

STUDY ON THE OPTIMIZATION OF THE IN-SITU GAS PRESSURE CALCULATION METHOD FOR COAL SAMPLES CONTAINING WATER

by

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To improve the accuracy of in-situ gas pressure measurement in coal seams, the calculation method for gas pressure in water-bearing, pressure-maintained coal samples was optimized. The method's reliability was verified by comparing calculation errors before and after optimization. Results indicate that incorporating the adsorption capacity attenuation coefficient, λ , and coal sample moisture content (ω) into the calculation improved stability and reliability. The average error decreased significantly from 15.79% -1.38%. This optimized method offers a reliable and convenient approach for accurately measuring in-situ gas pressure in water-bearing coal seams while maintaining high calculation accuracy.

Key words: *gas pressure calculation, pressure-retaining coring, water-bearing coal samples*

Introduction

Gas is a byproduct of coal mining, and accurately determining its pressure is crucial for preventing and controlling gas-related disasters [1-4]. The primary method for measuring coal seam gas pressure involves direct underground drilling, where pressure gauges are installed to record gas pressure changes after the boreholes are sealed [5]. However, this direct measurement method has significant drawbacks, including strict site requirements, challenges in maintaining seal integrity, lengthy testing durations, and potential result distortions [6]. To address these issues, researchers have developed innovative methods to calculate gas pressure using measurable parameters related to gas desorption characteristics, offering improved stability and reliability in gas pressure estimation [7]. Based on the concept of *five guarantees coring*, Xie *et al.* [8] put forward the principle and technology of in-situ pressure and gas preservation coring in deep coal seam in the field of coal mine. This approach enables low disturbance pressure coring and self-sealing sampling within the confined spaces of coal seam boreholes [6].

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Leveraging this technology, Cui *et al.* [9] proposed a method to calculate in-situ gas pressure based on the pressure-holding coring process. This method offers a reliable and practical approach for estimating gas pressure in deep coal seams.

The water content of coal samples significantly affects in-situ gas pressure calculations. By incorporating the adsorption capacity attenuation coefficient, λ , and coal sample moisture content, ω , the calculation method is optimized. The method's reliability is validated through both indoor experiments and theoretical calculations. This optimized calculation method offers a rapid and precise approach for determining in-situ gas pressure in coal mines, providing reliable parameters for both coal mine safety and accurate coalbed methane resource assessments.

Calculation method of in-situ gas pressure in deep coal seam

According to the calculation principle of in-situ gas pressure in deep coal seam [9], the coal seam contains adsorbed gas and free gas, and the in-situ gas content of coal seam in unit mass coal is m_{m0} [9]:

$$m_{m0} = \frac{abp_1}{1+bp_1} \frac{M_g}{V_M} + \phi \frac{M_g}{\rho_c RT} p_1 \quad (1)$$

where a and b are the adsorption constants, p_1 – the in-situ gas pressure of coal seam, M_g – the molecular weight of methane, V_M – the molar volume of methane under standard conditions, ϕ – the porosity, ρ_c – the apparent density of coal, R – the ideal gas constant, and T – the coal seam temperature.

According to the law of conservation of mass, m_{m0} is equal to the gas mass contained in the coal sample in the pressure holding coring device m_{mc1} :

$$m_{c1} = m_c m_{m1} = \frac{abp_1}{1+bp_1} \frac{M_g}{V_M} m_c + \phi \frac{M_g}{\rho_c RT} p_1 m_c \quad (2)$$

where m_c is the mass of the pressurized coal sample.

After the gas pressure in the pressure holding space of the coring device is balanced, the pressure holding space contains the adsorbed gas in the balanced coal sample, the free gas in the coal sample pore and the free gas in the pressure holding space. Therefore, the sample mass after the gas pressure balance is m_{mc2} , namely:

$$m_{mc2} = \frac{abp_2}{1+bp_2} \frac{M_g}{V_M} m_c + \left(V_{con} - \frac{m_c}{\rho_c} + \phi \frac{m_c}{\rho_c} \right) \frac{M_g}{RT} p_2 \quad (3)$$

where p_2 is the gas pressure in the pressure holding space after equilibrium, V_{con} – the volume of packing space, and p_{con} – the gauge pressure of the pressure controller.

Due to deviations between the actual and ideal gas states, the gas compression factor, Z , is applied to adjust the ideal gas equations in eqs. (2) and (3) [10]. Furthermore, the coal sample in the sample tank is treated as representing the in-situ reservoir during initial equilibrium, while the expanded coal sample is considered as part of the pressure-holding space. As a result, the free gas content in eq. (2) should include both the free gas in the coal sample's pores/fractures and the free gas in the sample chamber's free volume. In eq. (3), the free gas content should be the sum of the free gas in the coal sample's pores/fractures, the free gas in the sample room's free volume, and the gas content in the expansion chamber. Therefore, m_{mc1} is:

$$m'_{mc1} = \frac{abp_1}{1+bp_1} \frac{M_g}{V_M} m_c + \left(\phi \frac{m_c}{\rho_c} + V_{free} \right) \frac{M_g}{ZRT} p_1 \quad (4)$$

Following coring, gas pressure changes in the coring device are continuously monitored. According to the gas pressure, p_2 , after the balance of the pressure holding space, the in-situ gas pressure, p_1 , of the coal seam can be obtained. Here, m_{mc2} is:

$$m'_{mc2} = \frac{abp_2}{1+bp_2} \frac{M_g}{V_M} m_c + \left(\phi \frac{m_c}{\rho_c} + V_{\text{free}} + V_{\text{exp}} \right) \frac{M_g}{ZRT} p_2 \quad (5)$$

where V_{free} is the free volume of the sample chamber, which is obtained by helium calibration, and V_{exp} is the volume of the expansion chamber. In this experiment, the expansion chamber is a standard 10 ml volume container. The adsorption constants a and b are obtained by fitting the experimental data of depressurization and desorption. Substituting them into eqs. (4) and (5), the in-situ gas pressure, p_2 , of coal samples with pressure and gas preservation can be calculated.

In summary, in order to calculate the in-situ gas pressure calculation method of coal seam, it is necessary to use Langmuir equation fit the isothermal adsorption curve to obtain the adsorption constants a and b values. There exists:

$$V = \frac{abp}{1+bp} \quad (6)$$

where V is the gas adsorption capacity in the adsorption process and p – the adsorption equilibrium pressure.

In order to further reflect the influence of moisture content on gas adsorption, the adsorption attenuation coefficient, λ , and the moisture content of coal sample, ω , are introduced to modify the Langmuir equation, eq. (6) [11]. There are : Langmuir volume correction formula considering moisture content:

$$V_w = \frac{abp}{1+bp} e^{(-\lambda\omega)} \quad (7)$$

where λ is the adsorption attenuation coefficient and ω – the moisture content.

Therefore, eqs. (4) and (5) become:

$$m''_{mc1} = \frac{abp_1}{1+bp_1} e^{(-\lambda\omega)} \frac{M_g}{V_M} m_c + \left(\phi \frac{m_c}{\rho_c} + V_{\text{free}} \right) \frac{M_g}{ZRT} p_1 \quad (8)$$

$$m''_{mc2} = \frac{abp_2}{1+bp_2} e^{(-\lambda\omega)} \frac{M_g}{V_M} m_c + \left(\phi \frac{m_c}{\rho_c} + V_{\text{free}} + V_{\text{exp}} \right) \frac{M_g}{ZRT} p_1 \quad (9)$$

Isothermal adsorption experiments were conducted to measure the gas adsorption capacity of coal samples at various equilibrium pressures, and the adsorption constants (a and b) were calibrated. Subsequently, a volume expansion and pressure reduction desorption test simulated the sample's expansion process in the pressure-holding coring device. Using the law of mass conservation, the gas content of the water-bearing pressure-holding coal core was calculated to verify the accuracy of the modified equation.

Experiment method and procedure

Preparation of water-bearing coal sample

The coal samples used in this study were sourced from Cheng Zhuang Coal Mine in Jincheng City, Shanxi Province, China. Basic physical parameters are provided in tab. 1.

Industrial analysis indicated that the coal rank is anthracite, with a particle size of 1-3 mm and a mass of 25 g. The free volume method was employed to calibrate the test volume

to 16.50 cm³. A 25 g dry coal sample was placed in a constant temperature and humidity curing box and cured at 30° C and 90% humidity for 72 hours. After 72 hours, the sample was weighed every 2 hours. When the mass remained constant for 2 hours, the sample was removed, and the water content of the coal sample was calculated to be 2.67%.

Table 1. Values of basic physical parameters of coal sample

Basic parameters	Unit	Symbol	Values
Molar mass of methane molecule	[gmol ⁻¹]	M_g	16
Visual density of coal	[m ³ t ⁻¹]	ρ_c	1.516
Coal seam matrix porosity	[%]	ϕ	6.5
Geothermal temperature	[K]	T	303.15
Standard molar volume of methane	[Lmol ⁻¹]	V_M	22.4
Perfect gas constant	[Jmol ⁻¹ K ⁻¹]	R	8.314
Coal sample weight	[kg]	m_c	25.00
Free volume of sample chamber	[ml]	V_{free}	50.81
Volume of expansion chamber		V_{exp}	10
Adsorption attenuation coefficient	[-]	λ	4.96
Moisture content of coal sample	[%]	ω	2.76

Boost adsorption test design

To verify the reliability of the calculation method, expansion desorption and isothermal adsorption experiments of water-bearing coal samples were conducted using the pressure-holding coal core gas pressure evolution experiment system. Isothermal adsorption experiment: the sample is placed in the sample room, and methane is gradually injected to determine the adsorption constants and other parameters required for calculating in-situ coal seam gas pressure. During this stage, seven pressure point expansion and desorption experiments were conducted. The sample was placed in the sample room and gradually expanded to simulate the expansion process of the coal sample in a pressure-maintaining coring device, providing actual gas pressure data for calculating the in-situ gas pressure of the coal seam. Five pressure points were established during this stage.

Validation of gas pressure calculation method for water-bearing holding pressure samples

By monitoring changes in gas pressure in the reference room and applying the gas state equation, the amount of injected gas can be determined, allowing for the calculation of the injected gas content. Simultaneously, the free gas content at each pressure point can be calculated based on the gas pressure in the sample room. Finally, the adsorbed gas content at each pressure point can be determined by subtracting the free gas content from the total gas content. As shown in tab. 2, with increasing gas pressure during the experiment, the proportion of adsorbed gas content gradually decreases.

Equations (6) and (7) are applied to tab. 1 to determine the adsorption state gas content at each pressure point during the pressure rise and pressure drop stages. The fitting results are shown in figs. 1 and 2.

Table 2. Antihypertensive desorption test data

Equilibrium pressure point [MPa]	Gas entry volume [m ³ per tonne]	Adsorbed gas content [m ³ per tonne]	The proportion of adsorbed gas [%]
0.21	15.17	8.94	70.39
0.76	8.19	14.11	50.68
1.14	6.44	16.28	44.01
1.69	12.77	17.93	36.68
2.60	17.17	18.72	27.94
3.09	12.31	19.12	24.84
3.81	14.84	19.26	21.08

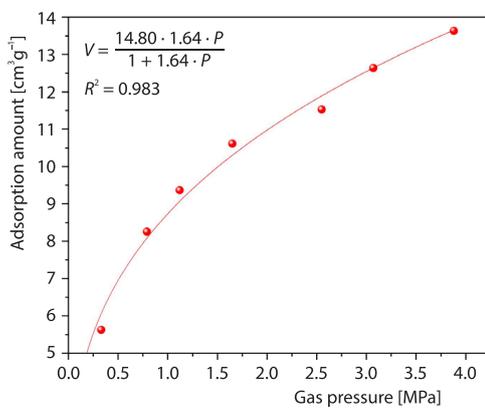


Figure 1. The adsorption constant before correction

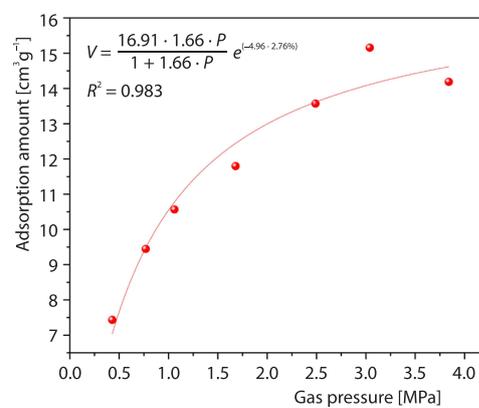


Figure 2. The adsorption constant after correction

The adsorption constant, a , in the pressure rise stage is 14.80 m³ per tonne, b is 1.64 1/MP, and R^2 is 0.983. Through the eq. (7) fitting, the adsorption constant, a , in the boosting stage is 16.61 m³ per tonne, the b value is 1.66 1/MPa, and the R^2 is 0.984. The fitting results exhibit minimal error. These calculations provide key parameters for verifying the calculation method of deep in-situ coal seam gas pressure.

By applying the adsorption constants to eqs. (8) and (9) and combining them with the results of the expansion desorption experiment, tab. 2, the gas pressure calculation method for water-bearing coal samples was verified. The inverse calculation results for gas pressure are presented in tab. 3.

Table 3. Physical and mechanical parameters of the basalt

Gas pressure before expansion [MPa]	Inverse pressure calculation results based on the mass conservation law [MPa]	Error	Corrected inverse calculation results [MPa]	Error
0.47	0.396	15.74%	0.456	2.98%
0.77	0.641	16.75%	0.755	1.95%
1.22	1.032	15.41%	1.222	0.16%
2.09	1.765	15.55%	2.105	0.72%
3.11	2.628	15.50%	3.145	1.13%

The traditional mass conservation law method exhibits significant calculation errors for water-bearing coal samples. The original mass conservation law is unsuitable for the expansion experiment results of water-bearing coal samples. However, the modified calculation method significantly reduces the calculation error. After optimization, the average calculation error decreased from 15.79%-1.38%. The optimized method accurately calculates the in-situ gas content of water-bearing coal samples and demonstrates high application value.

Conclusion

To refine the calculation of in-situ gas pressure in coal seams, the influence of water content in coal samples is considered. The gas adsorption attenuation coefficient, λ , and water content, ω , are incorporated to optimize the calculation method. During the adsorption process, as gas pressure increases, the sample absorbs progressively less gas. The proportion of adsorbed gas content decreases from 70.39%-21.08%. The original mass conservation law does not apply to the expansion experiment results of water-bearing coal samples. After optimization, the average calculation error decreased from 15.79%-1.38%. The optimized method accurately calculates the in-situ gas content of water-bearing coal samples and demonstrates significant application value.

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Nomenclature

a – adsorption constants, [m^3 per tonne]	V – gas adsorption in the adsorption process, [m^3 per tonne]
b – adsorption constants, [MPa^{-1}]	V_{con} – pressure space volume, [m^3]
M_g – molecular mass of methane, [gmol^{-1}]	V_{exp} – volume of expansion chamber, [ml]
m_c – quality of pressure holding coal sample, [kg]	V_{free} – free volume of sample chamber, [ml]
p_1 – in-situ gas pressure of coal seam, [MPa]	V_M – methane standard molar volume, [Lmol^{-1}]
p_2 – banced pressure space gas pressure, [MPa]	<i>Greek symbols</i>
R – ideal gas constant, [$\text{Jmol}^{-1}\text{K}^{-1}$]	ρ_c – visual density of coal, [kgm^{-3}]
T – geothermal temperature, [K]	ϕ – porosity, [%]

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