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Study on Microscopic Pore Characteristics of Tight Sandstone

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Abstract. Pore structure of tight sandstone reservoir is an important factor determining the physical property and oiliness of the reservoir, therefore the experimental study on the sample of tight sandstone in the 4 block of the central Dzungaria Basin was carried out through CT scanning. The optimal threshold segmentation method is applied to binary image segmentation, and core porosity is calculated. The pixel size is considered as the aperture, and the relationship between pore size and porosity is studied by changing the image pixel size. The results show that: the optimal segmentation threshold K is 114, and the overall porosity of core is 4.1%, which is basically consistent with the experimental results of pore infiltration. With the decrease of image pixel points, core porosity decreases, and there is a logarithmic relationship between them.

1. Introduction

Computed Tomography (CT) calculated the absorption coefficient of each unit volume of the section by measuring the attenuation information of a selected section of an object transmitted by multiple X-ray beams, and then obtained the density distribution image of the section [1]. At present, CT technology has been widely used in biology, materials, archaeology, medicine, petroleum geology[2], electronics and other fields. CT scanning is used to detect rock without damage in order to analyze and study the microstructure of rock. LI Yu-bin et al. [3], ZHAO Xiucai et al. [4], YI Min et al. [5], who studied the porosity of rock cores respectively, but these experiments were all based on the original CT single image generated by the CT computer system, without further studying the pore diameter and porosity of rock. In this study, MATLAB was used to study the pore structure characteristics of dense sandstone based on CT scanning.

Digital image processing technology, involving optical technology, microelectronics technology, computer technology and mathematical analysis, etc, possesses the characteristics of comprehensive strong and wide application range [6, 7]. Specifically, many technologies are included, such as image...
visual foundation, image transformation, image enhancement, image recovery, image compression, image coding, image decoding, image transmission, image recognition and image analysis. MATLAB can complete the above theoretical verification and engineering implementation. MATLAB software can efficiently carry out numerical calculation, and the graph function is complete.

2. CT scanning experiment

2.1 Experimental scheme

The cores used in this experiment were taken from the dense sandstone reservoirs in the 4 block of the central Dzungaria Basin, with a diameter of 2.53mm and a height of 4.37mm. 1000 grayscale images were obtained using the VersaXRM-500 micron CT scanner with a resolution of 2.018 μm.

2.2 Analysis of experimental results

Gray image segmentation is the basis of image processing. Image segmentation techniques can be divided into two types: histogram based grayscale image segmentation and non-histogram segmentation. The method of non-histogram segmentation was used in this study. By binary image segmentation, the gray value of pixel points on the image is set to 0 or 255, presenting the entire image with an obvious black and white effect. The porosity can then be calculated by separating the pores from other components. The optimal threshold \( k^* \) of image segmentation is determined by equation (1). The grayscale above the threshold changes to 255, representing pores. The grayscale below the threshold changes to 0, representing other components.

\[
\min_{k \in I_{\max}} \left\{ f(k) = \frac{\sum_{i=I_{\min}}^{k} p(i)}{\sum_{i=I_{\min}}^{I_{\max}} p(i)} \right\}
\]

Where, \( \Phi \) represents the core porosity, \( k \) represents the gray threshold, \( I_{\max} \) represents the maximum grayscale, \( I_{\min} \) represents the minimum grayscale, and \( p(i) \) represents the number of pixels with a grayscale value of \( i \).

The experimental results of porosity and permeability are given in Table 1.

| Label | Length (cm) | Width (cm) | Porosity (%) | Permeability (mD) |
|-------|-------------|------------|--------------|-------------------|
| 2-33/54 | 4.37 | 2.53 | 4.7 | 0.01 |

According to the measured porosity, the optimal segmentation threshold \( k^* \) is 114, and the diagram of the segmentation process after selecting the optimal threshold is shown in Fig. 1.

![Fig.1 The diagram of optimal threshold segmentation](image-url)
3. Study on characteristics of pores

Porosity is calculated from the segmented image. The porosity of each scanning layer can be obtained by dividing the area of the white part of the graph by the area of the cross section of the core. Similarly, the overall porosity can be obtained by dividing all pore volume by core volume. In the CT scan image, the area is represented by the number of pixel points, so the calculation formula of porosity is given in equation (2).

\[ N = \frac{A_0}{A} \times 100\% \]  

Where, \( N \) represents the porosity, \( A_0 \) represents the number of pixels with grayscale value 255, and \( A \) represents the total number of pixels with image grayscale value 0 and 255.

3.1 Calculation of core porosity

According to equation (2), the porosity of each CT scan image was calculated, and its mean value was taken as the overall porosity of the core. The curve of porosity with the number of scanning layers was obtained as shown in Fig. 2:

![Fig.2 The Curve of porosity change](image)

As can be seen from Fig.2, the porosity of the middle part of the core is relatively high, and the porosity varies greatly with the number of scanning layers. The peak porosity of dense sandstone occurs in 573 layers, with a porosity of 7.29% , and the overall porosity is 4.1%.

3.2 Influence of pore diameter on porosity

A digital image is essentially a matrix. For example, an image with a resolution of M by N is a matrix of M rows and N columns. Take the CT image of this scan as an example, the original image resolution is 1024 * 1024, and each pixel point is a square with a 2.018 \( \mu m \) side length. The pixel edge length of 2.018m was considered as the pore size of the specimen by LI Jian-sheng et al. [8]. The relationship between pore size and porosity can be obtained by changing the image resolution and finding the corresponding porosity when different pore sizes are obtained. The resolution of the 450th layer CT scan image of the core was adjusted to 2048 * 2048, 512 * 512, 256 * 256, respectively, so as to obtain the pore diameter and porosity. The relationship between pore diameter and porosity can be intuitively shown. The original CT scan image resolution was 1024 * 1024, and all image resolution was adjusted to 2048 * 2048, 512 * 512, 256 * 256 in batch. The pore diameter and overall core porosity were obtained as shown in Table 2.
Table 2 Core porosity and pore size

| Pore diameter (µm) | 1.009 | 2.018 | 4.036 | 8.073 |
|-------------------|-------|-------|-------|-------|
| Overall porosity (%) | 6.55  | 6.13  | 5.29  | 3.78  |

Fig. 3 The variation of porosity with pore size

As shown in Fig. 3, porosity decreases with the increase of pore diameter. The porosity of core obtained by digital image processing technology is between 3% and 7%, and the measured porosity of core by overpressure hole infiltration experiment is 4.7%. The difference between the two groups of data is small, which meets the requirements within the allowable error range. The fitting formula is given in equation (3).

\[ y = 0.0567x^2 - 0.736x + 5.5966 \]  

Where, \( y \) represents the porosity and \( x \) represents the pore diameter.

4. Conclusion
(1) In this study, the optimal segmentation threshold \( K \) of CT image was 114, and the overall porosity of core was 4.1%, which was basically consistent with the results of the hole infiltration experiment.

(2) The original images were compressed to generate new images with a resolution of \( M/x \times M/x \) pixels. Taking the pixel size of the new image as the pore diameter, the porosity of the new image was calculated again, and it was found that the core porosity decreased with the decrease of pixel points. The relationship between porosity and pore diameter was described by the formula \( y = 0.0567x^2 - 0.736x + 5.5966 \). The correlation coefficient \( R^2 \) was 0.9443 and the fitting degree was high.

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