Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 2, No. 3, 2022

Research on Gas Content Determination Method of Coal Mine Closed Core

Shiwei Wang[1, 2], Wei Qiao[1, 2]

[1]State Key Laboratory of the Gas Disaster Detecting, Preventing and Emergency Controlling, Chongqing, 400037, China
[2]China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing, 400037, China

Abstract: In order to improve the accuracy and expand the measuring range of coal seam gas content, Sihe Mine has introduced a long-distance sealed coring gas content measuring device, which can seal the hole after drilling coal samples, and the sampling depth can reach more than 300m, but no suitable gas content measuring method has been formed yet. Through theoretical analysis, coal sample high pressure adsorption and desorption experiment, gas content measurement and contrast engineering test, the gas content measurement process and loss compensation model of long-distance closed coring were studied, and the gas content measurement method of long-distance closed coring was formed. The gas content in coal seam measured by this method is about 4.71% higher than that measured by core tube on average, which improves the measurement accuracy of gas content in coal seam and is of great significance for promoting gas control in coal mine.

Keywords: Gas content, Sealed core, Gas loss, Compensation model.

1. Introduction

Coalbed gas content is one of the most basic parameters for evaluation and development of coalbed methane resources, prediction of coalbed gas outburst risk, and coal mine gas prevention and control[1]. Accurate determination of coal seam gas content is of great significance to coal mine safety production. There are two main types of gas content determination methods in coal mines: the direct measurement method of underground sampling and the indirect inverse method of pressure measurement[2-4]. Due to the problems of long pressure measurement period, high cost, and great influence by geological conditions, the indirect inverse method of pressure measurement has its limitations and cannot meet the requirements of efficient mine production. The direct measurement method of downhole sampling is more suitable for downhole field application due to its simple procedure, short measurement period and accurate measurement results[5-6].

At present, coal mine underground sampling methods mainly include orifice powder, coal core tube method, SDQ pressure air injection method and so on[7-13]. The orifice-to-powder method is greatly affected by the coal sample on the pore wall, and it is difficult to achieve fixed-point sampling. In the coal core tube method, since the front end of the core tube is open after the coal sample is drilled, the gas loss of the coal sample is relatively large during the withdrawal of the coal core tube from the borehole. The SDQ air pressure ejection method is suitable for softer coal seams with firmness coefficient (f) less than 0.8. The firmness coefficient (f) of No. 3 coal seam in Sihe Mine is about 1.5. In order to improve the measurement accuracy of coal seam gas content and increase the measurement range, Sihe Mine has introduced a long-distance closed coring device, but a matching gas content measurement method has not yet been formed.

2. Coring Process

The coring process of the long-distance closed coring device is as follows: firstly, use the directional drilling machine to drill to the predetermined position; secondly, withdraw the drill pipe and drill bit from the drilling hole, replace the coring device and send it to the bottom of the hole quickly; thirdly, use the coring device to drill the coal samples, seal the coring device after drilling; finally, withdraw the coring device and drill pipe from the borehole. The coring process flow is shown in Figure 1.

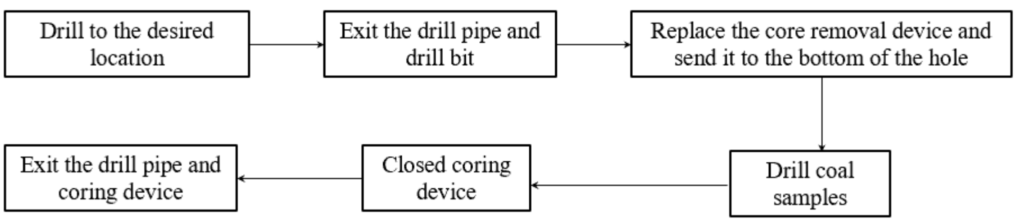


Figure 1. Process flow chart of airtight coring

3. Determination of Gas Content in Coal Samples

3.1. Coal Sample Gas Content Calculation (Q)

According to the coring process of the long-distance closed coring device, the gas content of the coal sample can be calculated according to the formula (1).

$$Q=(V_0+V_1+V_2+V_3+V_4)/M+Q_a \tag{1}$$

Where,

Q is gas content of tested coal samples, m3/t;

V_0 is coal sample gas loss, mL;

V_1 is gas desorption capacity of coal sample in airtight state, mL;

V_2 is underground atmospheric pressure natural desorption gas volume, mL;

V_3 is the amount of natural desorption gas at atmospheric pressure on the ground, mL;

V_4 is ground crushing natural gas desorption, mL;

M is coal sample quality, g;

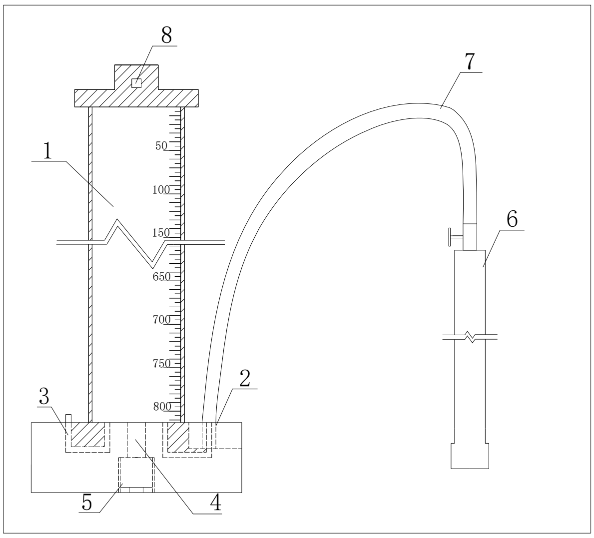
Q_a is amount of non-desorbable gas at atmospheric pressure, m3/t.

3.2. Coal Sample Gas Loss Calculation (V_0)

According to the coring process of the long-distance closed coring device, the gas loss of coal samples is studied in two parts. First, after the drilling rig drills to the predetermined position, the coal sample gas loss (V_{01}) during the period from when the drilling is stopped to when the coring device is sent to the bottom of the hole. In this process, the coal sample has not been separated from the original coal body, and the gas of the coal sample escapes to the borehole through the coal wall at the bottom of the hole, resulting in gas loss. The second is the gas loss (V_{02}) of the coal sample during the process from the start of drilling the coal sample to the complete sealing of the coring device. In this process, the coal sample gradually peeled off the original coal body and became broken, and the coal sample gas quickly escaped into the borehole, resulting in gas loss. Due to the different particle sizes of coal samples in the two processes, different compensation models are used for calculation.

3.3. Determination of Gas Desorption Capacity in Closed State of Coal Samples (V_1)

During the process of withdrawing from the borehole, the coal sample is in a state of airtight desorption, and the gas desorption amount of the coal sample in this process can be directly measured by the downhole desorption instrument. When the airtight coring device is withdrawn from the borehole, the inner coring barrel is removed and connected to the downhole desorption device, and the desorption valve of the inner coring barrel is opened. When the coal sample is sealed, the gas desorption amount will be released instantaneously through the downhole desorption instrument, and the desorption amount will be recorded. The downhole gas desorption device is shown in Figure 2.



1—pipe body; 2—inlet nozzle; 3—liquid outlet; 4—watering channel; 5—bottom plug; 6—coring inner cylinder; 7—connecting hose; 8—lifting lug

Figure 2. Connection diagram of downhole desorption device

3.4. Determination of Natural Gas Desorption Under Normal Pressure in Wells (V_2)

In the closed state of the coal sample, after the gas desorption amount is released through the desorption device, the coal sample enters the natural pressure desorption state. During the desorption process at atmospheric pressure, the readings of the measuring tube were recorded every one min, and the observation results were recorded continuously for 30 min.

3.5. Determination of Natural Desorption Gas at Atmospheric Pressure (V_3)

After the coring inner cylinder is sent to the laboratory, the coring inner cylinder is connected to the ground gas desorption instrument for ground atmospheric desorption. After desorption for a period of time, the desorption is completed when no more bubbles emerge from the glass tube within five minutes, and the desorption amount of coal sample gas in the process is recorded. The laboratory gas desorption device is shown in Figure 3.

Figure 3. Laboratory gas desorption device

3.6. Determination of Natural Gas Desorption By Ground Crushing (V_4)

First, the coal sample in the cored inner cylinder is placed in the coal sample basin to remove non-coal substances such as gangue, and then it is placed on the balance to weigh the total weight of the coal sample. Take two equal amounts of coal samples from the coal sample basin, choose the whole core or larger coal samples, and the coal sample quality is generally 100~300g. Put two weighed coal samples into the pulverizer respectively, carry out natural desorption of coal sample pulverization, and record the desorption amount.

3.7. Calculation of non-desorbable Gas at Atmospheric Pressure (Q_a)

The amount of non-desorbable gas at atmospheric pressure is calculated using the Langmuir formula (2).

$$Q_a = \frac{0.1ab}{1+0.1b} \times \frac{100 - A_{ad} - M_{ad}}{100} \times \frac{1}{1+0.31M_{ad}} + \frac{F}{\gamma} \quad (2)$$

Where,

Q_a is the amount of non-desorbable gas at atmospheric pressure, m3/t;

a is gas adsorption constant of coal, m3/t;

b is gas adsorption constant of coal, MPa-1;

Mad is the moisture content of coal, %;

Aad is the coal ash, %;

F is the porosity of coal;

γ is the bulk density of coal, t/m3.

4. Research on Gas Loss Compensation Model

4.1. Research on Compensation Model for Gas Loss (V_{01})

(1) Gas gushing strength of coal wall at the bottom of the hole

According to the "Handbook of Coal Mine Gas Disaster Prevention and Utilization (Revised Edition)", the functional relationship between the gas gushing intensity and the exposure time of the coal wall at the bottom of the hole can be expressed as:

$$q_t = q_0 e^{-at} \quad (3)$$

Where,

q_t is when the coal wall exposure time is t, the gas gushing intensity on the coal wall, m3/m2 · min;

t is exposure time, d;

a is the gas gushing attenuation coefficient;

q_0 is the initial gas gushing intensity of exposed coal wall (t=0), m3/m2 · min.

(2) The initial gas gushing strength of the coal wall at the bottom of the hole

According to the "Prediction Method of Mine Gas Emission" (AQ1018-2006), the initial gas emission intensity of the exposed coal wall underground can be expressed as:

$$q_0 = 0.026[0.0004(V^r)^2 + 0.16] \cdot Q \quad (4)$$

Where,

q_0 is the initial gas gushing intensity of exposed coal wall(t=0), m3/m2 · min;

V^r is the volatile content in coal;

Q is coal seam gas content, m3/t.

(3) Compensation model for gas loss (V_{01})

The gas loss of the coal sample in the process of long-distance closed coring technology from stopping the drilling to the core device and sending it to the bottom of the hole can be expressed as:

$$V_{01} = \int_0^t q_0 e^{-at} \cdot S dt \quad (5)$$

Where, S is hole bottom coal wall area, m2.

Substitute Equation (3) and Equation (4) into Equation (5), and it can be arranged to get:

$$Q_0 = 2.6 \times 10^4 \left[0.0004(V^r)^2 + 0.16\right] \frac{1}{Ma}(1 - e^{-at}) SQ \quad (6)$$

The coal seam gas content (Q) was set to 5m3/t, 8m3/t, 10m3/t, 13m3/t, 15m3/t, and the exposure time (t) was set to 2h, 4h, 6h, 8h, 10h. Substitute the above set value and the measured coal seam volatile matter of 8.02%, attenuation coefficient of 0.0079d-1, and coal sample mass of 500g into formula (6), and the calculation results are shown in Table 1.

Table 1. Calculation results of coal sample gas loss

Q \ h	2	4	6	8	10
5	0.0006	0.0012	0.0017	0.0023	0.0030
8	0.0009	0.0018	0.0028	0.0037	0.0029
10	0.0011	0.0023	0.0035	0.0046	0.0058
13	0.0020	0.0030	0.0045	0.0060	0.0075
15	0.0017	0.0035	0.0052	0.0070	0.0087

It can be seen from Table 1 that the long-distance closed coring technology from the stop of drilling to the process of sending the coring device to the bottom of the hole, under the conditions of different gas content and exposure time, the coal sample gas loss is small. It has little influence on the measurement results of coal seam gas content and can be ignored.

4.2. Research on Compensation Model for Gas Loss (V_{02})

Analysis of gas desorption law of coal samples

Coal samples were collected in Sihe Mine. Based on the high-pressure adsorption-desorption experimental device, the laboratory carried out desorption experiments under different gas adsorption equilibrium pressures (2.12MPa, 2.54MPa), and the desorption time was set to 90min. The fitting results of the square root of the gas desorption amount and the desorption time of the coal sample are shown in Figure 4.

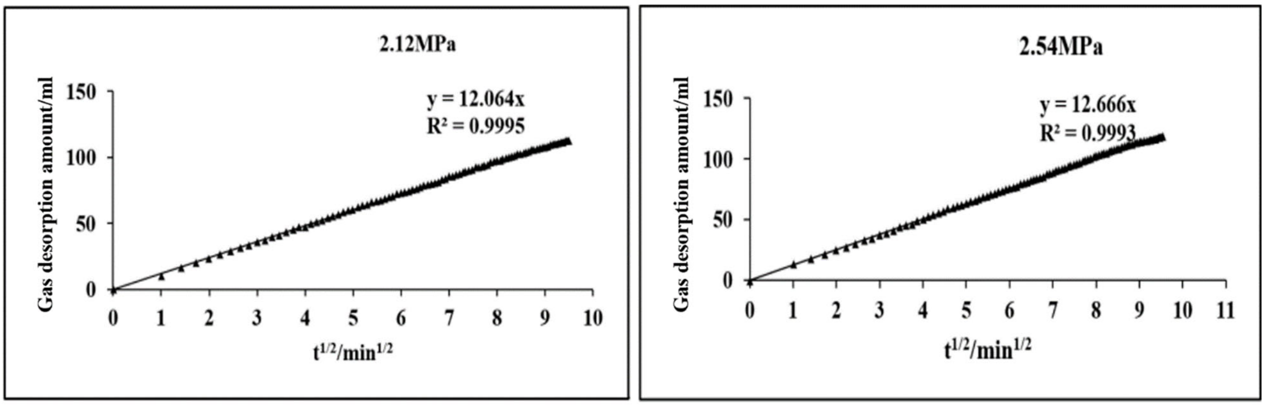


Figure 4. Relationship between gas desorption amount of coal sample and square root of time

It can be seen from Figure 4 that under different gas adsorption equilibrium pressure conditions, within 90 minutes of desorption time, the desorption amount of coal sample gas is proportional to the square root of the desorption time, that is,

$$V = k\sqrt{t} \tag{7}$$

Where, V is coal sample gas desorption capacity; t is desorption time; k is coefficient.

Coal sample gas desorption equation

From the high-pressure adsorption-desorption experiments of coal samples, it can be seen that the gas desorption amount of long-distance airtight cored coal samples can be expressed as:

$$V_{02}+V_1+V_2 = k_1\sqrt{t_0+t_1+t_2} \tag{8}$$

Where,

V_{02} is the gas loss of coal samples from the start of drilling coal samples to the complete sealing of the coring device, mL;

V_1 is gas desorption capacity under the closed state of coal sample in the exit process of coring device, mL;

V_2 is underground atmospheric pressure natural desorption gas volume, mL;

k_1 is coefficient;

t_0 is the time required from the start of drilling coal samples to the complete sealing of the coring device, min;

t_1 is the gas desorption amount in the closed state of the coal sample corresponds to the time required for the gas desorption in the normal pressure state, min;

t_2 is the desorption time of the coal sample under the normal pressure state, the longest desorption time is 30min.

The gas desorption amount from the start of drilling the coal sample to the complete sealing of the coal sample by the coring device (V_{02}) can be expressed as:

$$V_{02} = k_1\sqrt{t_0} \tag{9}$$

The gas desorption amount of the coal sample during the withdrawal of the closed coring device from the borehole can be expressed as:

$$V_1 = k_1\sqrt{t_0+t_1} - V_{02} \tag{10}$$

The gas desorption amount under normal pressure in the coal sample can be expressed as:

$$V_2 = k_1\sqrt{t_0+t_1+t_2} - V_1 - V_{02} \tag{11}$$

(3) Calculation of the gas desorption amount in the closed state of the coal sample corresponding to the time required for desorption under normal pressure (t_1)

The time required by the coring device from the start of drilling the coal sample to complete sealing t_0, the gas desorption amount in the closed state of the coal sample V_1, and the gas desorption amount V_2 (t2=30min) when the coal sample is desorbed under normal pressure in the well for 30min are all known. Substitute the above data into equations (9) to (11) to obtain:

$$V_1 = k_1\sqrt{t_0+t_1} - k_1\sqrt{t_0} \tag{12}$$

$$V_2(t_2=30) = k_1\sqrt{t_0+t_1+30} - V_1 - k_1\sqrt{t_0} \tag{13}$$

And it can be derived:

$$\frac{V_2(t_2=30)+V_1}{V_1} = \frac{\sqrt{t_0+t_1+30}-\sqrt{t_0}}{\sqrt{t_0+t_1}-\sqrt{t_0}} \tag{14}$$

In equation (14), only t1 is the unknown quantity, and the value of t1 can be obtained by solving the equation.

(4) Compensation model of coal sample gas loss (V_{02})

From equation (11), it can be known that the gas desorption amount under normal pressure in the coal sample is:

$$V_2 = V(t_0+t_1+t_2) - V_1 - V_{02} \tag{15}$$

And it can be derived:

$$V_1+V_2 = k_1\sqrt{t_0+t_1+t_2} - V_{02} \tag{16}$$

According to the measured or calculated value of each quantity in equation (16), take $\sqrt{t_0+t_1+t_2}$ as the abscissa and V_1+V_2 as the ordinate to draw a graph, perform linear fitting on each data point, and the intercept between the fitted line and the ordinate is the value V_{02}, that is, gas loss of coal samples with airtight coring technology.

5. Comparison Test of Gas Content Determination

5.1. Sampling in The Test Area

The directional long hole was constructed in the 64# drilling site of Xihuifeng Avenue in Sihe Mine, and coal samples were taken by closed coring device at positions of 150m, 200m, 300m, 350m and 400m in depth. At the same time, drilling through the layers is carried out at the horizontal distances of 150m, 200m, 300m, 350m and 400m from the 64# drilling site in the west return air road, and coal core pipes are used to drill coal samples. The gas content of each coal core was measured respectively, and then the gas content measurement results of the long-distance airtight coring at the same position were compared and analyzed with the measurement results of the gas content of the coal core by the core-coring pipe. The reliability of the long-distance airtight coring device and the accuracy of the gas content measurement results were evaluated. The core drilling arrangement is shown in Figure 5.

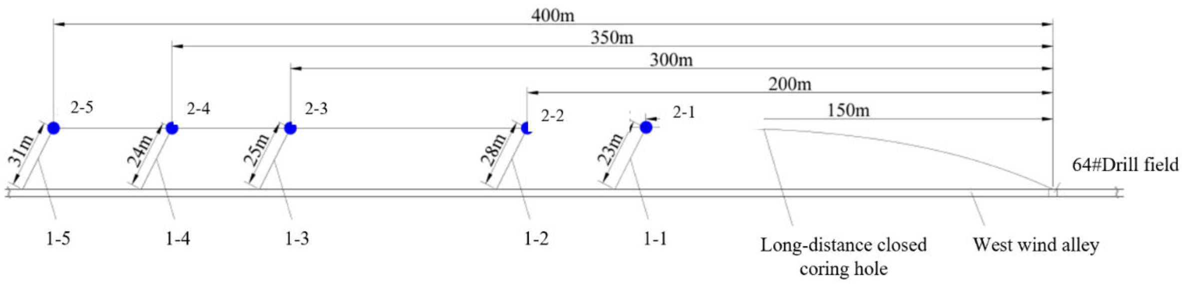


Figure 5. Schematic diagram of the arrangement of core drilling holes in the test area

5.2. Comparative Analysis of Measurement Results

Table 2 shows the comparison results of the gas content determination between the long-distance airtight coring device and the coal core tube.

Table 2. Determination results of gas content in the test area

No.	Sampling depth(m)	Sampling weight(g)	Gas loss(m^3/t)	Atmospheric pressure desorption gas(m^3/t)	Gas desorption amount of crushed coal(m^3/t)	Atmospheric pressure adsorption gas(m^3/t)	Gas content Q(m^3/t)	Error
1-1	23	408	0.06	0.03	3.25	3.52	6.86	6.71%
2-1	150	401	0.24	0.04	3.52	3.52	7.32	
1-2	28	325	0.19	0.06	3.85	3.52	7.62	-1.57%
2-2	200	603.8	0.08	0.35	3.55	3.52	7.50	
1-3	25	382	0.16	0.23	2.69	3.52	6.60	8.64%
2-3	300	638.9	0.14	0.02	3.49	3.52	7.17	
1-4	24	325	0.07	0.03	3.24	3.52	6.86	7.43%
2-4	350	695	0.23	0.02	3.60	3.52	7.37	
1-5	31	377	0.21	0.06	3.51	3.52	7.30	4.93%
2-5	400	558	0.28	0.08	3.78	3.52	7.66	
Mean value	/	/	/	/	/	/	/	5.23%

It can be seen from Table 2 that compared with the conventional method for measuring gas content by coring (coal core tube), the gas content measurement results of long-distance airtight coring are higher, and the average measurement results are about 5.23% higher.

6. Conclusion

(1) The gas loss of long-distance airtight coring can be obtained by plotting the abscissa $\sqrt{t_0+t_1+t_2}$ as the abscissa and the ordinate $V(t_1)+V(t_2)$ as the ordinate, fitting each data point linearly, and solving the intercept of the fitting line and the ordinate.

(2) Compared with the core tube sampling, the gas content of the long-distance airtight coring is higher, and the average is about 5.23% higher. The measurement results are reliable, and the measurement range is increased to more than 300m.

Acknowledgment

This work is financially supported by China Coal Science and Industry Group Co., Ltd. Special Key Projects of Science and Technology Innovation and Entrepreneurship Funds(2022-2-TD-ZD009), Enterprise independent scientific research key research and development project(2022ZDXM11), which are gratefully acknowledged.

References

[1] Qiu Yang. Research on the calculation method of gas loss in the determination of coal seam gas content by desorption method [D]. Xi'an: Xi'an University of Science and Technology, 2017.

[2] Feng Shi'an. Comparative study on determination methods of coal seam gas content [D]. Anhui: Anhui University of Science and Technology, 2013.

[3] Yan Guoqiang. Study on direct fitting and determination method of coal seam gas content [D]. Shandong: Shandong University of Science and Technology, 2016.

[4] Dai Yang. Comparative analysis of gas content determination with different sampling methods [J]. Zhongzhou Coal, 2012, 31(12): 31-32.

[5] Kong Delei. Analysis of main influencing factors of gas occurrence in Baode coal mine 8# coal seam [J]. Coal Engineering, 2017, 49(8): 182-184.

[6] Yu Bufan. Technical Manual of Coal Mine Gas Disaster Prevention and Utilization (Revised Edition) [M]. Beijing: Coal Industry Press, 2005: 68~76.

[7] Jing Xingpeng. Airtight coring measurement device and testing technology for coalbed methane content [J]. Journal of Xi'an University of Science and Technology, 2019, 39(4): 603~609.

[8] Cheng Bo, Qiao Wei, Yan Wenxue, et al. Research progress on determination method of coal seam gas content in coal mine [J]. Mining Safety & Environmental Protection, 2019, 46;246(04): 98-103.

[9] Jing Xingpeng. Research on the integrated technology of gas content determination in mechanical airtight coring [J]. China Safety Production Science and Technology, 2015, 11(11): 59-63.

[10] Zhang Dingliang. Sealed coring device for underground coal seams in coal mines [J]. China Coal Geology, 2015, 27(7): 81-87.

[11] Long Weicheng. Gas content testing technology of airtight coring in coal seams and its application in directional long drilling [J]. Journal of South University of Technology, 2018, 23(6): 16-21.

[12] Zhang Hongliang. Study on gas desorption law of coal in negative pressure environment [D]. Henan: Henan University of Technology, 2015.

[13] Wang Bin. Experimental study on factors influencing gas content determination by downhole borehole desorption method [D]. Xuzhou: China University of Mining and Technology, 2015.