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RESEARCH PAPER

# Shale high pressure isothermal adsorption curve and the production dynamic experiments of gas well

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**Abstract:** The high pressure static adsorption curves of shale samples from Silurian Changning-Weiyuan Longmaxi Formation were tested by using high pressure isothermal adsorption equipment. The physical modeling of depletion production was tested on single cores and multi-core series by using self-developed shale gas fluid-solid coupling experiment system. The adsorption and desorption laws were summarized and a high pressure isothermal adsorption model was established. The calculation formula of gas content was corrected, and the producing law of adsorption gas was determined. The study results show that the isothermal adsorption law of the shale reservoir under high pressure was different from the conventional low pressure. The high pressure isothermal adsorption curve had the maximum value in excess adsorption with pressure change, and the corresponding pressure was the critical desorption pressure. The high pressure isothermal curve can be used to evaluate the amount of adsorbed gas and the producing degree of adsorption gas. The high pressure isothermal adsorption model can fit and characterize the high pressure isothermal adsorption law of shale. The modified gas content calculation method can evaluate the gas content and the proportion of adsorbed gas more objectively, and is the theoretical basis of reserve assessment and production decline analysis. The producing degree of adsorption gas is closely related to the pressure, only when the reservoir pressure is lower than the critical desorption pressure, the adsorption gas can be produced effectively. In the process of gas well production, the pressure drop in the near-well area is large, the production of adsorption gas is high; away from the wellbore, the adsorption gas is low in production, or no production.

**Key words:** shale; high pressure isothermal adsorption; excess adsorption; critical desorption pressure; shale gas; adsorption curve

## Introduction

With abundant micro- and nano-scale pores, organic-rich shale reservoir can form self-generating and self-preserving unconventional gas pool. A large amount of shale gas (generally more than 40%) exists in adsorption state in shale pores. Therefore, it is of great significance to study the shale adsorption rule for gas content calculation, reserves estimation and production prediction[1–2]. Current studies on isothermal adsorption rule of shale are mostly based on the CBM adsorption theory by in-door isothermal adsorption test[3–4]. This type of test is often conducted at the pressure of 6 to 15 MPa, which is much lower than the pressure of the shale reservoirs put into development in China[5–8] (reservoirs in Changning-Weiyuan regions of Sichuan Basin range 70 °C to 120 °C in temperature and 30 to 60 MPa in pressure). It's still uncertain whether the test methods and theories under low-temperature & low-pressure can reflect the real gas adsorption/desorption rules of actual shale reservoir. Studies by foreign researchers[9–12] suggested that different from the conventional adsorption rule, the isothermal adsorption curve of shale under high-pressure tends to rise first and then drop, which indicates that calculating the gas content under the reservoir condition with low-pressure test curve and the Langmuir model has some limitation[13–15]. Adsorbed gas accounts for a large proportion of the total gas content, and is the major gas source for gas well during the low-production and stable production periods. Determining the adsorption/desorption rules of shale gas under reservoir conditions is the basis for preparing shale gas development program and studying production decline rule.

No consensus has reached on the mechanism of isothermal adsorption of shale under high pressure, and the adsorption/desorption rules remain unclear, which will lead to inaccurate

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calculation of gas content and large error in development program. Therefore, with shale samples recovered from the Silurian Longmaxi Formation in the Changning-Weiyuan regions, Sichuan Basin, several tests are carried out under reservoir pressure by using the high-pressure isothermal adsorption instrument (at the maximum testing pressure of 69 MPa), such as the isothermal adsorption test, and tests on producing characteristics and rule of adsorbed gas. On the basis of these tests, an isothermal adsorption model is built and a revised shale gas content calculation method is proposed, to explore the fundamental theory of high-efficiency development of shale gas.

## 1. Experimental design

### 1.1. Samples

Samples for test were recovered from the $Long_1^1$ sub-member of the Longmaxi Formation in the Changning-Weiyuan region, Sichuan Basin. Some fundamental parameters are listed in Table 1. Samples were split into two groups: one group was dried and then crushed into 0.15–0.25 mm (100 to 60 meshes) shale grains for isothermal adsorption test; the other group includes columnar samples for developing characteristics test.

### 1.2. Instrument

The isothermal adsorption test was carried out by using the classic volumetric method, with a high-pressure gas isothermal adsorption instrument which has a maximum operating pressure of 69 MPa, the precision of the pressure sensor of 0.05% of the maximum measuring range, the maximum constant temperature of oil bath of 177 °C, and the control precision of 0.1 °C. The developing characteristics test was conducted on a self-developed instrument for physically modeling the depletion development of shale gas, which can model shale gas flow with different scales, gases and cores.

### 1.3. Test procedure

#### 1.3.1. Test for high-pressure isothermal adsorption

The experimental instrument is shown in Fig. 1, and the procedure is as follows: (1) place 100 g samples into the sample cylinder, check the gas tightness, and measure the free space volume in the test system using a benchmark cylinder (including space volume of reference cylinder and associated line, residual free space of sample cylinder and associated line space volume, shale intergranular pore) repetitively until the error was below 3%; (2) vacuumize and close the sample cylinder, fill the reference cylinder with methane gas with a certain pressure, open the sample cylinder valve after the pressure stabilized to connect the gas in the two cylinders, and record the equalized pressure after the pressure stabilized; the adsorption amount is given by:

$$n_{\text{test}} = 10^6 \left[ \frac{p_0 V_c}{Z_0 RT} - \frac{p_1 \left( V_c + V_s \right)}{Z_1 RT} \right] \tag{1}$$

(3) Close the sample cylinder, fill the reference cylinder with gas, and repeat the above-mentioned equalizing process until the completion of the whole test.

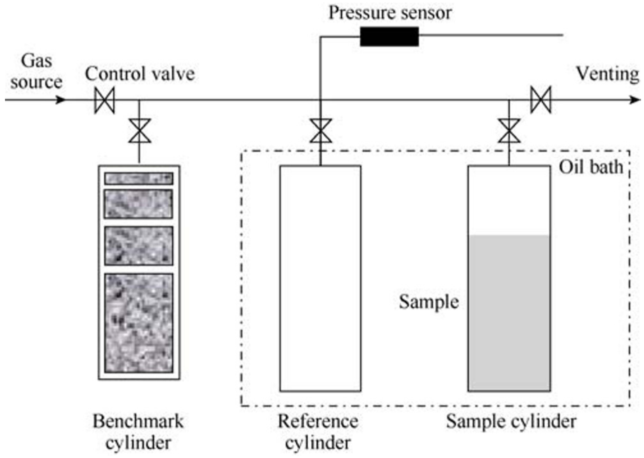


**Fig. 1. Instrument for isothermal adsorption test using the volumetric method.**

#### 1.3.2. Test for modeling the shale gas development

The test was carried out by the instrument shown in Fig. 2, with the procedure as follows: (1) columned shale samples recovered from the same formation were dried and placed into a displacement system, after saturated with methane gas to the initial formation pressure state, the outlet was opened for modeling the depletion development process under the reser-

**Table 1. Fundamental parameters of samples.**

| Region | Sample No. | Cored layer | Depth/ m | TOC/ % |
|---|---|---|---|---|
| Changning | No.1 from Well N01 | $Long_1^1$ of Longmaxi Formation | 2 516 | 4.60 |
| | No.2 from Well N03 | $Long_1^1$ of Longmaxi Formation | 2 391 | 4.20 |
| Weiyuan | No.1 from Well V02 | $Long_1^1$ of Longmaxi Formation | 2 568 | 3.46 |
| | No.2 from Well V03 | $Long_1^1$ of Longmaxi Formation | 3 177 | 3.71 |
| | No.3 from Well V04 | $Long_1^1$ of Longmaxi Formation | 3 500 | 2.93 |

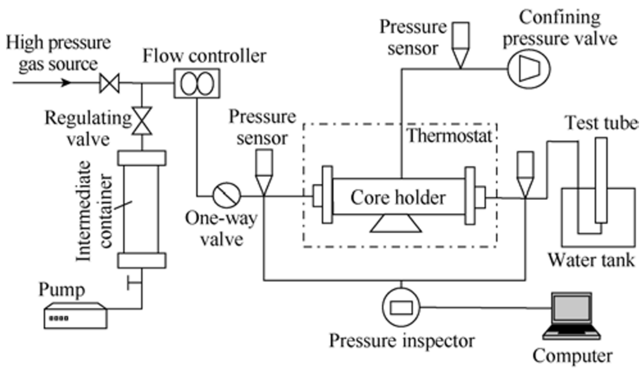


**Fig. 2. Instrument for modeling the shale gas development characteristics.**