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Influence of Pore Geometry on Sandstone Pore Analysis Based on a Digital Core

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A digital core obtained without damage and contact can provide intuitive and quantitative analysis data for sandstone pore structure analysis. However, pore analysis results based on digital cores are quite different from experimental results due to limitations of scanning resolution, quality, pore extraction method, and experimental errors. In this research, the influence of pore geometry on pore analysis is studied from pore angles and pore resolution. First, sharp angles are extracted by image processing, and the influence of angles on pore radius distribution is analyzed. Then, by up–down sampling, high- and low-resolution digital cores are reconstructed, and the effects of resolution on pore connectivity and throat structure are discussed.

Keywords: digital core, sandstone, pore structure, pore radius distribution, pore analysis

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INTRODUCTION

The digital core obtained by CT scanning technology can provide visual and quantitative data for pore structure characterization without damage and contact [1, 2]. However, many experiments have shown that pore analysis results extracted from digital cores are often deviated from the experimental results [3–5]. On the one hand, they are affected by the accuracy of pore extraction and the resolution limitation of scanning. On the other hand, there are errors in the experimental measurement method because of the microstructure inside the pores [6–8]. Therefore, analyzing the influence of pore geometry on pore analysis in a digital core is helpful to guide designing and developing experiments, application of digital core technology, and understanding the mechanism of pore microstructures on seepage [9, 10].

This study analyzes two sandstones with size 655 × 655 × 655 um^3, in the Ordos area. The digital cores are obtained by CT scanning technology with 1.0-um physical resolution. Combined with image processing to extract the pore structure, the influence of pore geometry is analyzed by simulation from two aspects:

1) Influence of pore angles

The pore shape of sandstone is complex and irregular, which reflects a large difference in pore size from a macroscopic view. From a microscopic view, the pores with the same size have different pore angles. These angles are ignored in both experimental tests and simulation, and every pore and throat are replaced by an ideal model. This also leads to error values in the experiment. In this study, the pore angles are extracted based on image processing, and the variation characteristics are analyzed.

2) Influence of digital core resolution

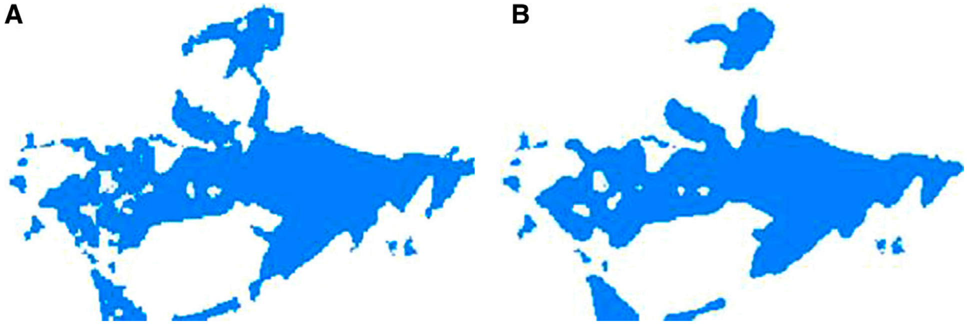

FIGURE 1 | Comparison of pore angles removed. **(A)** Original pore. **(B)** Pore without angles.

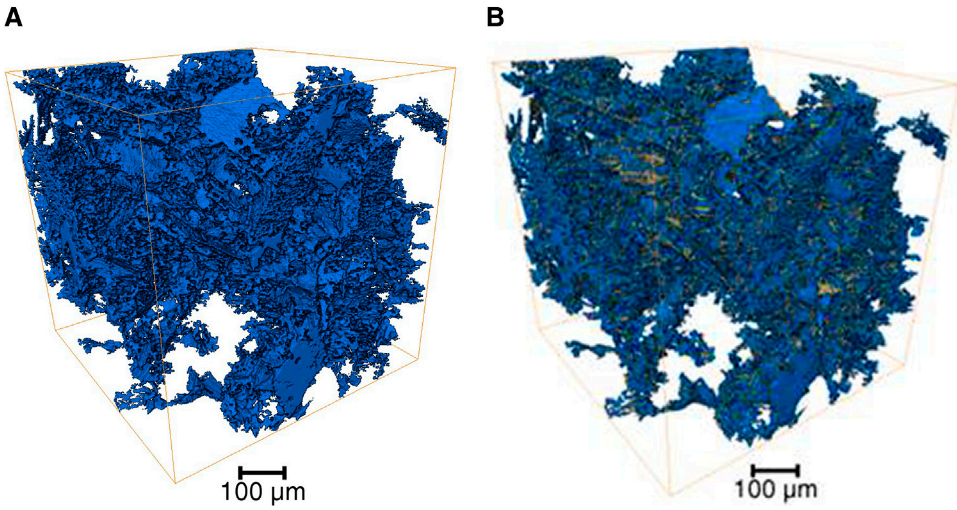

FIGURE 2 | Effect of pore angle in 3D. **(A)** Original pore. **(B)** Pore and angles (gray).

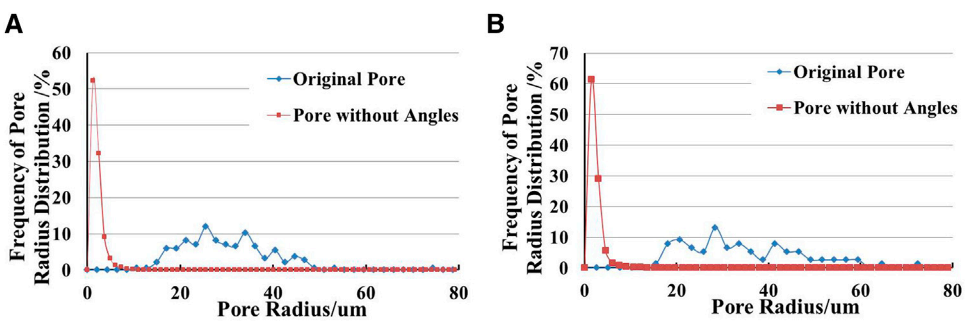

FIGURE 3 | Comparison of pore radius distribution. **(A)** Sample 1. **(B)** Sample 2.

Scanning resolution and scanning field of view are contradictory. Under the same image resolution, higher scan resolution leads to a smaller field of view. Although higher resolution can obtain more detailed information, only a partial core can be collected due to the small field of view. Conversely, the resolution has to be reduced in order to obtain an overall scanning image from the core sample. Meanwhile, resolution variation will affect the pore morphology. In this study, digital cores with different resolutions are reconstructed from the same scanning results to analyze their influence on porosity and connectivity.

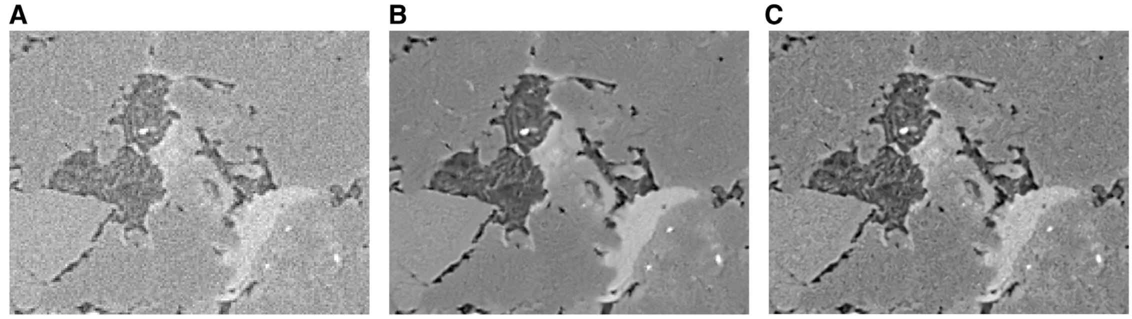

FIGURE 4 | Sample parts with different resolutions. **(A)** Low resolution. **(B)** Original. **(C)** High resolution.

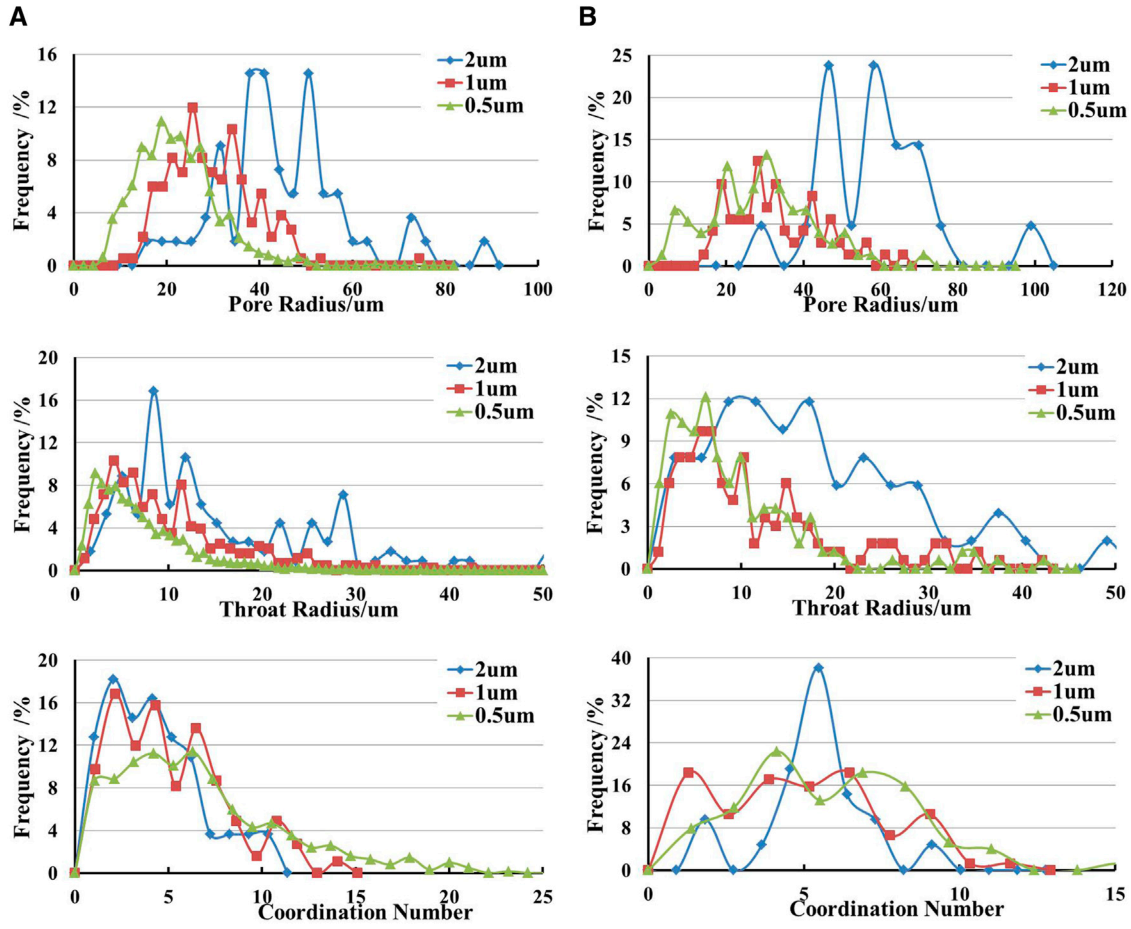

FIGURE 5 | Distribution of pore and throat radius and coordination number under different physical sizes. **(A)** Sample 1. **(B)** Sample 2.

INFLUENCE OF PORE ANGLES

Based on the image processing method (**Eq. 1**) and logical operation, the pore angles are removed and the edge is smoothed. The effect comparison is shown in **Figure 1**. In **Eq. 1**, we set $W = [-1, 1]$.

$$\mathbf{G}(\mathbf{x}) = \mathrm{Median}\{f(x - m, y - n), (m, n \in W)\}. \tag{1}$$

In **Figure 1B**, pores and edge are smoother and the ideal pore network model is closer to it. However, removing pore angles affects the porosity as single holes are relatively reduced and some small pores are directly smoothed out in the 2D slice. Therefore, combined with a logical operation, small pores are retained. The comparison in 3D is shown in **Figure 2**. The influence of pore angles on radius is shown in **Figure 3**.

In **Figure 3**, each sample has a large difference in pore radius distribution. The original pore size decreases and the large pores are divided into smaller ones with angles removed, which results in an increasing number of small pores. What needs to be considered here is that the overall porosity decreases after the pore angles are removed. The porosity of sample 1 changes from 8.9% to 7.5%, and that of sample 2 changes from 5.7% to 4.9%. The permeability of sample 1 changes from 0.1162 to 0.1069 μm^2, and that of sample 2 changes from 0.1177 to 0.1230 μm^2. The change in sample 2 indicates that angles in pores can reduce permeability. While in sample 1, porosity and permeability decrease by 1.4% and 0.0093 μm^2, respectively, which illustrates there are more angles in it and the structure is more complex than the structure of sample 2. The degree of variation can also be used to evaluate the complexity of the pore structure.

INFLUENCE OF DIGITAL CORE RESOLUTION

Based on the principle of the same physical size, digital cores with high and low resolutions are established by using up–down sampling methods for each sample. In **Figure 4**, parts of sample 1 are shown. **Figure 4A** shows a 0.50-um size sample with high resolution by up-sampling. **Figure 4B** shows a 2.0-um size sample with low resolution by down-sampling. The pore size, throat size, and coordination number distribution of the two samples are shown in **Figure 5**.

In **Figure 5**, the pore radius and throat radius distribution of the two samples have a significant deviation to the left in the core with 0.5 um. It indicates that, due to improvement of physical resolution, more details could be observed, and pores with small size would increase. Pores that cannot be observed at a low physical resolution will be observed at a high resolution. On the contrary, the distribution deviates to the right at high physical resolution. The trend of coordination numbers is opposite. It indicates that the connectivity is enhanced due to an increase in recognizable pores. The resolution analysis can provide predictable results of pore distribution at different pore scales which is useful for analyzing the pore structure in the core.

CONCLUSION

In this study, the influence of pore geometry on pore characteristics based on a digital core is introduced. The influence of pore angles and physical resolution on pore distribution, throat distribution, and coordination number characteristics are analyzed. It also concludes that the existence of pore angles greatly affects the variation of pore size distribution, which is the reason for the obvious difference between experimental measurement and digital core analysis results. Meanwhile, we analyzed the throat, pore size, and coordination number in the same physical size with different resolutions, which can predict pore characteristics of the whole core at different resolutions, which makes the analysis results more objective. This article proposes a new method for pore analysis based on a digital core.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

XL: conceptualization, methodology, investigation, writing—original draft, and visualization. DR: validation, formal analysis, resources, writing—review and editing.

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