

# Comparison between steady state method and pulse transient method for coal permeability measurement

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**Abstract.** Coal permeability measurement is significant for research on reservoir characteristics and development of coalbed methane. In order to find a favourable method to obtain exact data of coal permeability, two different methods are operated to investigate coal permeability evolution. Steady state method is applied with constant upstream gas pressure and downstream pressure to keep constant pressure difference. Permeability is measured when velocity of gas flow is constant. Pulse transient method is applied with a pulse upstream pressure increment to discharge gas through coal sample to downstream gas reservoir. Permeability is calculated when the upstream reservoir and downstream reservoir reach a new equilibrium pressure. Experiments by different methods are both conducted on 2.5 cm diameter, 2.5–5 cm long cylindrical samples at same constant confining pressure and axial pressure, using both non-adsorbing (helium (He)) and strongly adsorbing (carbon dioxide (CO<sub>2</sub>)) gases. Every single coal sample is measured by both methods, while all samples are collected from Southeast Ordos Basin in China. The results are compared to investigate the advantages and disadvantages of the two methods. Permeability measured by steady state method is slightly larger than that measured by pulse transient method, which indicates that pulse transient method is preferable for measuring low permeability measurement. Factors that may influence the results of measurement are analyzed. Steady state method may destroy the structure of coal and slightly enlarge the pore fracture, with constant pore pressure, which results in higher permeability. On the contrary, pulse transient method keeps samples close to in situ condition, which obtains more exact data. However, several improvements are needed to minimize the error of the pulse transient methods. Temperature has important influence on permeability measurement.

## 1. Introduction

Coal permeability measurement is significant for research on reservoir characteristics and development of coalbed methane (CBM). Gas permeability varies during the process of CBM recovery, since the stress condition would change and coal fracture-pore system would change accordingly. Gas transport in coal seams is significantly different from that of other rock types due to



gas sorption and coal swelling. The stress level, gas pressure and fracture geometry of coal are related to the processes of gas sorption, diffusion, transport, and coal swelling [1].

Significant experiments have been applied to investigate gas permeability and its evolution in coal. It is known that laboratory measured permeability of coal to sorting gases such as  $\text{CH}_4$  and  $\text{CO}_2$  are lower than permeability to nonsorting gases such as Helium (He) [2]. Sorbing gas permeability decreases with increasing pore pressure due to coal swelling [3-4], and increases with decreasing pore pressure due to matrix shrinkage [5-6], under constant total stress. Experiments have shown that  $\text{CO}_2$  is adsorbed preferentially relative to  $\text{CH}_4$  in most instances [7-8].

Several methods have been applied for measuring coal permeability, such as steady state method, pulse transient method and pore pressure oscillation method. However, results from different measurement methods of gas permeability have significantly differences. It is because structures of coals are usually compact with low permeability, while coals with large fractures have higher permeability. These differences lead to different results of the same coal, due to different applied ranges of permeability measuring methods [9]. In order to find a favorable method to obtain exact data of coal permeability, two different apparatus are operated with steady state method and pulse transient method to investigate coal permeability evolution.

## 2. Experimental methods

### 2.1. Sample Preparation

Coal samples were collected as bituminous coal from Southeast Ordos Basin in China, with depth of 400-800 meter. Samples were drilled parallel to the bedding plane. Experiments by different methods are both conducted on 2.5 cm diameter, 2.5-5 cm long cylindrical samples at same constant confining pressure and axial pressure, using both inert (helium (He)) and strongly adsorbing (carbon dioxide ( $\text{CO}_2$ )) gases.

### 2.2. Experimental setup

The experiments in this study are operated in two standard triaxial apparatuses for gas flow-through and permeability testing, which can also load separate confining pressure and axial pressure on samples by water or oil (Figure 1). Coal samples are sandwiched within triaxial core holders between two cylindrical stainless steel loading platens with through-going flow connections and flow distributors. The sample and axial platens are isolated from the confining fluid by a polyvinyl chloride (PVC) rubber jacket.

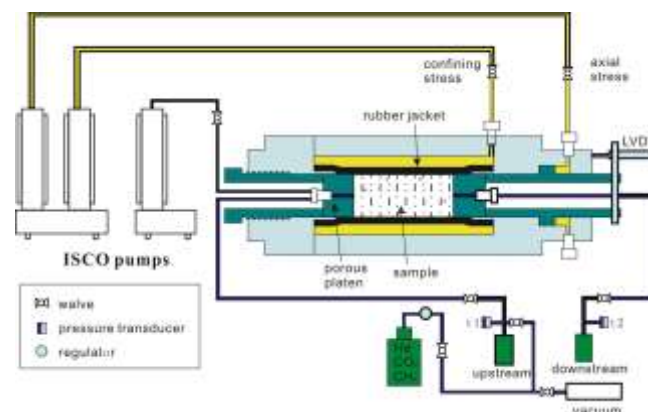


Figure 1. Permeability testing tri-axial setup.

Steady state method injects gas from a gas tank directly through the core holder, applying constant upstream pressure to keep a constant gas flow rate, with the downstream reservoir open to the atmosphere to measure gas permeability. Pulse transient method uses two low-volume stainless steel

tubes with certain volumes as upstream and downstream reservoirs. While gas reservoirs are kept in water baths to get temperature constant. The gas-pressurized upstream reservoir is discharged through the sample to the downstream reservoir with equilibration time defining permeability of the sample [10-11]. Pressure transducers measure upstream and downstream fluid pressures.

### 2.3. Measurement procedure

**2.3.1. Permeability measured by steady state method.** Steady state method is applied with constant upstream gas pressure and downstream pressure to keep constant pressure difference. Permeability is measured when velocity of gas flow is constant. The permeability to gas is commonly calculated with the following equation.

$$k_g = \frac{2p_o q_g m_g L}{A(p_1^2 - p_2^2)} \quad (1)$$

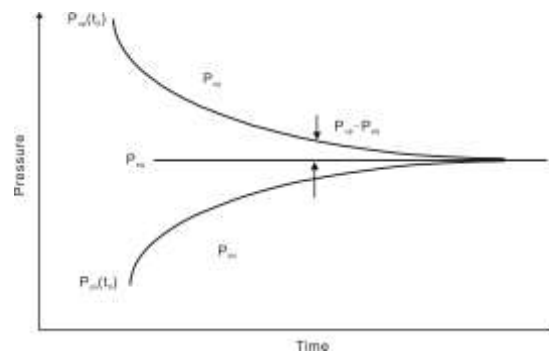
where  $k_g$  is the coal permeability to gas;  $p_o$  is the standard atmospheric pressure;  $q_g$  is the gas flow rate at standard atmospheric pressure;  $p_1$  and  $p_2$  are the upstream and downstream gas pressures, respectively;  $\mu_g$  is the coefficient of kinetic viscosity for the gas at the mean pressure  $((p_1+p_2)/2)$  at the experimental temperature;  $L$  is length of the sample; and  $A$  is the cross-sectional area of the core.

**2.3.2. Permeability measured by pulse transient method.** Pulse transient method is applied with a pulse upstream pressure increment to discharge gas through coal sample to downstream gas reservoir. Permeability is calculated when the upstream reservoir and downstream reservoir reach a new equilibrium pressure. The governing equation for the pressure pulse through the coal sample is written as follows.

$$P_{up}(t) - P_{dn}(t) = (P_{up}(t_o) - P_{dn}(t_o)) e^{-at} \quad (2)$$

$$a = (kA / mbL) \left( 1 / V_{up} + 1 / V_{dn} \right) \quad (3)$$

Where  $P_{up}(t) - P_{dn}(t)$  is the pressure difference between the upstream and downstream reservoirs at time  $t$ ; and  $(P_{up}(t_o) - P_{dn}(t_o))$  is the initial pressure difference between the upstream and downstream reservoirs at time  $t_o$ .  $\alpha$  is the slope of the line when plotting the pressure decay  $P_{up}(t) - P_{dn}(t)$  on semi-log paper against time (Figure 2).  $A$  and  $L$  are the cross sectional area and length of the sample, respectively, which define the dimensions of the sample.  $\mu$ ,  $\beta$ ,  $V_{up}$ , and  $V_{dn}$  are the dynamic viscosity and compressibility of the gas, and the volume of the upstream reservoir and downstream reservoir, respectively. Permeability  $k$  is calculated from Eq. (3) where it is the only unknown.

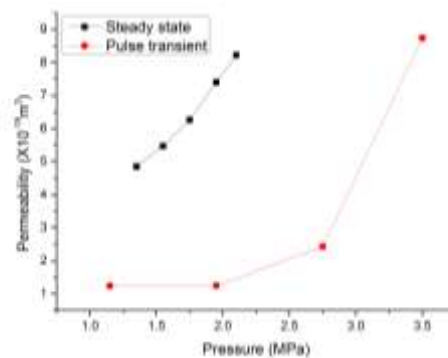


**Figure 2.** Typical pressure decay plot of upstream and downstream pressure vs time

### 3. Results

#### 3.1. Results of permeability with two methods

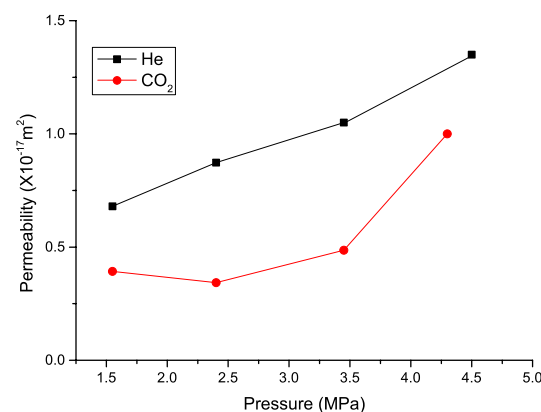
Samples were applied with constant confining and axial stresses at same value by steady state method and pulse transient method. Permeability was measured at different pore pressures while using He and CO<sub>2</sub>. Figure 3 shows He permeability evolution of Sample 1 as a function of applied pore pressure for constant confining and axial stresses at 4 MPa. Permeability increases as pore pressure increases by both of the two methods. However, it indicates that permeability measured by steady method is higher than that measured by pulse transient method for almost 3-4 times. As applied with constant upstream pressure, gas may enlarge the pore fracture, which leads gas flow through the sample faster than pulse transient pressure. Sample 1 is embedded with small fractures, due to which gas at lower pressure is hard to flow through. Thus permeability increases faster at higher pressure when it was measured by pulse transient method.



**Figure 3.** He permeability evolution of Sample 1 with two methods

#### 3.2. Results of permeability with two gases

Permeability was measured with He as non-adsorbing gas and CO<sub>2</sub> as adsorbing gas. Fig. 4 shows permeability evolution of Sample 2 with pulse transient method. Permeability was measured as pore pressure increase with constant confining and axial stresses at 6 MPa. He permeability is higher than CO<sub>2</sub> permeability, as a result of CO<sub>2</sub> adsorption. As CO<sub>2</sub> will be adsorbed into pores of coal at first, the permeability decreases first, and increases when the pore pressure increases above the threshold Langmuir pressure. The trend of CO<sub>2</sub> permeability evolution is affected by gas sorption and coal swelling [1, 3-4].



**Figure 4.** Permeability evolution of Sample 2 with two gases.

#### 4. Results

Steady state method is based on constant pressure difference applied by constant upstream pressure and downstream pressure equal to atmosphere pressure. This large difference between upstream and downstream pressure may destroy the structure of coal and slightly enlarge the pore fracture, with constant pore pressure, which results in higher permeability. On the contrary, upstream and downstream pressure of pulse transient method have smaller difference range in the process of coming to equilibrium pore pressure. This method keeps samples under nearly in-situ condition, which obtains more exact data. Furthermore, temperature has an important influence on permeability measurement. Gas volume may easily change due to the high compressibility of gas, which makes steady method hard to keep gas at constant temperature. However, with pulse transient method, gas reservoirs are kept in water baths to get temperature constant, thus volume change effects in the reservoirs are minimized. Permeability measured by steady state method is slightly larger than that measured by pulse transient method, which indicates that pulse transient method is preferable for measuring low permeability measurement.

#### 5. Conclusion

Coal permeability to gases was measured by steady state method and pulse transient method in this study. It indicates that results by steady state method are higher than that by pulse transient method. Several reasons have been discussed. Conclusions can be drawn as following.

1) Pulse transient method is preferable for measuring low permeability measurement, as it can be applied under nearly in-situ condition, while steady state method is easier to destroy coal micro fractures.

2) Pulse transient method can minimize the errors resulted from temperature, by using water bath to keep reservoirs at constant temperature.

3) Permeability to He is higher than CO<sub>2</sub> due to adsorption capacity of CO<sub>2</sub>. CO<sub>2</sub> permeability may decreases first due to its adsorption and coal swelling, and increases when the pore pressure increases above the threshold pressure.

#### Acknowledgments

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