, and at the same time, analyze different minerals, which is a qualitative assistant analysis tool. The analysis of core Scanning electron microscopy image is conducive to the understanding of the percolation characteristics and reservoir sensitivity.

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According to figure 6, it can be found that the radius of small pores in the core is about 0.1-1μm, while the width of large pores and large fractures is about 1-200μm. The results obtained by electron microscopy are consistent with those obtained by constant-rate mercury penetration and NMR. The advantage of scanning electron microscopy is that it can visually see the structure and shape of pores.

|   |   |
|---|---|
| 12 | 0.27 |
| 13 | 0.31 |
| Average | 0.44 |

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![Figure 6-1. Sample no.2-1 Scanning electron microscopy image](image1.png)

![Figure 6-2. Sample no.2-23 Scanning electron microscopy image](image2.png)

5. Conclusion

The rock cores were measured by constant constant-rate mercury penetration, Nuclear Magnetic Resonance and Scanning Electron Microscopy and comparative analysis of the results, the conclusions are as follows:

1) The average throat radius of tight core is 0.483μm, and the average pore radius is 122.7μm.

2) The permeability increases with the increase of the average throat radius, and the small throat radius is the main reason for the low core permeability.

3) The scope of the three methods of constant-rate mercury penetration, nuclear magnetic
resonance and electronic scanning is different. The pore measurement effect of constant-rate mercury penetration is better, the throat measurement of nuclear magnetic resonance is more accurate, and the results of electronic scanning are intuitive. Only when the three methods complement each other, can the results be consistent with the reality.

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