Three-dimensional reconstruction of tight sandstone with CT scanning

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Abstract. The evaluation of reservoir rock pore structure is the basic research work for the exploration and development of unconventional oil and gas fields. In this work, the CT scanning experiment of tight sandstone was carried out, the gray value distribution of the CT image was analyzed, and the three-dimensional reconstruction of the rock sample was conducted by the linear interpolation method after the threshold segmentation. The results show that grey level are centrally distributed between 0~150 in the original CT image. The pixels with the gray value in the 50-100 interval have the highest occurrence frequency. The pore diameter of the tight sandstone sample is small, the distribution is scattered, and the connectivity is poor.

1. Introduction

The pore structure evaluation of reservoir rocks is of great significance for the exploration and development of unconventional oil and gas fields[1, 2]. However, the rock mass medium is buried deep underground, and the in-situ detection technology of its internal pore structure is difficult, costly and has low reliability[3]. Laboratory means are often used to obtain parameters for characterizing the pore structure of rock. Core observation is to extract petroleum hydrocarbons from rock core by a certain solvent in advance and to analyze it by fluorescence spectrum. But this method destroys the original appearance of rock and has defects such as failure to understand the fabric information of rocks. At present, the fluorescence microscopic image technology can be used to accurately observe the structure of core and the distribution of hydrocarbon fluorescence. This method relies on perception of fluorescence color and intensity by human eyes or true color cameras, which has the fundamental disadvantage of the same color with different spectrum.

The emergence of X-CT scanning technology is a good solution to the above problems. Through the CT scanning experiment on rock samples, the nondestructive testing of the internal structure of the sample can be realized, and then the pore structure inside the core can be displayed intuitively through three-dimensional reconstruction.
2. CT scanning experiment

2.1. Design of experimental scheme
The core used in this experiment is taken from tight sandstone reservoir in block 4 of central Junggar basin, with a diameter of 25.3mm and a height of 43.7mm. The experimental instrument is VersaXRM-500 micron CT scanner. The core scanning volume resolution is 2.018µm and the projection number is 1000.

2.2. Experimental result processing
The experimental results are processed and the pore structure characteristics of rocks are studied from various aspects.

2.2.1. Analysis of gray distribution histogram. The gray histogram of an image is obtained by calculating the occurrence frequency or probability of each grey level in the image to reflect the statistical characteristics of the gray level value[4]. In MATLAB, a function that specializes in drawing a histogram is provided, which can draw the histogram of the image, the histogram of the adjusted gray level and the balanced histogram, and the corresponding image.

Using the functions provided in MATLAB to process the image, the gray distribution histogram of tight sandstone core CT scanning image is obtained, as shown in Figure 1 and Figure 2.

In the process of CT scanning, objects with different densities have different X-ray absorption degrees, which are represented by different gray values in the image. In CT scan images of rocks, there are 256 levels of gray value, 0 is the darkest (all black), 255 is the brightest (all white), and different gray values represent substances with different density.

![CT scanning diagram and gray scale histogram of core 30 layer.](image)

**Figure 1.** CT scanning diagram and gray scale histogram of core 30 layer.
In Figure 1 and Figure 2, it is found that in the same scanning area, the number of pixels with a gray value of about 100-200 decreases with the increase of depth, and the increase frequency of pixel with a gray value of 50-100 with the depth is higher. It shows that there are less pores and greater core density at this time. On the whole, the porosity of tight sandstone core is relatively low.

In addition, the gray distribution histogram can be used to get the approximate range of gray distribution intuitively, and the optimal segmentation threshold is initially estimated. The original CT image gray value distribution is more concentrated, and the range is between 0~150, which is not conducive to the threshold segmentation for images. After the image equalization, the contrast of different parts is enhanced, the range of the grey level distribution becomes wider, the peaks and the valleys are obvious, which is beneficial to distinguish the pore and matrix of the rock.

2.2.2. Digital image segmentation. Grayscale image segmentation is the first step and the foundation of image processing. There are two kinds of image segmentation techniques: histogram based gray-scale image segmentation and non histogram segmentation. The non histogram segmentation method is selected in this study.

The two value segmentation of the image will make the pixels on the image only have 0 or 255 grey level, and the whole image will present a significant black and white effect. The porosity is separated from other regions by two value segmentation, and porosity is calculated. The best threshold $k^*$ for image segmentation is determined by measured porosity [5].

\[
f'(k^*) = \min \{f'(k) = \Phi - \frac{\sum_{i=I_{\text{min}}}^{k} P(i)}{\sum_{i=I_{\text{min}}}^{I_{\text{max}}} P(i)}\} \quad (1)
\]

Where $\Phi$ is the porosity of core, $k$ is the gray threshold, $I_{\text{min}}$ and $I_{\text{max}}$ are the maximum and minimum values of gray scale, and $P(i)$ is the body prime number with gray value of $i$. The gray values above the threshold value changed to 255, representing the pores, and the gray values below the
threshold changed to 0, representing other components. The experimental results of the overpressure porosity and permeability of the core are shown in Table 1.

| Number | Sample mark | Length /cm | Width /cm | Porosity /% | Permeability /md |
|--------|-------------|------------|-----------|-------------|-----------------|
| 1      | 2-33/54     | 4.37       | 2.53      | 4.7         | 0.01            |

According to the measured porosity, the best segmentation threshold $k^*$ is 114, and the schematic diagram of the segmentation process after selecting the best threshold is shown as Figure 3.

![Figure 3. Image optimal threshold segmentation diagram.](image)

2.2.3. *Image smoothing processing.* In the image acquisition and quantization processing, some noise may be produced. In the transmission process, it may also be affected by various interference signals to produce noise, which will affect the identification of the pore structure in the CT image. Therefore, in image processing, image filtering is needed to remove noise. Commonly used filters are low pass filter, high pass filter and median filter. In this study, mean filter and Gauss filter, are used to smooth the image. The result is shown in Figure 4.

![Figure 4. Image after smoothing processing.](image)

From Figure 4, it can be seen that although filtering can eliminate the noise in the core image, it reduces the porosity of the filtered image, which is very common in tight sandstone. Because the pores
below the image resolution are common in the tight sandstone, if they are clustered together, the pores are shown to be gray, but if dispersed, it can not be displayed in the image [6]. So it has little influence on the rock with large pore size, but if the pore size is small, the result will be quite different. Combined with many influencing factors, 3×3 median filter with better effect is selected.

3. 3D reconstruction of core

3D reconstruction of images is to extract information of 3D object from two dimensional image sequences, visualize the organization structure of 3D objects, and strengthen the original details in the image [7]. The three dimensional reconstruction of this study is mainly based on the data extracted from the CT scanning image, restoring the three-dimensional structure of the original specimen and establishing the three-dimensional model of the core, so as to observe the pore structure of the core more intuitively.

The main steps of 3D reconstruction of core CT image are follows: readin of the image, smoothing processing of the image, creation of a graphic output window, establishment of coordinate system, data interpolation, setting of color light and so on. In this research, the image interpolation method in 3D reconstruction is linear interpolation method based on gray level. The formula (2) is shown as follows:

\[ f_{i}(i,j) = (1-\lambda)f_{k}(i,j) + \lambda f_{k+1}(i,j) \]  \hspace{1cm} (2)

where \( f_{k}(i,j) \) and \( f_{k+1}(i,j) \) are the scanning image of layer \( k \) and layer \( k+1 \), \( \lambda=d_{1}/(d_{1}+d_{2}) \), \( d_{1}, d_{2} \) are the distances from the interpolated image to the \( k \) and \( k+1 \) layer images. The 3D reconstruction diagram of core is shown in Figure 5.

![Figure 5. 3D reconstruction diagram of core.](image)

The pore structure of core can be visually observed in Figure 5, at the same time, the reconstructed 3D model provides a model foundation for microscopic percolation numerical simulation of tight sandstone.

4. Conclusion

(1) The gray scale histogram of the core CT image in the study area shows that the occurrence frequency of the pixels with gray value in the 50-100 interval is the highest, indicating that most of the rock samples are of large density, the porosity is low and the rock is dense.

(2) The Threshold segmentation is carried out according to the measured porosity, and the best segmentation threshold \( K \) is 114. The 3×3 median filter is selected in the smoothing processing, which can reduce the noise pollution and better reveal the core pore characteristics.

(3) The CT scanning image is read by MATLAB program. The core is 3D reconstructed based on the gray linear interpolation method and the reconstructed image is obtained. The pore structure of the core can be observed more intuitively. At the same time, it lays the foundation for the numerical simulation of tight sandstone microscopic percolation.

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