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Pore structure characteristics of deep carbonate gas reservoir based on CT scanning

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ABSTRACT

Carbonate gas reservoirs are rich in reserves, with various types of reservoirs, developed cross-scale porous media, and complex seepage mechanisms. In this paper, the natural cores of the fourth member of the Dengying Formation in the Anyue gas field were selected, CT scanning experiments were carried out, and digital cores were constructed. The plane pore characteristics, three-dimensional pore characteristics and pore and throat distribution frequency characteristics of the digital core are studied respectively.

The results of CT scanning show that: (1) the pore and throats of pore-type reservoirs are small, poor in connectivity, and the karst caves and fractures are underdeveloped, with low seepage capacity; (2) The pore and throats of cavity-type reservoirs are relatively large in size, with good connectivity, medium and small-sized karst caves and micro-fractures are widely developed, and the seepage capacity is good; (3) Fracture-cavity-type reservoirs have large pore and throats and good connectivity, and various-sized cavities and various types of fractures are widely developed in the reservoir, and the entire rock block area is full of Interconnected fracture-cavity network system with excellent seepage capacity.

Keywords: Carbonate gas reservoirs, CT scanning, Pore structure characteristics, Fracture-cavity-type reservoirs

1. INTRODUCTION

Carbonate gas reservoirs have been affected by constructive diagenesis such as karst weathering in the geological history period, and developed cross-scale porous media, so the interior of the reservoirs presents a pattern of coexistence of pores, fractures and cavities[1, 2]. Carbonate gas reservoirs have various reservoir types and strong heterogeneity. The actual gas reservoir is a composite reservoir containing multiple types of reservoirs, and the different types of reservoirs are distributed horizontally and vertically, resulting in complex macroscopic seepage laws of gas reservoirs and large differences in gas well productivity[3]. Different types of reservoirs have unique microscopic pore structure characteristics, which are often the key to determining the macroscopic seepage characteristics of reservoirs. It is of great significance to study the microscopic pore structure characteristics of reservoirs to grasp the macroscopic seepage law of reservoirs and the overall development effect of gas reservoirs.

In recent years, CT scanning technology, as an effective means to study the characteristics of rock pore structure, has been widely used in various types of reservoirs such as sandstone, carbonate rock, and shale, and has achieved great results[4-5]. The CT scanning experiment has the characteristics of intuitiveness, non-destructiveness and accuracy. It can not only qualitatively analyze the reservoir space characteristics and heterogeneity of the core, but also quantitatively calculate the rock physics and pore structure parameters. It is a very effective method for the study of the core microstructure.

The Dengying Formation gas pool in the Anyue Gas Field is a typical representative of deep ancient karst weathered crust carbonate gas pools in China, with a large gas-bearing area (7500 km^2), abundant reserves (600 billion m^3), and deep reservoir burial (about 5000 m), high formation temperature and pressure, poor pore-permeability correlation, diverse pore types, and strong reservoir heterogeneity[6-8]. In this paper, natural cores from the fourth member of the Dengying Formation in the Anyue gas field were selected, CT scanning experiments were carried out, and digital cores were then established. The microscopic pore structure of

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three types of typical reservoirs in the selected block and its influence on the seepage capacity of the reservoir are analyzed and studied. In order to provide references for the formulation of efficient development strategies for carbonate gas reservoirs.

Table 1 Experimental Core Physical Parameters

Sample number	Well number	Length/cm	Diameter/cm	Permeability/mD	Porosity/%	Core type
#1	MX-105	10.145	6.632	0.009	1.89	Pore-type
#2	MX-108	7.758	6.742	0.552	3.64	Cavity-type
#3	MX-109	6.905	6.594	3.484	3.87	Fracture-cavity-type

2. METHODOLOGY

2.1 CT scanning principle and equipment

CT imaging technology is an important method for constructing 3D digital cores, and its main principles are as follows. X-ray scanning is performed on the core sample by CT scanning equipment. When the rays with certain energy pass through the core, they will be scattered or absorbed by the rock, resulting in the continuous attenuation of the overall intensity of the rays. The attenuation coefficient is defined according to the Lambert-Beer's law, and the attenuation coefficient is obtained by quantitatively studying the above physical process, so as to obtain the density distribution of the internal structure, and then obtain the two-dimensional image of the section according to the imaging technology. The processed 2D images are then superimposed to form a 3D digital core.

The instrument used in this experiment is a Phoenix v|tome|x m micron CT scanner (made in Germany), equipped with an industry-leading 300kV micro-focus ray tube, which can achieve high magnification ratio and high-precision scanning. The tomographic interval of this instrument is 1 mm, and the resolution is about 40 μm.

2.2 Sample information

The scanning samples in this study were all taken from gas reservoirs of the fourth member of the Dengying Formation in the Anyue Gas Field, including 1 core for each type of pore type, pore-cavity type, and fracture-cavity type, totaling 3 cores. The selected cores have a permeability between 0.009-3.484×10^{-3} μm^2 and a porosity between 1.89-3.87%. The specific parameters of the cores are shown in Table 1.

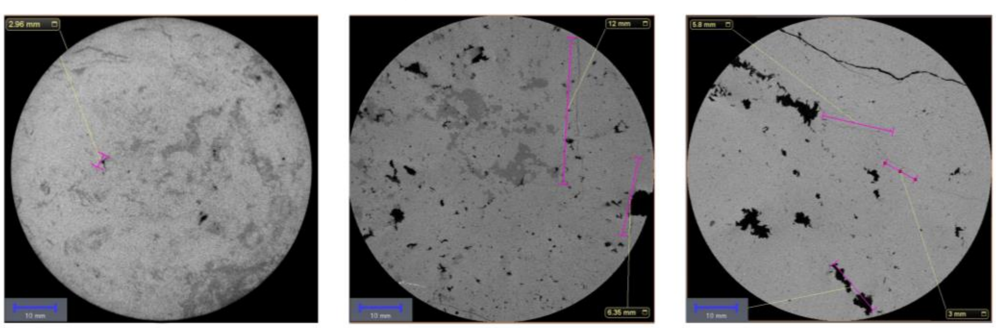
3. MATERIAL AND METHODS

3.1 Planar pore characteristics of digital core

Figure. 1. is the grayscale image of the end faces of three rock samples obtained by CT scanning. It can be seen that the surface porosity of sample 1 is only 1.34%, and there are few large-scale cavities and cracks on the end surface, and only a few small cavities are scattered in the middle of the end surface. Most of the remaining pores are too small to be directly observed with the naked eye.

The surface porosity of sample 2 is 3.45%, and large pores, small cavities and sporadic fractures are generally developed on the core end surface, indicating that this type of reservoir has a strong storage capacity, a certain seepage capacity, and a good development potential. The surface porosity of sample 3 is 4.52%. Large pores, various types of cavities, and various fractures including structural fractures and dissolution fractures are generally developed on the core end surface, indicating that this type of reservoir has excellent storage capacity and seepage capacity.

3.2 Stereoscopic pore characteristics of digital core



(a) Cross section of sample 1 (b) Cross section of sample 2 (c) Cross section of sample 3

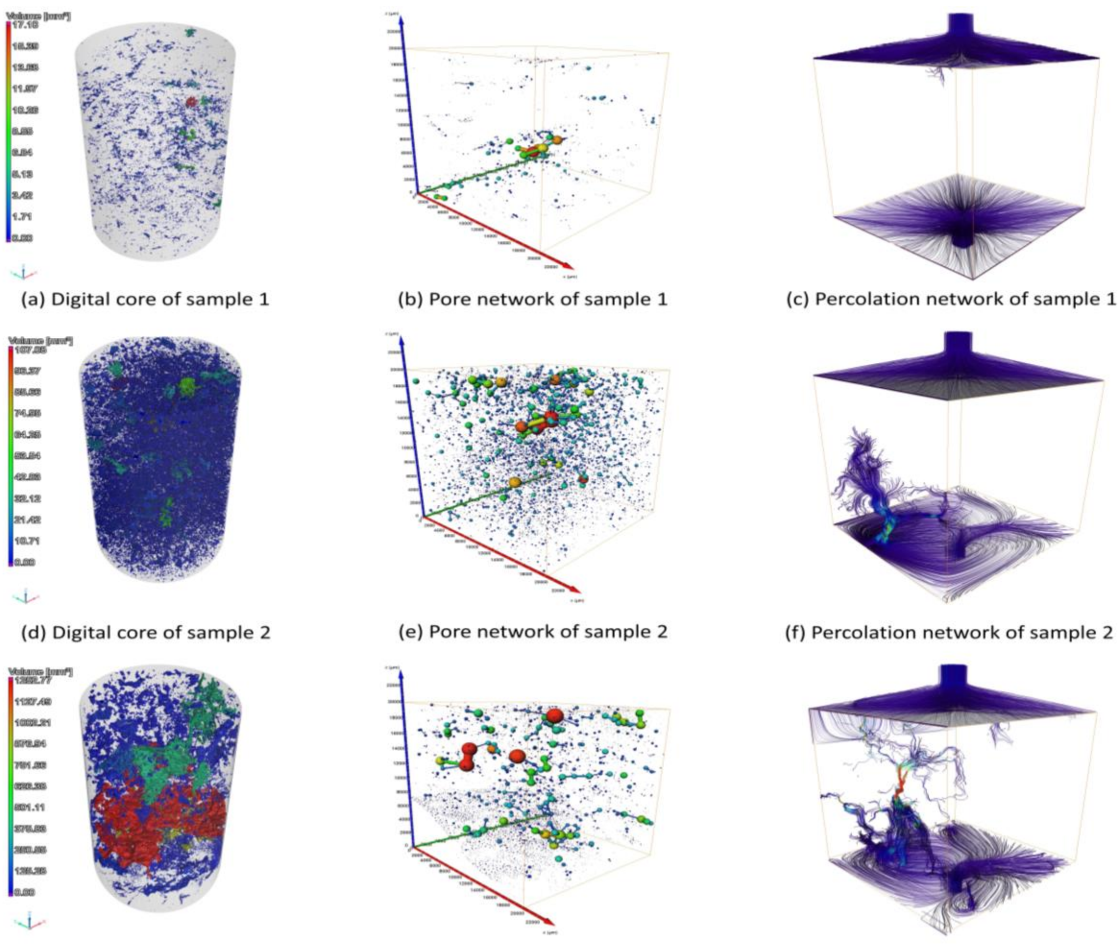
Fig. 1. Grayscale images of core sections after CT scanning (a) pore type, with a surface porosity of 1.34%; (b) cavity type, with a surface porosity of 3.45%; (c) fracture-cavity type, with a surface porosity of 4.52%

Figure. 2. shows the digital core, pore network model and seepage network model constructed after CT scanning of three rock samples. Observing Figure. 2. (a)-(c), it is easy to see that the total number of identifiable pores in the digital core of sample 1 is 23469, the volume of identifiable pores is between 0-17.10mm^3, the pore size is small, and the fractures and cavities are less developed . The connectivity of the pore network model of sample 1 is very poor, and the connected pore throats cannot be identified in most of the internal rock blocks. In addition, the streamline of the seepage network model of sample 1 is very thin, there is no dominant seepage channel inside, and the seepage capacity is very weak.

Observing Figure. 2. (d)-(f), it is found that the total number of identifiable pores in the digital core of sample 2 is as high as 134498, and the identifiable pore volume is between 0-107.08 mm^3, which shows that compared with sample 1, the overall size of the internal pores of sample 2 becomes larger, and the number of identifiable pores increases significantly. The connectivity of the pore network model of sample 2 is very good. The whole rock block area is densely distributed with large and small connected pore throats, and there are sporadic large-scale cavities in the middle. The good connectivity of sample 2 determines its relatively high seepage capacity. In addition, the streamlines of the seepage network model of sample 2 are thicker and denser, indicating that this type of reservoir has a stronger seepage capacity.

Observing Figure. 2. (g)-(i), it is found that the total number of identifiable pores in the digital core of sample 3 is 87123, and the identifiable pore volume is between 0-1127.49 mm^3, which shows that the pore size inside sample 3 is large, and various karst caves and cracks are well developed. Large karst cavities and large-sized pore throats coordinated with them are distributed in the entire rock block area of sample 3. The connectivity of the pore network model is very good, which also determines that it has a very good ability to seep gas. The streamlines of the seepage network model of sample 3 are very dense and strong, and there are dominant seepage channels throughout the rock sample, indicating that sample 3 has a very strong seepage capacity.

3.3 Pore distribution characteristics of carbonate reservoir



(a) Digital core of sample 1 (b) Pore network of sample 1 (c) Percolation network of sample 1

(d) Digital core of sample 2 (e) Pore network of sample 2 (f) Percolation network of sample 2

(g) Digital core of sample 3 (h) Pore network of sample 3 (i) Percolation network of sample 3

Fig. 2. Ct experimental results of natural carbonate cores

Figure. 3. shows the pore distribution frequency in different intervals based on the statistics of digital cores of experimental samples. The pore distribution laws of sample 1, sample 2 and sample 3 are very similar, showing a distribution trend of "high on the left and low on the right" as a whole. Among them, small pores with a size between 0.05-0.2 mm accounted for the highest proportion among all samples, accounting for 79.52%, 70.72% and 73.67%, respectively, which indicates that most of the pores inside carbonate rocks are small pores. The difference in the pore distribution of the three samples is that the proportion of 1-5mm karst caves is quite different, accounting for 0.9%, 1.35% and 1.98% respectively. The existence of karst caves can greatly improve the seepage capacity of the surrounding bedrock, which is an important factor affecting the seepage capacity of cores and an important criterion for distinguishing pore-type reservoirs from cavity-type and fracture-cavity reservoirs.

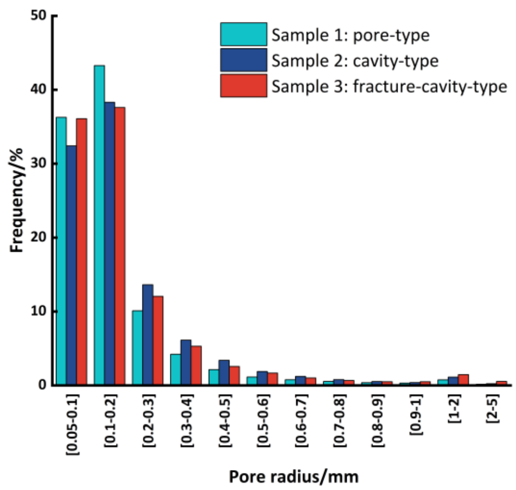


Figure. 3. Pore distribution frequency according to CT

Fig. 4. shows the throat distribution frequency in different intervals based on the statistics of digital cores of experimental samples. The throat distribution laws of different samples have different characteristics. The throat distribution frequency of sample 1 presents a distribution characteristic of "high on the left and low on the right". Throats with a size between 0.01-0.02 mm accounted for 25.42% (the highest), and large throats larger than 0.5 mm accounted for only 0.66%. , the overall throat size is small, which is the key factor restricting the seepage capacity of pore-type reservoirs. The throat distribution frequency of sample 2 also showed a distribution characteristic of "left high and right low". Throats with a size between 0.05-0.1 accounted for the highest proportion of 34.76%, and large throats with a size greater than 0.5mm accounted for 1.13%. , the overall throat size of this sample is significantly larger than that of sample 1 (pore-type), and the seepage capacity is also significantly enhanced. The distribution of throats in sample 3 is relatively uniform, and the throats with a size larger than 0.05 mm accounted for 47.94%, and the large throats with a size larger than 0.5 mm accounted for 4.95%, which was significantly higher than that of samples 1 and 2. The high proportion of large throats results in the widespread distribution of high-speed diversion channels inside the fracture-cavity reservoirs, which significantly increases the producing speed of this type of reservoirs.

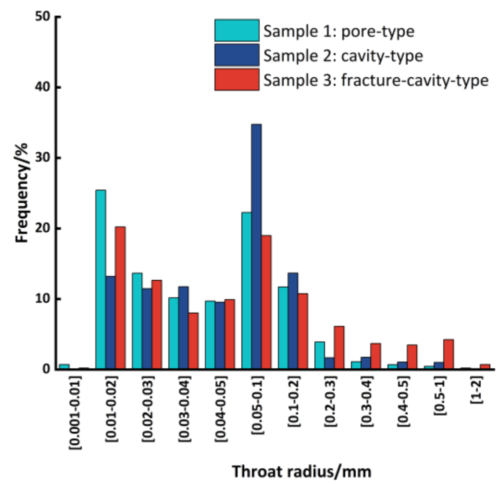


Figure. 4. Throat distribution frequency according to CT scanning results

4. CONCLUSIONS

(1) The main pore types of carbonate pore-type reservoirs are small matrix pores, less developed cavities and fractures, small pore throats, poor connectivity, and lack of high-speed diversion channels, resulting in low seepage capacity of this type of reservoir.

(2) Medium and small-sized karst cavities and micro-fractures are widely developed in carbonate cavity-type reservoirs, with large pore throats, good connectivity, and scattered distribution of high-speed diversion channels, resulting in good seepage capacity.

(3) Karst cavities of various sizes and various types of fractures are widely developed in carbonate fracture-cavity reservoirs, with large pore throats and good connectivity. The entire rock block area is full of interconnected fracture-cave network systems, resulting in very good seepage capacity.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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