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THE GAS PERMEABILITY OF MARINE SEDIMENTS IN THE SHENHU AREA OF SOUTH CHINA SEA

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ABSTRACT

The paper presents the gas permeability of marine sediments in the Shenhu Area of South China Sea. The sediments were obtained at the depth of 1600m below sea level. The solid density and volume weighted mean diameter of the sediments were 2.421 g/cm^3 and 6.491 μm, respectively. The gas permeability of the marine sediments was measured by steady state method with confining pressures of 2MPa, 5MPa, 8MPa, 10MPa, 15MPa, 20MPa, 23MPa. The effective gas permeability of the sediments decreased from 2.638 × 10^{-16} m^2 to 0.872 × 10^{-16} m^2 as the confining pressure increased from 2 MPa to 23 MPa. The porosity of the sediments decreased from 41.82 % to 29.54 % as the confining pressure increased from 0 to 23 MPa. The gas permeability of the sediments was determined to be 1.535 × 10^{-16} m^2 with confining pressure of 15 MPa and the porosity of 32.00 %. The longitudinal deformation of the sample was very sensitive to the confining pressure, and the compressibility of the sample in the radial direction was not obvious. The particle size term in the classical Kozeny-Carman equation was revised by a correction factor (N), and the experimental results fitted well with the curves when N value was 2.40. The reference group experiments indicated that the measurement results were reproducible.

Keywords: gas permeability; South China Sea; marine sediments; steady state method; Kozeny-Carman equation

1. INTRODUCTION

Natural gas hydrates (NGHs) were ice-like compounds formed by water and gas molecules. It was widely found in deep ocean sediments and permafrost regions, where high pressure and low temperature exist.[1] The permeability characteristics of hydrate reservoirs were the decisive factors for gas production. Current experimental studies were mainly focus on artificial sediments,[2-4] and the numerical simulations for gas production were also based on relative high permeability.[5] The effective permeability of natural sediment cores was measured to be 1-100 mD in the Eastern Nankai Trough, which was 2–3 orders of magnitude less than conventional estimates.[6] The mean permeability of the sediments in the South China Sea was measured to be 1.5 - 7.4 mD in the field when the mean effective porosity ranged from 32 % to 35 %.[7] There were few permeability studies on very low permeability (< 1 mD) porous media such as natural cores and marine sediments, because it was difficult to obtain samples. In addition, the lack of measuring methods for very low-permeability porous media was also a major reason. We tried to use the deionized water to pass through the natural sediments obtained from Shenhu Area of South China Sea (ϕ= 0.30) at a constant pressure of 15 MPa, only very little water was injected into the sample in 10 hours. For the porous media with very low permeability, such as the sediments used in this study, due to its low diffusivity, gas may be the only media to go through the compacted sample. [8].

In this work, we used steady-state method to measure the effective gas permeability of sediments obtained from the Shenhu Area of South China Sea at the depth of 1600m below sea level. The steady-state method follows Darcy's law. The gas permeability measurements were carried out under different confining pressures.

2. EXPERIMENTS

2.1 Apparatus

As shown in Fig. 1, the apparatus used for the gas permeability measurements consists of a confining cell, a constant-pressure pump, a buffer vessel and a newly developed interface to ensure airtight, etc. The confining pressure (P_C) was supplied by the constant-pressure pump, and its value was recorded on a computer through a digital pressure gauge. The buffer vessel with the inner volume of 400 mL made of 316L stainless steel was used to provide a steady gas flow. The volume of buffer vessel was expressed by V_0. The gas used for the gas permeability measurements was pure argon (more than 99%). Two high-precision manometers were installed on both sides of the buffer vessel. The inlet pressure labeled as P_1 was recorded once per second during the gas permeability measurements. The outlet pressure labeled as P_0 was set to be the atmospheric pressure. In addition, all tests were carried out in a constant temperature room at 20 °C.

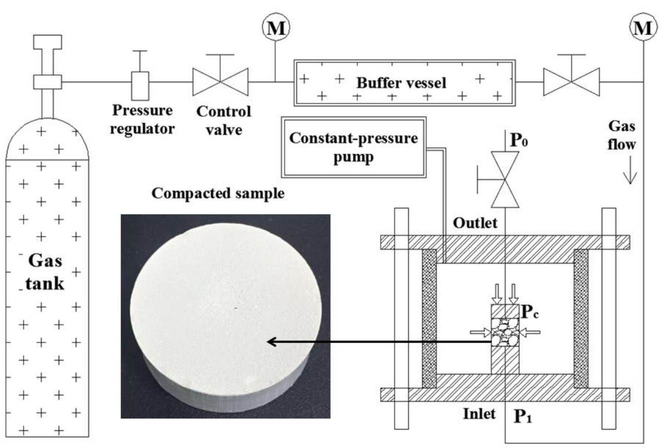

Fig. 1. The schematic diagram of experimental apparatus used for gas permeability measurements.

2.2 Materials

The sediments were obtained from the Shenhu Area of South China Sea at the depth of 1600m below sea level. In this study, the sample used as the porous media was dried for 120 hours at the temperature 393.15K and then pulverized. The solid density and volume weighted mean diameter the sample were 2.42 g/cm^3 and 6.491 μm, respectively. Sample I and sample II with a mass of 46.95 g and 47.05 g were placed into the cylinder tank, respectively, and then installed the piston to preliminarily compact the samples. The axial pressure of the piston cylinder was 15 MPa and the compression time lasted 2 hours. The resulting heights of sample I and sample II were 17.25mm and 17.22 mm, respectively. The resulting diameters of sample I and sample II were 49.61mm and 49.80 mm, respectively. Hence, the initial porosity of sample I and sample II were 41.82% and 42.04%, respectively.

2.3 Method to measure gas permeability

The Darcy's law was employed to measure the gas permeability due to the continuous gas flow through the sample under steady conditions, and the effective gas permeability K_{eff} could be applied as follows:[9]

$$K_{eff} = \frac{\mu_g Q_g}{A} \frac{2hP_m}{(P_m^2 - P_0^2)} \tag{1}$$

Where the μ_g was viscosity of argon, Q_g was the average gas volume rate, h was the length of sample, A was the sample cross-section, and P_m was the average of gas pressure at the inlet.

As shown in Fig.1, the inlet of the cylinder sample was subjected to a given pressure P_1 and the outlet was subjected to constant atmospheric pressure of P_0. There was a pressure decrease (ΔP) after a period of time (Δt) under the driving force of the pressure difference. By assuming a quasi-static flow and the ideal gas state equation,[10] the average gas volume rate (Q_g) and the average of gas pressure at the inlet (P_m) could be calculated with the following equations, respectively :

$$Q_g = \frac{V_0 \Delta P}{P_m \Delta t} \tag{2}$$

$$P_m = P_1 - \frac{\Delta P}{2} \tag{3}$$

Combining the Eqs. (1-3), the effective gas permeability K_{eff} could be expressed as follows:

$$K_{eff} = \frac{\mu_g V_0 \Delta P}{A \Delta t} \frac{2h}{(P_1 - \frac{\Delta P}{2})^2 - P_0^2} \tag{4}$$

3. RESULTS AND ANALYSIS

3.1 The relative displacement

The sample was placed in triaxial cell with confining pressure of P_C. Fig. 2 shows the radial and longitudinal deformations of the sample I and sample II as confining pressure increased from 0 to 23 MPa. The pressure points of experiments were 2MPa, 5MPa, 8MPa, 10MPa, 15MPa, 20MPa, 23MPa, respectively. The radial deformations of sample I and sample II were 1.724 mm and 1.465 mm, respectively. The longitudinal deformations of sample I and sample II were 1.960 mm and 2.381mm, respectively. Hence, the longitudinal deformation of the samples was very sensitive to the confining pressure, and the compressibility of the samples in the radial direction was not obvious.

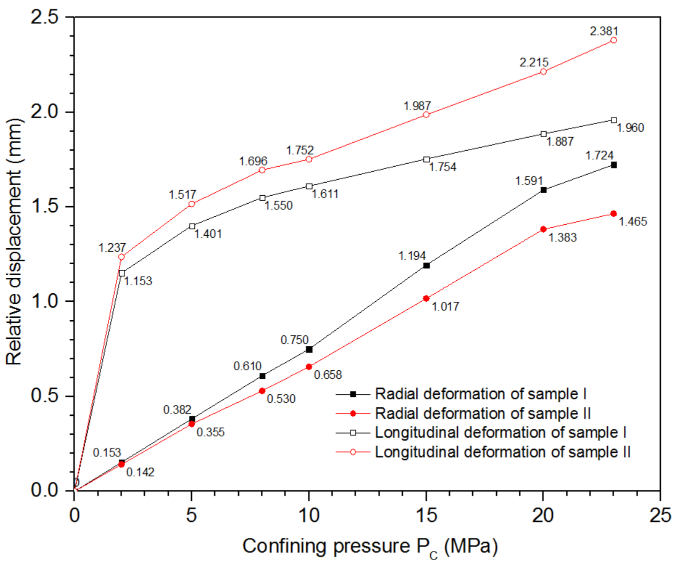

Fig.2. The radial and longitudinal deformation of the sample over confining pressure

3.2 The effective gas permeability and corresponding porosity change

Fig. 3 shows the results of effective gas permeability and corresponding porosity changes. The gas permeability and the porosity were very sensitive to the confining pressure. The experimental results could be divided into three stages. In stage I, the gas permeability of the samples decreased rapidly as the confining pressure increased from 2 MPa to 5 MPa. In stage II, the gas permeability of both samples gradually slowed down as the confining pressure increased from 5 MPa to 15 MPa. In stage III, with the confining pressure increased from 15 MPa to 23 MPa, the rate of gas permeability reduction was obviously higher than that of the stage II. Taking the Sample I as an example, with the confining pressure increased from 0 MPa to 23 MPa, the porosity of sample I decreased from 41.82 % to 29.54 %. Also, The effective gas permeability of the sample I decreased from 2.638 × 10^{-16} m^2 to 0.872 × 10^{-16} m^2 as the confining pressure increased from 2 MPa to 23 MPa. Taking the measurement point of 15 MPa confining pressure as an example, the effective gas permeability of sample I was 1.535 × 10^{-16} m^2, the porosity of sample I was 32.00 %.

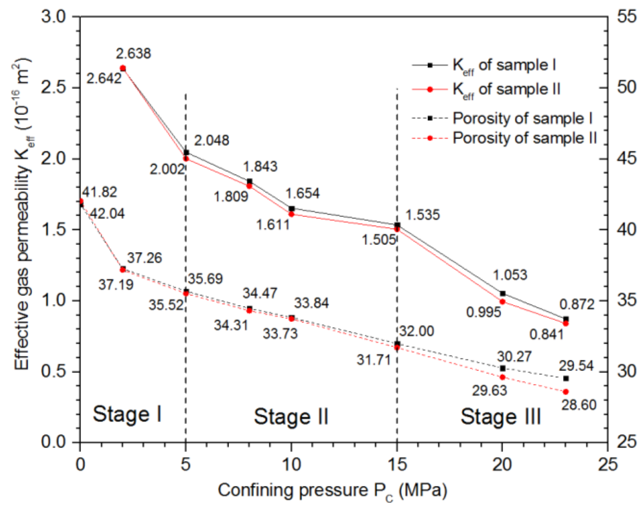

Fig.3. The effective gas permeability results, and corresponding porosity changes.

3.3 The revision of Kozeny-Carman Equation

The classical Kozeny-Carman (KC) equation of permeability-porosity relationship was applied to groundwater flow, chemical engineering and other fields. KC equation could be simplified as the following formula.[11]

$$K_0 = \frac{\phi^3}{36k(1-\phi)^2}D^2 = \frac{\phi^3}{180(1-\phi)^2}D^2 \tag{5}$$

Where k was the KC constant, and we employed k = 5 as the empirical KC constant in this work，ϕ was the porosity of the sample, D was the mean diameter of the sediments (D = 6.491 μm).

The surface of particles in the sediments was not smooth and the particles were not spherical. Hence, the particle size term in the KC equation was revised by a correction factor (N) in this paper. The revised formula was expressed as follows:

$$K_0 = \frac{D^N}{180}\frac{\phi^3}{(1-\phi)^2} \tag{6}$$

Fig. 4 shows the relationship between the effective gas permeability and the porosity of the sample. The mean diameter (D = 6.491 μm) was used as the volume weighted mean diameter of the sediments. Three kinds of N values were used to verify the experimental results. It fitted well with the experimental results when N value was 2.40. Besides, all the experimental results suited at the curves of N =2.35 and N=2.45. Therefore, it could be considered that the particle size correction factor of marine sediments at the depth of 1600m below the sea level in the Shenhu Area of South China Sea was about 2.4.

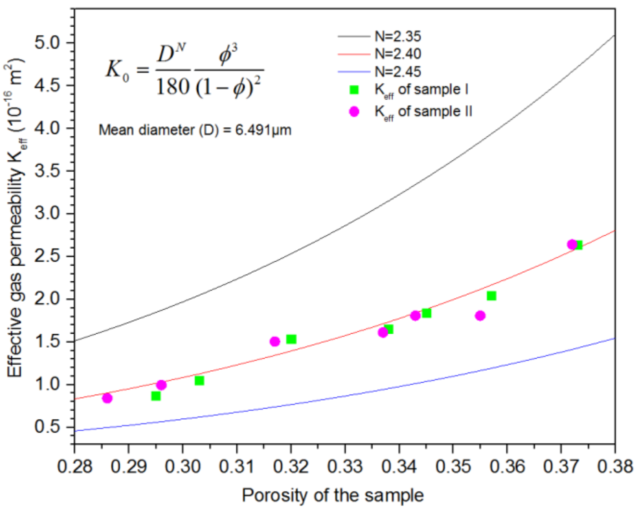

Fig.4. The relationship between the effective gas permeability and the porosity of the sample

4. CONCLUSION

Based on the experimental results, the following conclusions could be drawn

(1) The solid density and volume weighted mean diameters of the sediments were 2.421 g/cm^3 and 6.491 μm, respectively.

(2) The effective gas permeability of the sample decreased from 2.638 × 10^{-16} m^2 to 0.872 × 10^{-16} m^2 as the confining pressure increased from 2MPa to 23MPa. The porosity decreased from 41.82 % to 29.54 % as the confining pressure increased from 0 to 23MPa.

(3) The gas permeability value was determined to be 1.535 × 10^{-16} m^2 with confining pressure of 15MPa and the porosity of 32.00 %.

(4) The longitudinal deformation of the sample was very sensitive to the confining pressure, and the compressibility of the sample in the radial direction was not obvious.

(5) The particle size term in the classical Kozeny-Carman equation was revised by a correction factor (N), and the experimental results fitted well with the curves when N value was 2.40.

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