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Original research paper

Study on experiment conditions of marine shale gas seepage law☆

Weiyao Zhu, Wei Tian*, Ying Gao, Jia Deng, Xueling Zhang, Qian Qi, Qian Ma

School of Civil and Environmental Engineering, University of Science & Technology Beijing, Beijing 100083, China

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Abstract

In order to discover the conditions suitable for testing shale gas seepage law, marine shale gas cores were taken from southern China. Samples were tested by using the differential pressure-flow rate method with actual gas under two modes (e.g. constant confining pressure and constant net confining pressure). Moreover, influences of the different confining pressure modes on the experimental results were analyzed. The results show that under constant confining pressure or constant net confining pressure mode, the gas seepage law curve has two sections. One is the curve section and the other is the pseudo linear section. Features of non-linear seepage were observed with the inflection points of 1 MPa and 1.3 MPa, as well as the average permeability damage rate of 52.41% and 40.56% respectively. The slip effect generated different influences. In the constant confining pressure mode, the change of injection pressure may cause stress sensitivity, which is not consistent with the actual situation in the reservoir development. The influence of the slip effect on seepage law was more substantial than stress sensitivity under the condition of low effective stress. In the constant net confining pressure mode a complete seepage law curve was obtained to simulate the seepage of the actual reservoir in a certain extent. The confining pressure effect had an insignificant influence on gas seepage. Comprehensive analysis shows that net confining pressure mode is the best way to test the seepage law of marine shale gas core in southern China.
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Keywords: Seepage law; Constant confining pressure; Constant net confining pressure; Slip effect; Effective stress; Confining pressure effect

1. Introduction

Shale gas is a type of non-conventional gas, which is of extreme importance. Its development has been paid ever more attention and the exploration in China is also in its formative years [1−13]. The experimental method is different from the conventional gas because of its special structural features of bedding, joints, microfractures [4,5,8,9]. Due to better lithology and larger permeability of core in conventional gas, the constant confining pressure mode is generally adopted to test the gas seepage law [14], without considering the stress sensitivity caused by the effective stress changes [15−21]. It is necessary to consider the influence on shale reservoirs with special physical properties, because the change of effective stress may lead to the destruction of the bedding and cracks in shale; which could influence test results of the shale seepage law. Thus, the test of shale gas seepage law has become an urgent problem needing to be solved. In this paper, the suitable test method to hold the experimental pressure was adopted to select the best condition for testing the gas seepage law of the marine shale gas cores [22−25]. Eventual results opt to provide a useful reference for China's shale gas research and development.

2. The characteristics of shale gas reservoir

The shale gas reservoir in Longmaxi Formation, southern China, is buried deep and types in black laminar clay (shale),

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* Corresponding author.
E-mail address: tw811227@163.com (W. Tian).

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lamellar silty clay (shale) and lamellar carbonate substance (gray or dolomitic) clay (shale), developed graptolite. Analysis of the lithological properties of shale gas reservoir shows that the sizes of main (major) nanopores were in the range of 5−200 NM, the porosity was in the range of 0.58%−4.27%, both were averaged to1.26%.The permeability was in the range of 0.00001−0.93 × 10^{-3} μm^2, averaged value was 0.0067 × 10^{-3} μm^2. The content of the organic matters was commonly lower and was averaged to 2.46%.

The X-ray diffraction analysis showed that the total amount of the clay minerals were relatively high with an average of 53.39%. Followed by quartz laminar or dispersed, with an average content of 29.15%, particle diameter was in the range of 0.03−0.05 mm, and with the high content of quartz lead to the result of high brittle minerals, which is good for making cracks and exploiting gas. Moreover, calcite and feldspar in clay mineral have an average content of 5.46% and 4.93%, respectively. Others, such as dolomite, gypsum, pyrite, and other minerals all together had only an average content of less than 5%.

The physical property of the reservoir was poor. The core analyzed the interformational pores, intragranular pores, and microfractures were developed and followed by the construction fractures as well as the intercrystalline micropores. The interformational pores included illite, chlorite flakes pores, pore mica flakes, raspberries pyrite intergranular pores, and more. The intragranular pores included quartz and intergranular solution hole that was caused by the dissolved feldspar. The pore diameter was in the range of 100 nm−50 µm, and was frequently had micro-cracks (width of 2−5 µm). The microfractures were mostly the fractures in Erie stone layer or the microfractures between brittle clay minerals and quartz; having a width of 5−20 µm. The maximum throat radius was 0.033 µm in average. The mean value of the throat radius was 0.010 µm. Mainstream pore throat radius was 0.0038 µm, in which microporous and the micro-throats belong.

3. Experiment

3.1. Apparatus and equipment

The seepage experimental device selected was a US core company's Autoflood (AFS300TM) flooding evaluation system. The high-pressure nitrogen tank provided the injection gas, and it controls the pressure by adjusting the regulator. The data acquisition system collected various data through the pressure system acquisition automatically. In order to simulate the characteristics of formation stress, the triaxial core holder was used in the laboratory, it measured the gas via a soap bubble flow meter. High-precision multi-stage piston displacement pump (Teledyne Isco 100 DX) controlled the confining pressure system. Pressure was measured by a high-precision digital sensor (DXD), whilst using a high linearity differential pressure sensor (validyne models) to accurately acquire the differential pressure at both ends of the core. The entire device was placed in a thermostat, and the temperature was set to 0−180 °C (Fig. 1).

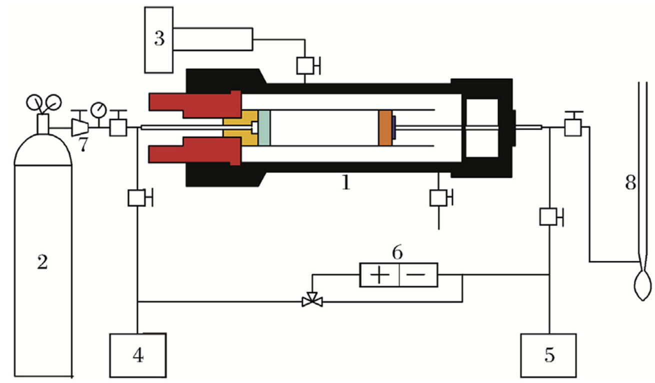

Fig. 1. Schematic diagram of the experimental system. 1- Triaxial core holder, 2- High pressure gas cylinder, 3- Multi-steps pump drive, 4, 5- Up-downstream pressure sensor, 6- High linearity differential pressure sensor, 7-Pressure regulating valve, 8-Soap bubble flow meter.

3.2. Project and steps

The experiments used an intact core from the Well LongShan-1, which served as the representative of the Qiongzhusi reservoir. The length of the core was 5 cm and the diameter was 2.5 cm. It used the on-site gas as the injection fluid. The experiment used the "differential pressure-flow rate method" with constant temperature and atmospheric pressure. According to different confining pressure control methods, the experiment was intended for constant confining pressure mode and constant net confining pressure mode. In comparison, the pressure for the constant confining pressure mode was set to 4 MPa, and the pressure in the constant net confining pressure mode was set to 3 MPa. This ensured that the core's effective pressure gave only a slight difference between the two modes while the confining pressure or the injection pressure changes.

3.2.1. Constant confining pressure mode

The constant confining pressure was 4 MPa, and the pressure points used in the injection pressure experiment were 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, and 2.0 MPa. This helped determine the stable flow under different injection pressures.

The experiment steps are as follows: (1) The core was dried for 48 h, then it's length, diameter, and porosity was measured through the Klinkenberg permeability via regression method. (2) The core was placed in the core holder, this helped connect the process, after which the initial value of the instrument was set to zero. The confining pressure was slowly set to four MPa, but there was no evident change. (3) In accordance to the predetermined injection pressure on-site gas was injected into the core for 30 min; then the soap bubble flow-meter was used to collect the time points thrice at the same volume continuously. The size of the three time points are as follows: "big-small-big" or "small-big-small"; and the difference between the two adjacent points was less than 0.03 s, then the stable flow was considered. It was necessary to extend the flowing time and to re-determine everything until the flow was stable; then record the pressure and flow. (4) Lastly, the next pressure points were

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