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Simulation of Three Dimensional Pore Model of Berea Sandstone Core by CT Scanning Method Based on AVIZO Software

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Abstract: In this paper, X-ray CT scanning was performed on the Berea sandstone core samples to obtain two-dimensional multimedia images. AVIZO software was used to binarize the two-dimensional core images and extract the core pore model. The maximum sphere algorithm was used to characterize the extracted core pores and the pore model, and a 3D pore network model was established. The theoretical method for establishing 3D digital core pore network was described in detail, and the parameter setting method in the algorithm was introduced. The research showed that, AVIZO software could be used to visualize modelling of the 3D digital core pore network, the extracted Berea sandstone pore network had good connectivity, showing obvious pore network size differentiation. The simulation model supported good reduction of the Berea sandstone core, and hydrodynamics related calculation can be carried out in the next step.

1. Introduction

Oil and natural gas resources, as the energy needed in China's industrial development, form an important pillar for China's future industrial upgrading, while energy security is an important guarantee for China's future industrial development[1]. Since the 21st century, following the significant increase of China's economic growth rate and the increasing expansion of industrial scale, the demand for oil and gas resources has grown exponentially[2]. Therefore, increasing the exploration and exploitation efficiency of oil and gas resources arouses greater concern. To explore and develop oil and natural gas fields, fine grid division and accurate evaluation are required for the rock reservoirs rich in oil and gas, especially the micro-complex 3D pore network structure in the rock of the Berea sandstone that constitutes the oil and gas reservoir, which not only affects the oil and gas reserves of the Berea sandstone rock reservoir, but also determines the oil and gas flow rate in the reservoir exploitation process as well as economic value evaluation of the reservoir exploitation.

The simulation experimental research methods for seepage mechanics mechanism of rock pore network in oil and natural gas reservoirs are mainly divided into 3D digital core simulation and hydropower simulation experiments[3]. Due to the limitation in its own experimental conditions, it is impossible for hydropower simulation experiment to simulate the pore network of complex reservoir rock. Since the 21st century, thanks to the iterative improvement algorithm by massive scholars and the rapid development of computerized tomography (CT) technology, the construction of 3D digital core through X-ray CT scanning and numerical simulation has become an effective means for 3D visual modeling to characterize the pore structure characteristics of reservoir rock core[4]. This visualization simulation technology has been widely applied in petroleum geology and reservoir engineering, making abundant mature and reliable research results in 3D digital core modeling. Without damaging the physical structure of the core, the CT scanning reconstruction technology can clearly visualize 3D model and establish the pore structure network of the reservoir rock core with precision and detail.

In 1980, Elliott et al.[5] designed and manufactured the world's first commercial X-ray CT scanner, which was widely used in the field of medical science. Initially with low resolution and high scanning cost, the CT scanning equipment had limited application. In 1990, Dunsmuir et al.[6] applied CT scanning technology to the field of geological engineering, and greatly improved the CT scanning resolution via technical upgrade, so that the scanning image can clearly reveal the millimeter pore structure of the rock. With the further development of computer image processing technology, CT scanning equipment has significantly greater noise reduction. In 2004, Coenen et al.[7] used CT scanning method to build a 3D digital core model with a resolution of micro or nano level. Since then, CT scanning technology is more widely used, with scanning modeling objects increasing day by day.

Based on the existing research results of the above experts and scholars, and considering the advantages of CT scanning method in establishing 3D digital core pore network model, this paper adopts AZIZO software to conduct 3D digital core visual modeling and simulation experiment.

2. AVIZO Software Function

As a commercial software launched by VSG, the United States, AVIZO was born in 1994 and can support Windows, Linux and Unix system environment after constant iterative optimizations. AVIZO software is well established for 3D visual modeling of porous media, fiber composites and alloy materials. By importing media files from scanning electron microscopy, NMR, X-ray scanners and microscopes, it conducts image processing and enjoys extensive applications in materials science, earth science, oceanography, climatology, environmental science, computational fluid mechanics, physics, etc.[7] AVIZO software provides users with calculation of the following parameters and open programming environment:

(1) Porosity, tortuosity, box-counting fractal dimension, absolute permeability;
(2) Pore throat distribution, coordination number, and average pore size/pore length;
(3) LBM/paraview unidirectional flow field post-processing;
(4) DVC in-situ loading test analysis;
(5) COMSOl/FLUENT interactive solution.

3. Fractal Theory and Maximum Sphere Algorithm

3D digital core model is a huge and disordered data body composed of a large number of 3D discrete data points, which represents the pore structure of real core in a discrete form, demonstrating great complexity and randomness. How to quickly and effectively analyze the characteristics of these 3D data points and how to simplify the extraction of the pore structure model of 3D digital core are of great significance for the pore network model analysis of 3D digital core and the simulation of reservoir fluid dynamics[8]. The basic topic of fractal theory and threshold segmentation research is the autocorrelation function of the target object. The pore and pore structure of rock are extremely complex, which demonstrates statistical self-similarity in terms of data statistics. At present, the pore structure established based on fractal theory provides an effective means to study the pore structure of micron-scale rocks [9]. The pore network model established by the maximum sphere algorithm has high computational efficiency and good similarity to the real core. Silin et al· [10,11] first proposed the concept of maximum sphere algorithm and established maximum spheres with different radii to represent the pore channel connecting the pores. Based on the research of this algorithm, Al-kharusi and Blunt[12] et al. provided a more comprehensive definition regarding how the maximum sphere algorithm identifies pores and throats of different sizes. Dong[13] improved and optimized the maximum sphere algorithm, and the established pore network model has greater computational efficiency and reduces the memory space occupied by the model.

The 3D digital core reconstruction technology represents the rock skeleton structure as a discrete data body, in which, the solid skeleton and pore space are binarized and represented by 0 and 1 respectively. For pore channel with high tortuosity, it is difficult to directly solve the Navier-Stokes equation and conduct numerical simulation calculation of fluid dynamics. The 3D pore network model uses the ball-and-stick model to indicate the pore and throat information. The larger pore space is represented as the spherical space, and the smaller connecting channel between the pores is represented as the throat. The 3D digital core model is combined with the 3D pore space representation method to establish a new 3D pore network model. The establishment of 3D digital core pore network model by using maximum sphere algorithm mainly consists of four steps:

(1) Establish the maximum spherical particle size radius;
(2) Determine the connectivity between the largest spheres;
(3) Pore and throat identification;
(4) Calculation of pore and throat parameters

4. Ct Scanning Experiment

This study examined the underground Berea sandstone core samples in Altay area, Xinjiang. The mineral composition of Berea sandstone is clastic quartz SiO_2, there is very small content of other mineral components and no cemented argillaceous structure. The core has strong homogeneity, good connectivity of pore structure, and large effective flow space. After cutting, the sample size was $2.56mm^3$, the scanning resolution was 5.345μm, the digital core porosity was 22.57%, and the voxel was set to 300^3. The CT scanner was Cougar Basic of Yxlon model from Germany, and part of the CT scan sections were shown in Figure 1.

5. Digital Image Processing

Filtering, noise reduction and binarization analysis should be performed on the original two-dimensional image obtained by CT scan to get the digital image reflecting the rock characteristics. The pore space structure of Berea sandstone was extracted after threshold segmentation in the image, as shown in the blue part in Figure 2. Transparent processing was applied to the sandstone skeleton, and semi-transparent processing was applied to the outer surface of the sandstone skeleton, leaving a light blue translucent boundary.

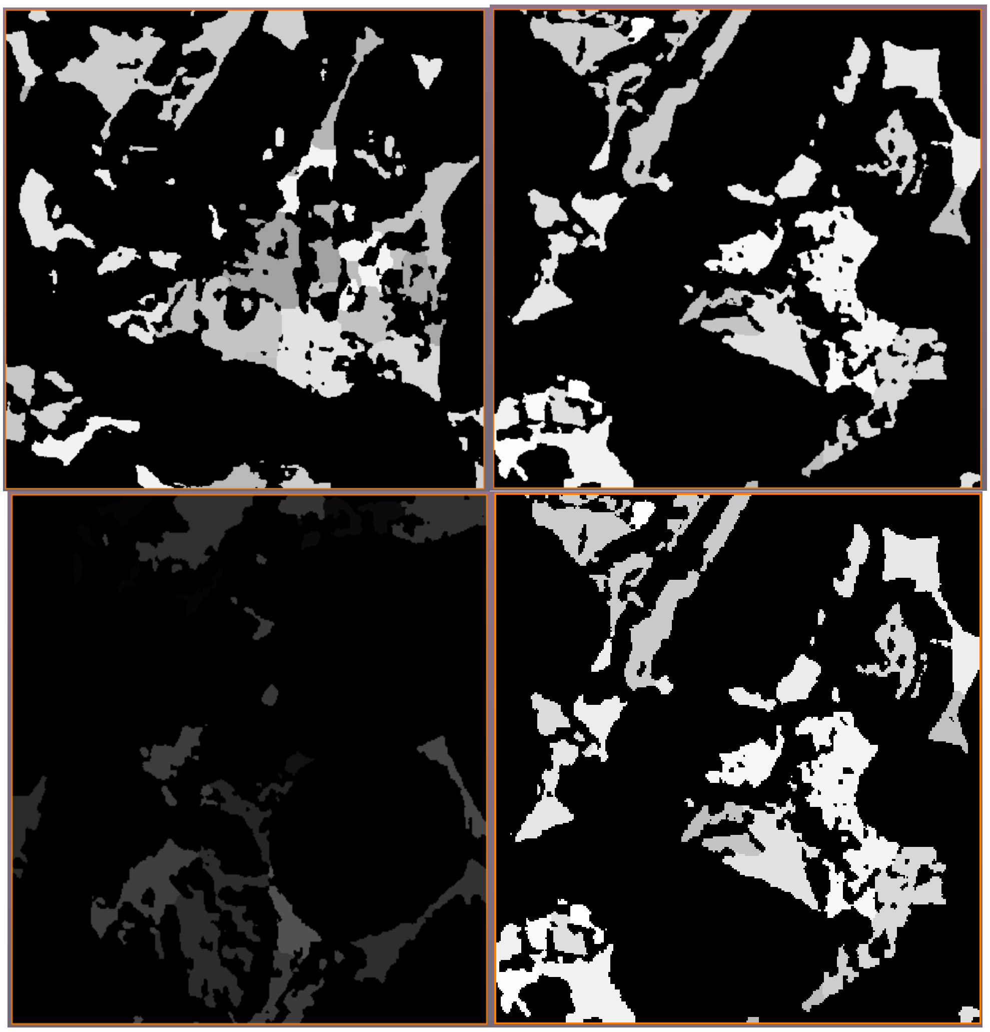

Figure 1: Scanning map of Bailey sandstone.

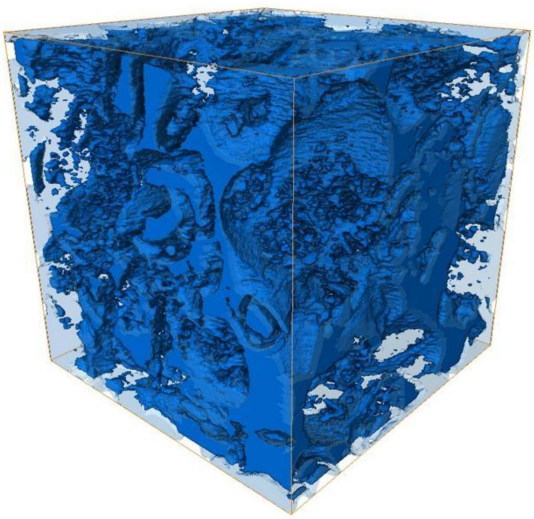

Figure 2: Chart of plane fitting results.

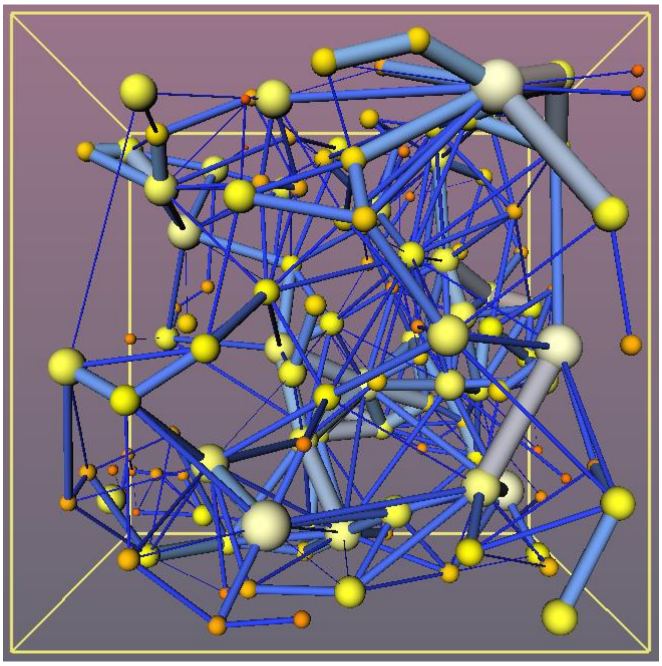

Figure 3: Three-dimensional pore roaring network model.

According to the maximum sphere algorithm, the pore space of the extracted Berea sandstone was reconstructed, and a 3D digital core pore network model (PMN for short) was established. As shown in Figure 3, the narrower the pore channel is, the darker the color is. The narrowest pore channel is dark blue, while the widest one is light blue. The spherical space with the smallest pore space is dark yellow, and the spherical space with the largest pore space is light yellow. It can be seen that the 3D pore structure of the Berea sandstone sample greatly simplifies the complex rock pore model shown in Figure 2. The reconstructed pore network has good connectivity, mainly as effective pore channel, and the main seepage channels are clearly visible, which greatly facilitates fluid dynamics simulation calculation in the next step.

5. Conclusions

In this paper, CT experimental scanning method was used to establish 3D visual digital core, and core pore structure was extracted based on fractal theory and maximum sphere algorithm. Finally, 3D visual pore network model was established to characterize the pore structure and pore throat characteristics of digital core. Pore structure characteristics of rock greatly affect the seepage characteristics of reservoir fluid. This study will facilitate the establishment of reservoir fluid flow model of oil and gas as well as in-depth analysis of the relationship between fluid and pore network, which can provide more reference information for the construction of rock physical model and reservoir logging evaluation, thus carrying great significance for studying 3D digital core pore structure network model.

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