



In-situ gas contents of a multi-section coal seam in Sydney basin for coal and gas outburst management

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Abstract

The gas content is crucial for evaluating coal and gas outburst potential in underground coal mining. This study focuses on investigating the in-situ coal seam gas content and gas sorption capacity in a representative coal seam with multiple sections (A1, A2, and A3) in the Sydney basin, where the CO₂ composition exceeds 90%. The fast direct desorption method and associated devices were described in detail and employed to measure the in-situ gas components (Q_1 , Q_2 , and Q_3) of the coal seam. The results show that in-situ total gas content (Q_T) ranges from 9.48 m³/t for the A2 section to 14.80 m³/t for the A3 section, surpassing the Level 2 outburst threshold limit value, thereby necessitating gas drainage measures. Among the gas components, Q_2 demonstrates the highest contribution to Q_T , ranging between 55% and 70%. Furthermore, high-pressure isothermal gas sorption experiments were conducted on coal samples from each seam section to explore their gas sorption capacity. The Langmuir model accurately characterizes CO₂ sorption behavior, with fit coefficients (R^2) greater than 0.99. Strong positive correlations are observed between in-situ gas content and Langmuir volume, as well as between residual gas content (Q_3) and sorption hysteresis. Notably, the A3 seam section is proved to have a higher outburst propensity due to its higher Q_1 and Q_2 gas contents, lower sorption hysteresis, and reduced coal toughness f value. The insights derived from the study can contribute to the development of effective gas management strategies and enhance the safety and efficiency of coal mining operations.

Keywords In-situ coal seam gas content · Direct desorption method · Gas component · Sorption capacity · Coal and gas outburst

1 Introduction

Coal mine gas emissions and outbursts have been long-standing challenges in the coal mining industry, posing considerable threats to the safety of miners and the efficiency of mining operations (Lei et al. 2023; Liu et al. 2020a; Si et al. 2015; Wu et al. 2020). The gas content within coal seams is a vital factor for comprehending and addressing these concerns (Liu et al. 2020b). Accurate measurement and analysis

of this parameter help to estimate coal seam gas reserves, assess the risk of coal and gas outbursts, and develop appropriate gas management strategies (Black 2018).

Gas content measurement techniques can be classified into two primary categories: indirect and direct (Diamond and Schatzel 1998; Hou et al. 2020). Indirect approaches depend on gas adsorption properties under particular pressure and temperature conditions or empirical data linking gas content with other factors such as gas pressure, emission rate, coal rank, and overburden depth (Hou et al. 2020; Ye et al. 2023). Nevertheless, indirect methods present various drawbacks, including difficulties in acquiring precise in-situ seam gas pressure measurements, the presumption of complete gas saturation in coal seams, and the complexity in determining the composition of multi-component seam gases (Xue and Yuan 2017). In contrast, direct methods assess the real amount of gas liberated from coal specimens and can be categorized into slow and fast desorption techniques (Wang et al. 2015; Yao et al. 2014). The slow desorption method

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requires weeks or months for a coal sample to reach a low desorption rate or to stop desorbing, while the fast direct desorption method expedites the process by crushing the sample upon arrival at the laboratory, obtaining gas content results within days (Xue et al. 2013).

Since the introduction of the direct gas content measurement method by Bertard et al. (1970), various systems have been developed for direct measurement of coal gas content. And these methods and their subsequent modifications have been effective in measuring coal seam gas content in cored coal samples. Bertard and his colleagues used an arrangement of three distinct containers (allocated for initial measurement, transportation, and crushing), a U-tube manometer, and a crusher to assess the volume of gas desorbed from coal samples collected from operational mining sites (Bertard et al. 1970). Kissell et al. (1973) tested the applicability of the “direct method” for determining the methane content of virgin coalbeds in the Vesta No. 5 coal. They conducted experiments using exploration cores to assess the method's effectiveness in estimating gas content and predicting the total gas emissions from a potential mine situated at the exploration site. The results indicated that the direct method, when applied to exploration cores, successfully provided accurate estimates of coalbed gas content and reasonably predicted the overall gas emissions from the prospective mine. Xue and Yuan developed an adapted direct method to measure gas content in coal seams by employing coal cuttings from underground boreholes, specifically in cases of soft, friable, or geologically intricate coal seams where acquiring cores may pose significant challenges (Xue and Yuan 2017; Xue et al. 2014). The modified method showed satisfactory results when applied in a soft seam at Huainan, China, demonstrating its potential as a viable alternative to the standard procedure for determining gas content when cores are not available. These findings suggest that the direct method can be a valuable tool in gas content analysis and mine planning, contributing to improved safety and efficiency in coal mining operations.

The Sydney Basin in Australia is known for its abundant coal resources and complex geological conditions, which make the assessment of gas content and sorption capacity particularly crucial for local coal mining operations (Faiz et al. 2007). Previous studies have primarily focused on the measurement of gas content and composition using various direct and indirect methods. However, there is a lack of comprehensive research on the relationship between in-situ gas content and gas sorption capacity in the context of coal seams from the Sydney Basin.

In this study, we aim to address this gap by investigating the in-situ coal seam gas content and gas sorption capacity in multi-section coal seams (A1, A2, and A3) in the Sydney Basin. The fast direct desorption method and associated devices were employed to measure the in-situ coal seam gas

components (Q_1 , Q_2 , and Q_3) and gas composition. High-pressure isothermal gas sorption experiments were conducted on coal samples from these seam sections to investigate their gas sorption capacity. The relationship between in-situ gas content and gas sorption capacity is analyzed to understand its implications for gas management and outburst risk in Australian coal mines.

2 Direct desorption method of determining coal seam gas content

There are two commonly used methods to estimate the gas content in a coal seam: the direct method and the indirect method. The direct method measures the total gas volume directly from a coal sample, while the indirect method estimates the gas content from sorption isotherms or empirical correlations under given temperature and pressure conditions. The fast and slow desorption methods are two types of direct methods, with the fast desorption method taking less than five days, while the slow desorption process takes over five days for gas to desorb from the intact core before the final crushing stage. Coal gas content is examined using the quick direct desorption method at the Coal Gas Laboratory A, and the gas composition is assessed employing a 4-channel Micro Gas Chromatograph.

2.1 Lost gas component (Q_1)

The lost gas component (Q_1) refers to the portion of gas that escapes from the coal sample during collection, prior to being sealed into the desorption canister. Q_1 needs to be estimated using the gas emission gathered after sealing the sample into the desorption canister. It is widely acknowledged that the volume of gas released during initial desorption is proportional to the square root of the desorption time (Zhang 2013), as shown in Fig. 1a and detailed in AS3980:2016 (Australia 2016). By projecting the best-fit line representing the initial gas emission from the time the core was sealed into the gas desorption canister to the midpoint between the start and end of coring the sample, an estimation of the gas volume lost during core sample recovery can be obtained. Q_1 can be estimated based on the following equation:

$$q = k\sqrt{t} - Q_1 \quad (1)$$

where, q = the accumulated volume of desorbed gas since coal is placed in the desorption canister and measurement commenced, m^3/t ; t = the time since the start of gas desorption in the hole, min; k = the slope of a regression line passed through canister desorption data.

Note: The desorbed volumes are expressed at STP conditions (20 °C, 101.325 kPa).

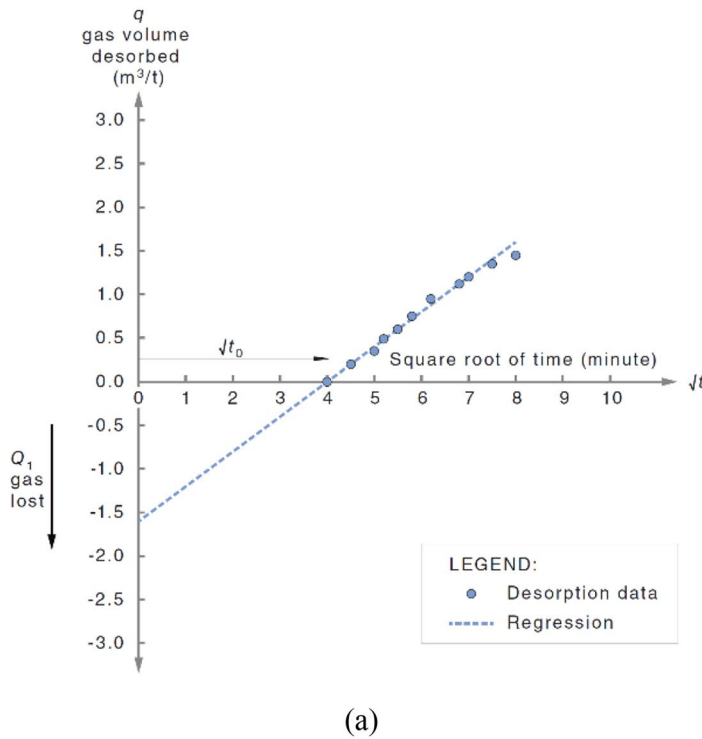


Fig. 1 Lost gas content (Q_1) calculation illustration **a** and its measuring apparatus **b** (Australia 2016)

2.2 Desorbed gas component (Q_2)

The desorbed gas component (Q_2) represents the volume of gas released from a coal sample while it is contained in a desorption canister. The fast desorption test typically lasts less than five days, often taking less than one day. Generally, gas released from a core sample is measured by water displacement using a graduated glass or plastic measuring flask. As shown in Fig. 2, the measurement apparatus can be set up so that the gas liberated from the core sample within the desorption canister enters the measuring flask via a tube connected to either the top or bottom of the flask. Connecting the tube to the top of the cylinder is preferred, as it prevents the desorbed gas from bubbling through the water column, thereby reducing the risk of gas loss through dissolution, particularly when the seam gas has a high CO_2 concentration (AS3980:2016) (Australia 2016). The desorbed gas (Q_2) is calculated by summing all volume increments determined over the measurement period. If there are n steps to complete the measurement, the Q_2 value can be expressed as:

$$Q_2 = \frac{1}{m} \sum_{i=1}^n \Delta V_i = \frac{V_n - V_1}{m} \quad (2)$$

here, m is the mass of sample, g; ΔV_i is the incremental volume of gas desorbed, which is the difference between the

current corrected gas volume at instant i and the previous corrected volume in the system at instant $i - 1$ (provided the cylinder has not been refilled). $i = 1$ of the measurement corresponds to the beginning of measurement and associated V_1 is the volume of void in the system at this instant.

2.3 Residual gas component (Q_3)

The residual gas component (Q_3) quantifies the gas released from a coal sample after crushing. The equipment for this process is illustrated in Fig. 3, and the procedure involves the following steps:

- (1) Perform a desorbed gas test on the coal sample to measure the gas that is released from the coal under a particular set of conditions.
- (2) Remove the coal core from the desorbed gas test apparatus and collect a representative sub-sample of the coal.
- (3) Seal the sub-sample into a crushing or grinding mill.
- (4) Crush the coal to a particle size such that 95% of the coal is less than $212 \mu m$.
- (5) Measure the volume of gas released from the coal sample using a water column similar to the one employed in the desorbed gas (Q_2) test.

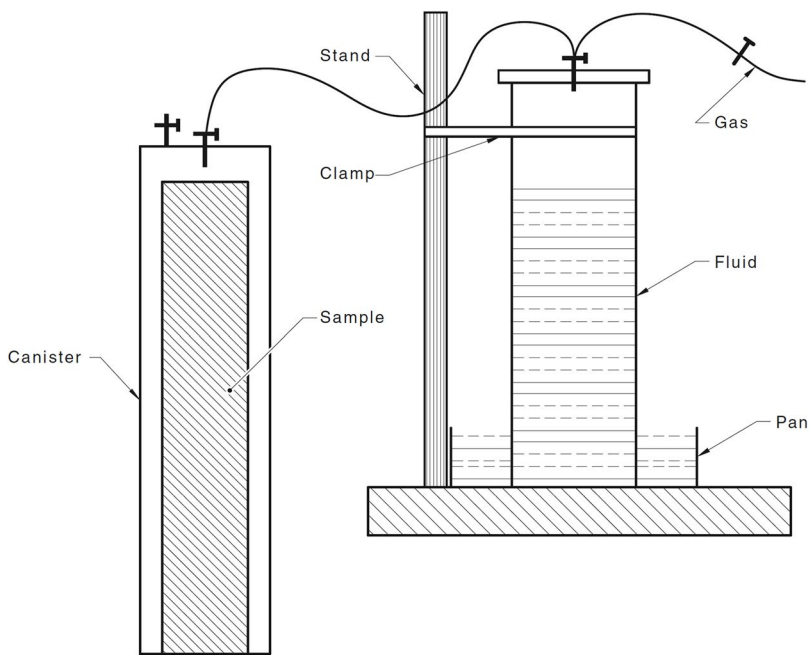


Fig. 2 Desorbed gas volume measurement apparatus for estimation of Q_2

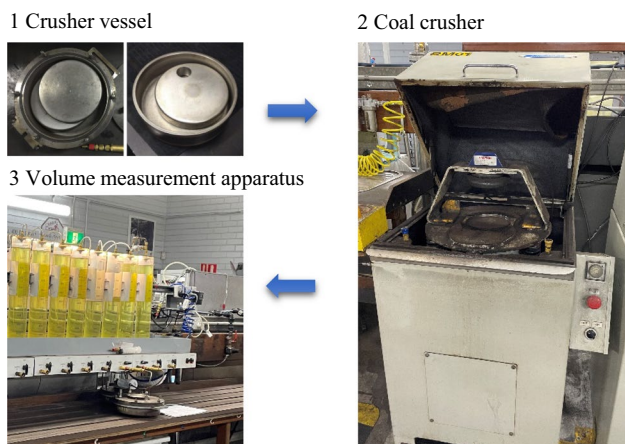


Fig. 3 Residual gas content measurement apparatus for estimation of Q_3

The result of this procedure is the Q_3 , which represents the quantity of gas that remains within the coal matrix after desorption, under the particular conditions applied in the desorbed gas test.

2.4 Measured total gas content (Q_T)

The total gas content is calculated by adding the three gas components (Q_1 , Q_2 , and Q_3), as demonstrated in Eq. (3),

and determined at a standard temperature of 20 °C and a pressure of 101.325 kPa.

$$Q_T = Q_1 + Q_2 + Q_3 \tag{3}$$

2.5 The limit of this method and its controls

The precision of the coal seam gas content measurement method outlined in Sect. 2.1 is subject to a variety of factors. These factors encompass system leakage, desorption rate (influencing the Q_1 calculation), gas solubility in water (especially CO_2), sample moisture content, partial pressure (impacting the equilibrium endpoint for desorption), temperature (affecting the desorption magnitude), and barometric pressure (altering the desorption magnitude). To mitigate errors stemming from these factors, a combination of procedural, measurement, and calculation controls can be implemented during the gas content determination process.

These controls comprise methods for detecting system leaks, evaluating samples based on an “as-received” condition, and utilizing a measurement apparatus designed to prevent gas loss through dissolution, particularly when dealing with seam gas containing high CO_2 concentrations. By adopting these controls, the overall gas estimation accuracy using this method is considered to have an error factor of $\pm 15\%$, aligning

with the targeted maximum relative error for gas content measurements in the coal mining sector (Moore 2012; Xue and Yuan 2017). This degree of accuracy guarantees that the method delivers dependable and consistent outcomes, rendering it an appropriate choice for evaluating gas content and composition in Australian coal mining industries.

3 Materials and methods

3.1 Sample preparation

The Sydney Basin, a major geological structure in Australia, spans an approximate area of 44,000 km² as depicted in Fig. 4a. Notably, it harbours significant coal reserves,

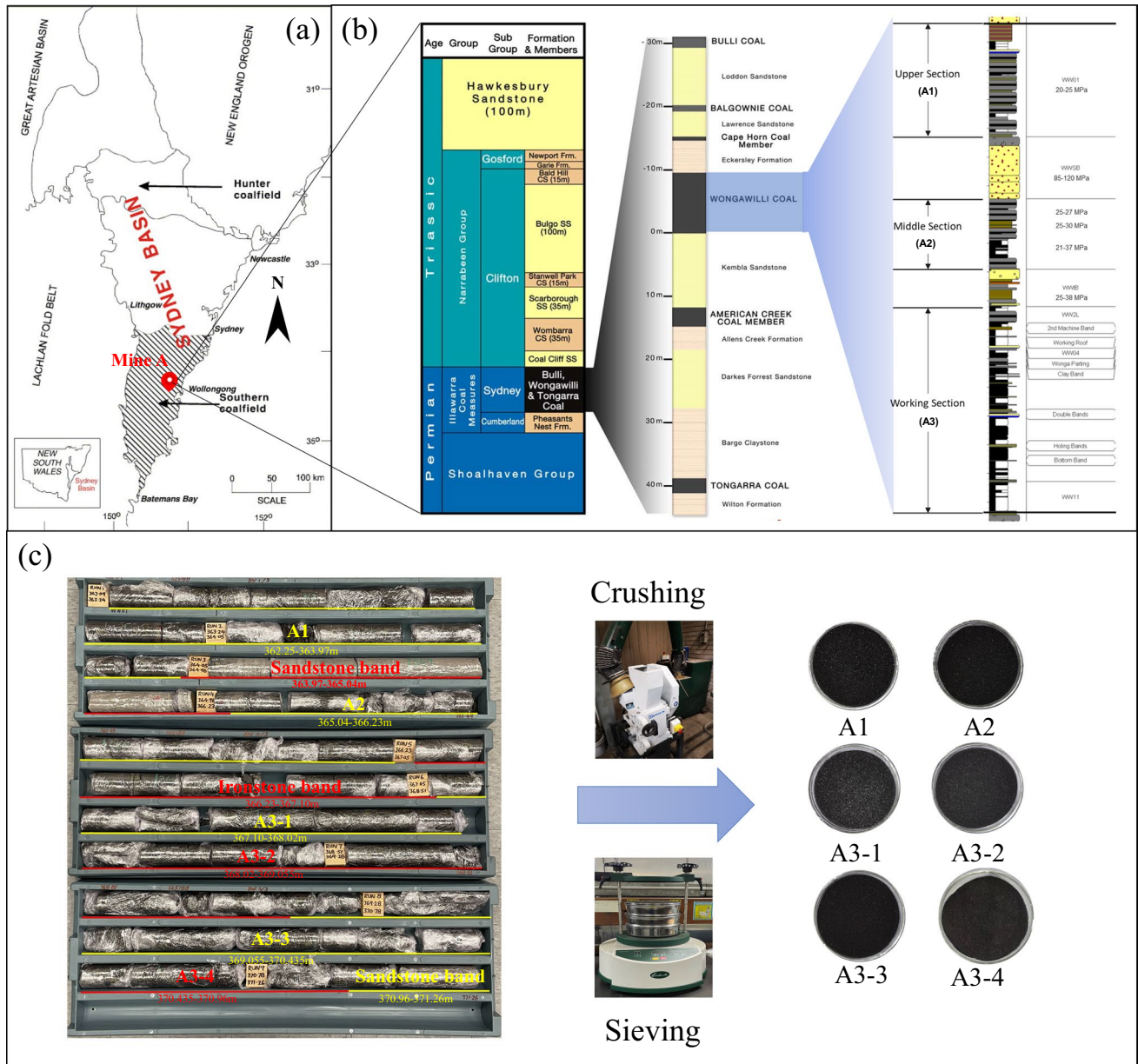


Fig. 4 Sample geological information and preparation. **a** Sampling location (Faiz et al. 2007); **b** Generalized stratigraphic column of the study area (Black 2023); **c** Sample preparation

Table 1 Proximate analysis and coal hardness results

Sample ID	Proximate analysis (%)				f (median)	
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}		
A1	0.91	21.8	19.0	58.3	1.28	
A2	0.74	25.0	18.0	56.3	1.31	
A3	A3-1	0.66	32.9	17.0	49.5	0.74
	A3-2	1.08	33.0	18.0	47.9	
	A3-3	4.06	15.0	29.5	51.4	
	A3-4	0.76	10.5	21.7	67.1	

M_{ad} is the moisture content on air-dried basis, A_{ad} is the ash content on air-dried basis, V_{ad} is the volatile matter content on air-dried basis and FC_{ad} is the fixed carbon on air-dried basis, f is the coal hardness

estimated around 37 billion tons. The principal coal-bearing strata of interest in our study are located in the Southern Coalfield, exhibiting various sections of coal seams with substantial thickness and coal content. Primarily, the coal seams in the Southern Coalfield, especially in our investigation area, are coking coal. Furthermore, the gas composition within these coal seams exhibits a high proportion of carbon dioxide (CO_2).

A typical stratigraphic column of the coal seams studied in the Southern Coalfield is depicted in Fig. 4b. It clearly outlines the multi-section seam under investigation, including upper section A1, middle section A2, and working section A3. Notably, the A3 section is further subdivided into four subsections. The thickness of these examined sections ranges from 8.5 to 9.5 m. The roof and floor of the seams are predominantly comprised of sandstone. The seam depth of cover increases from around 240 m to approximately 380 m along the western and northern perimeters. The seam consistently dips to the northwest at an angle of around 1.5° (Black 2023).

In this study, coal samples were extracted from surface-to-inseam (SIS) boreholes and initially analyzed at the gas laboratory at Mine A to determine gas content using the direct desorption method, as outlined in Sect. 2. Following this, core samples were transported to the university laboratory for further processing. Six specific subsections from the coal seam A were pulverized using a jaw crusher to a fine powder with a particle diameter of less than $212 \mu\text{m}$, as shown in Fig. 4c. These pulverized samples were then sieved and packaged for subsequent analysis. This granularity is commonly used for rapid desorption analysis (Q_3) as a standard procedure in gas content testing according to AS3980:2016 (Australia 2016), and for indirect coal seam gas content measurement. Following sample preparation, a proximate analysis was conducted in accordance with AS 1038.3–2000 (Australia 2000) to assess moisture, ash, volatile content, and fixed carbon. This analysis was carried out

utilizing an automatic thermos-gravimetric proximate analyzer (TGA 8000). Additionally, the hardness of the coal was evaluated using the Protodyakonov strength coefficient (f), an important measure for predicting outbursts (Wang et al. 2020). The results of these analyses are presented in Table 1 and Fig. 5.

3.2 Lab experiment of gas sorption isotherms

A purpose-built high-pressure isothermal sorption system at University of Wollongong was used to test the gas sorption isotherms, as shown in Fig. 6, which consists of six modules: gas supply and control module, adsorption and desorption module, pressure acquisition module (accuracy: 0.001 Pa), vacuum degassing module, temperature control and measurement module (accuracy: 0.001 °C), and high-precision weight measurement module (accuracy: 0.0001 g) (Li et al. 2023). The test procedure is as follows:

- (1) Dry the samples in a vacuum drying oven at 100°C for 1 h and cool in a desiccator.
- (2) Conduct airtightness test of the sorption canister by injecting 5.0 MPa helium and keep for 24 h; re-seal if pressure drop is higher than 20 kPa.
- (3) Degas the sorption canister for 2 h using a vacuum pump till relative pressure reaches -100 kPa , and let it stand for 24 h; inject helium to measure dead space volume.
- (4) Charge CO_2 into the canister with samples, and test adsorption and desorption isotherms at pressure gradient of 0.5 MPa, maximum pressure of 5.0 MPa, and equilibrium time of 24 h.
- (5) Maintain thermostatic water bath and room temperature at 30°C during sorption test.

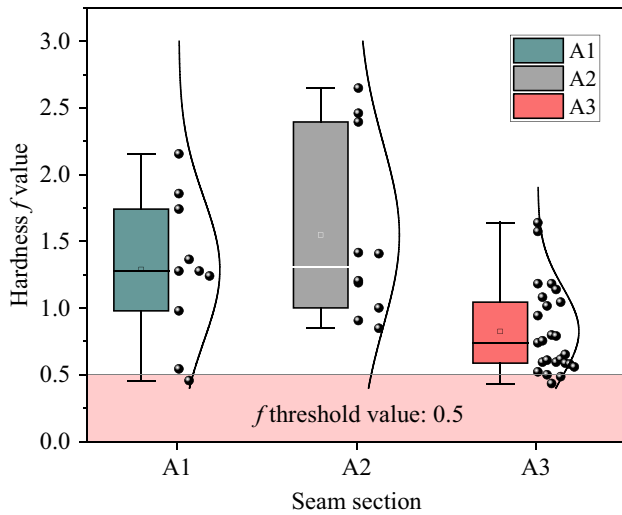


Fig. 5 Coal harness testing results of samples from A1, A2 and A3 seam sections

The Langmuir equation is a mathematical model that is commonly used to describe the adsorption of gases onto a porous surface.

$$V = \frac{V_L P}{P + P_L} \tag{4}$$

where, V = the adsorption volume under equilibrium pressure P , cc/g; V_L = the Langmuir volume, which represents the limit gas adsorption capacity when the gas pressure is infinite, cc/g; P_L = the Langmuir pressure, which represents the pressure at which the adsorption volume V reaches half of the V_L , MPa.

3.3 Sorption hysteresis characterization

The distinction between adsorption and desorption isotherms is commonly referred to as ‘‘sorption hysteresis.’’ Traditionally, the adsorption and desorption processes have been assumed to be fully reversible, leading to the tendency of overlooking sorption hysteresis. However, laboratory experiments have shown that coal desorption is often lower than the corresponding adsorption volume at the same pressure, and this discrepancy can be significant.

The sorption hysteresis phenomenon can be explained as follows: during the adsorption phase, gas molecules under high-pressure conditions embed themselves in poorly micropores. The embedding of these molecules, comparable in size to the pores, causes the coal matrix to swell, further constricting the pore channels. As the gas pressure decreases during the desorption phase, some molecules become trapped in these poorly connected micropores and cannot desorb and diffuse out (Li et al. 2022a; Wang et al. 2014). This phenomenon has significant implications for assessing coal seam gas drainage and predicting gas emissions during coal mining operations.

Therefore, it is crucial not to disregard sorption hysteresis. To quantify the sorption hysteresis, a hysteresis index (HI) is used to calculate the sorption hysteresis gas volume, as illustrated in Fig. 7 and Eq. (5).

$$HI = \frac{A_{hy}}{A_{hf}} \times 100\% \tag{5}$$

here A_{hy} , and A_{hf} represent the measured hysteresis area, the hysteresis area in the fully irreversible case. When HI is 0, that means no hysteresis is observed and it is a completely

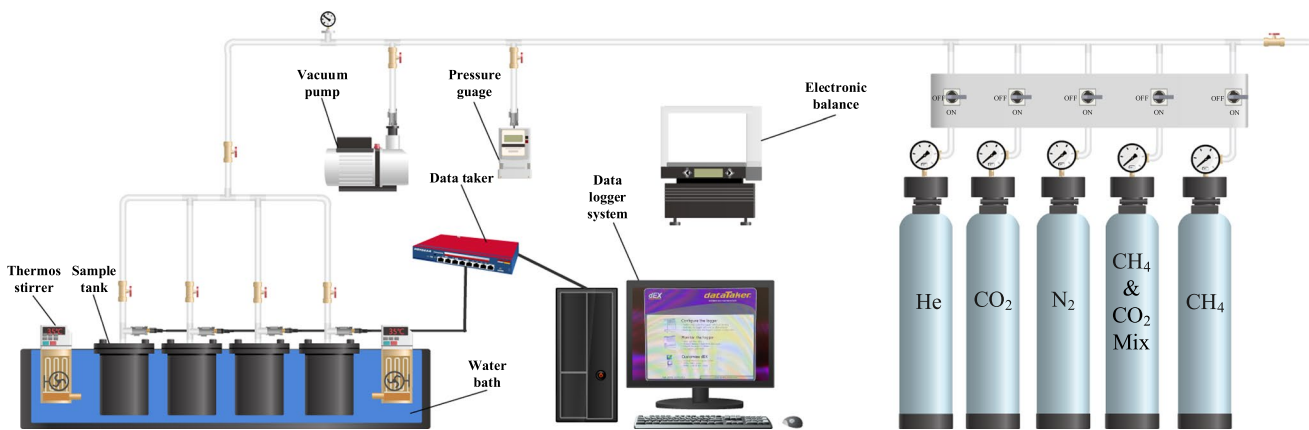


Fig. 6 Structural diagram of adsorption and desorption test system

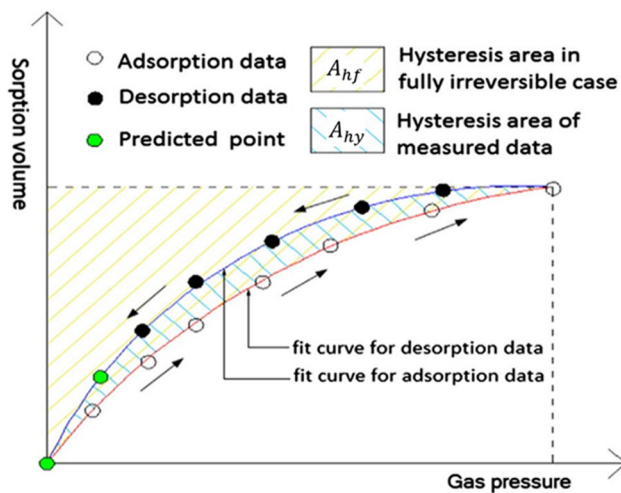


Fig. 7 Explanation of the hysteresis index (Wang et al. 2014)

reversible state. When HI is 100%, that means it is a completely irreversible state.

4 Results and discussion

4.1 Analysis of in-situ coal seam gas contents of multi-seam sections

4.1.1 Coal seam gas content and outburst threshold limits (TLV)

The Australian outburst TLV varies linearly based on gas composition, increasing from a minimum in CO_2 rich conditions ($5 \text{ m}^3/\text{t}$) to a maximum in CH_4 rich conditions ($9 \text{ m}^3/\text{t}$), as illustrated in Fig. 8, with the presence of CO_2 seam gas considered a significantly higher outburst risk than CH_4 seam gas. The Level 1 TLV (green area) for ‘normal’

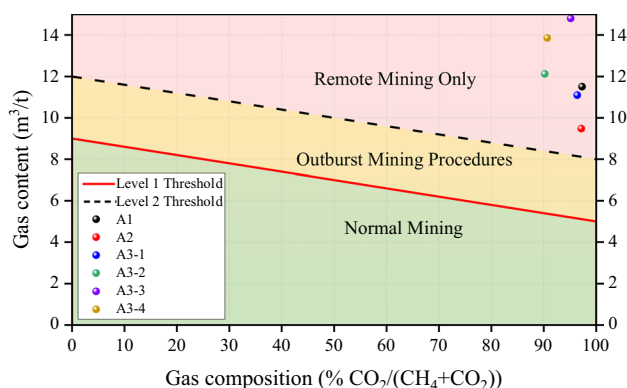


Fig. 8 In-situ gas content of coal seam A and outburst threshold limits (TLV) (Clarke 1994)

mining stands at $9.0 \text{ m}^3/\text{t}$ in purely CH_4 conditions and $5.0 \text{ m}^3/\text{t}$ in CO_2 conditions. If gas content is not reduced below the Level 1 TLV, mining allowed only under outburst mining procedures. The Level 2 TLV (yellow area) for outburst mining is set at $12.0 \text{ m}^3/\text{t}$ in purely CH_4 conditions and $10.0 \text{ m}^3/\text{t}$ in CO_2 conditions. Mining is only allowed via remote-operated equipment if gas content exceeds the Level 2 TLV (red area), with all personnel required to steer clear of the outburst risk zone. (Black 2019; Black and Aziz 2010).

Based on the direct desorption measurement results obtained from coal seam A, the gas content of the upper section A1, mid-section A2, and working section A3 of the seam is analysed. As shown in Fig. 8, the CO_2 composition in all three seam sections exceeds 90%. The virgin gas contents in all seam sections surpass the Level 2 TLV. Therefore, it is crucial to implement gas drainage measures to reduce the gas content below the respective TLVs in each seam section. Gas drainage techniques, such as pre-drainage boreholes, cross-measure boreholes, or in-seam drilling, can be employed to extract the gas and alleviate the risk of gas outbursts or other gas-related hazards. Moreover, proper gas drainage management ensures the safety of mining operations, improves coal production efficiency, and potentially contributes to the extraction of coal seam gas as an energy resource (Huang et al. 2019; Lin et al. 2022b; Shi et al. 2023; Zhao et al. 2019).

4.1.2 Q_1 , Q_2 , Q_3 and Q_T gas content component

Figure 9 displays the distribution of the Q_1 , Q_2 , Q_3 and Q_T gas content components for the A1, A2, and A3 seam sections. The total gas content (Q_T) in the working section A3 ranges from 11.10 to $14.80 \text{ m}^3/\text{t}$, which is higher than that of the upper section A1 ($11.51 \text{ m}^3/\text{t}$) and the middle section A2 ($9.48 \text{ m}^3/\text{t}$). Among the three gas components, the desorbed gas content (Q_2) varies from $6.24 \text{ m}^3/\text{t}$ in the A2 seam section to $10.3 \text{ m}^3/\text{t}$ in the A3-3 subsection. Q_2 contributes the most to the total gas content (Q_T), with proportions ranging between 55% and 70%, as shown in Fig. 10. The lost gas component (Q_1) spans from $0.29 \text{ m}^3/\text{t}$ in the A1 seam section to $2.01 \text{ m}^3/\text{t}$ in the A3-2 subsection. The lost gas content (Q_1) contributes the least to the total gas content (Q_T), with proportions ranging from 3% to 17%. The residual gas content (Q_3) varies from $2.31 \text{ m}^3/\text{t}$ in A3-2 subsection to $4.92 \text{ m}^3/\text{t}$ in A1 seam section, with proportions ranging from 19% to 43%.

Comparing the three sections, the Q_1 and Q_2 gas contents of all A3 seam subsections are higher than those of the A1 and A2 seam sections, along with their respective contribution proportions. This observation is in line with previous studies that suggest Q_1 and Q_2 gas contents, measured during the early stages of desorption, are closely related to the propensity for coal and gas outbursts (Black et al. 2010).

Therefore, it is reasonable to suggest that the A3 seam section has a higher potential for outbursts compared to the A1 and A2 seam sections. This conclusion is further supported by the analysis of coal hardness, where the f value of A3 seam section (0.74, as shown in Table 1) is close to the critical value, which is significantly lower than that of the A1 and A2 seam sections. Coal hardness is an important factor in determining the potential for coal and gas outbursts, as lower hardness values indicate a higher likelihood of sudden release of gas and coal. Therefore, the combination of higher Q_1 and Q_2 gas contents and lower coal hardness in

the A3 seam section suggests an increased risk of outbursts in this area.

Furthermore, the A1 and A2 coal seam sections exhibit higher residual gas content (Q_3) compared to A3, indicating greater challenges in gas drainage and lower efficiency in removing gas from these sections. It is worth noting that when the continuous miner cuts coal, significant volumes of residual gas are released into the air return ways. This can lead to exceeding gas limits and adversely impact the normal production of the mine. Therefore, reducing the residual gas content is crucial to mitigate the potential hazards of gas explosions and prevent coal seam gas accumulations in tailgate or air return ways (Lin et al. 2022a).

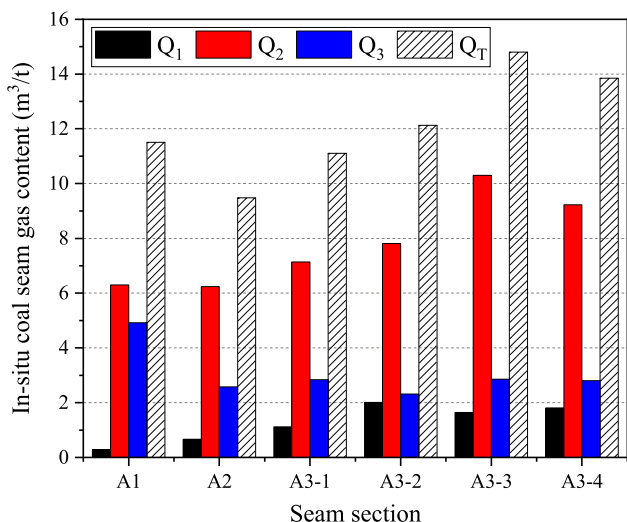


Fig. 9 Q_1 , Q_2 , Q_3 and Q_T gas content of different seam sections of coal seam A

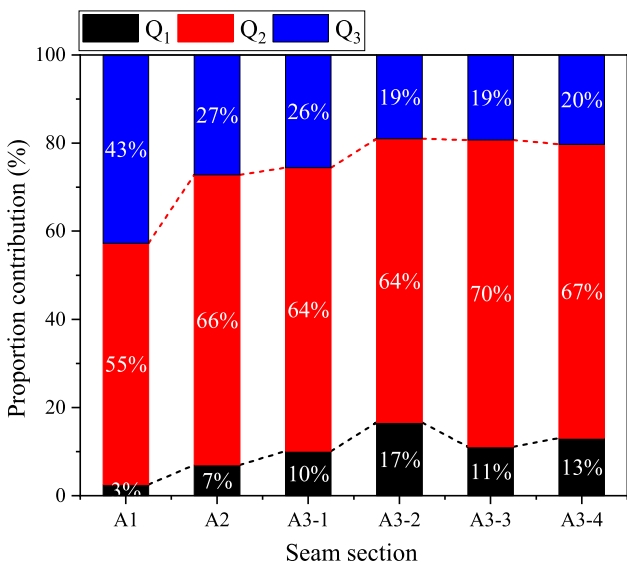


Fig. 10 The proportion contribution of Q_1 , Q_2 , Q_3 to Q_T of each seam section

4.2 CO₂ sorption isotherms and hysteresis

It is reasonable to focus on CO₂ sorption isotherms in this study, given that the gas composition of the tested coal seam is more than 90% CO₂. Figure 11 and Table 2 present the CO₂ adsorption and desorption isotherms and Langmuir model fitted results of samples from three seam sections (A1, A2, and A3). The Langmuir model demonstrates excellent performance in describing the sorption behaviour of CO₂, with fit coefficients R^2 greater than 0.99, emphasizing the model's suitability for representing the CO₂ sorption process in these coal samples.

Analysis of the experimental and characterization results reveals variations in sorption capacities for CO₂ among the tested coal samples from the different seam sections. The Langmuir volume of CO₂ ranges from 23.02 m³/t for A2 section and 31.38 m³/t for A3-3 section, with a considerable sorption hysteresis degree ranging from 15.83% to 22.48%. The sample from A3 section exhibits the highest Langmuir volume and a moderate Langmuir pressure for adsorption, indicating a strong adsorption capacity, which could be attributed to the presence of well-developed micropores in the coal reservoir (Li et al. 2022b; Li et al. 2023b; Chen et al. 2022). The high hysteresis degree of A1 and A2 samples could be attributed to the high proportion of poorly connected pores, which contribute to the trapping of CO₂ gas (Wang et al. 2014; Zhang and Liu 2017).

4.3 The relationship between in-situ gas content and gas sorption capacity

The in-situ gas content and gas sorption capacity of a coal seam are interconnected factors that significantly impact the determination of coal seam gas reserves and the propensity for outbursts in underground mines. In this section, we examined the relationship between in-situ gas content and gas sorption capacity, utilizing the data obtained from the A1, A2, and A3 seam sections. So as to comprehend how variations in sorption capacity affect the in-situ gas content

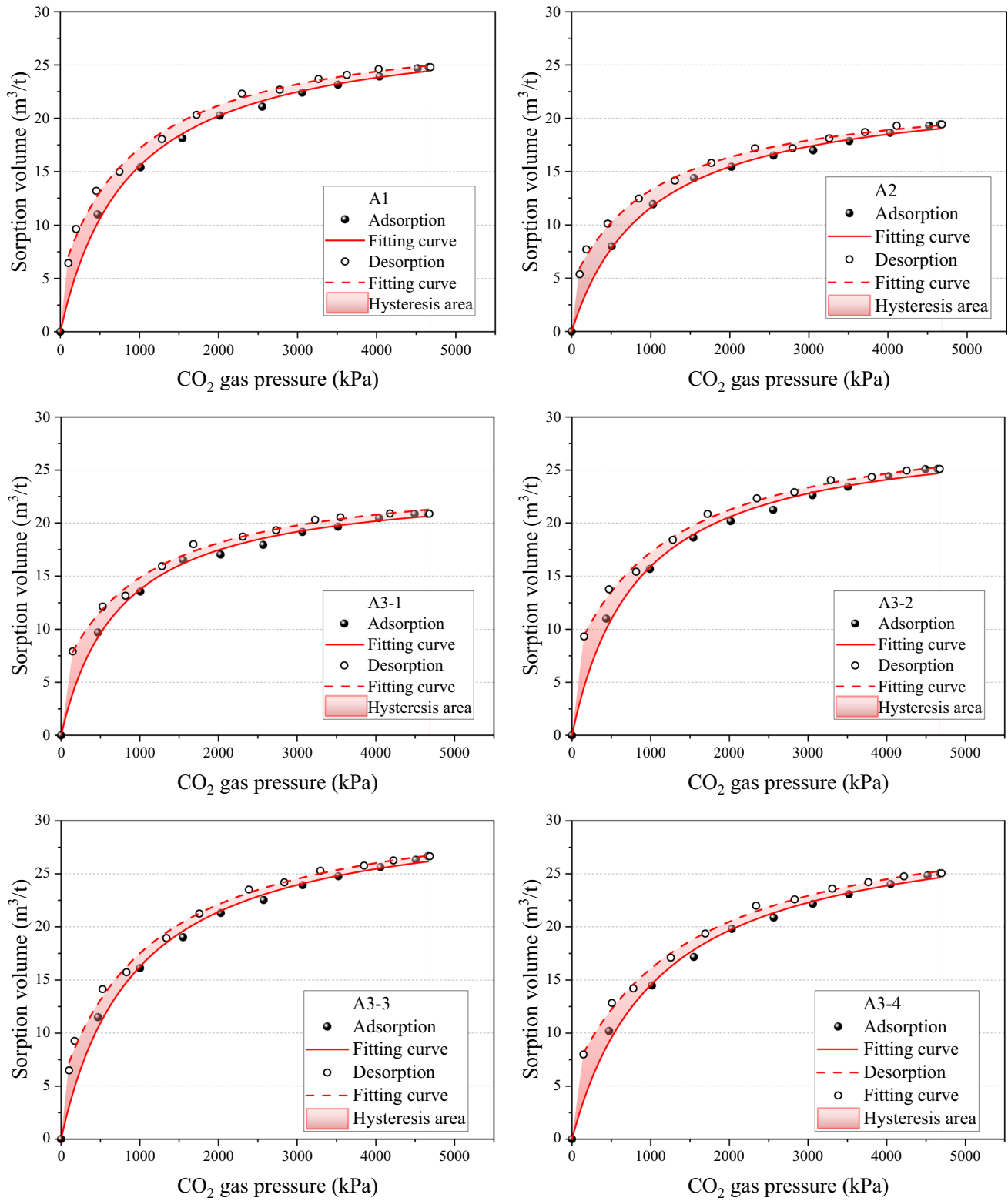


Fig. 11 CO₂ sorption isotherms and hysteresis

Table 2 Model fitted parameters for CO₂ ad-/desorption isotherms and its hysteresis index

Sample ID	Sorption parameters			Sorption hysteresis index (HI) (%)
	V _L (m ³ /t)	P _L (kPa)	R ²	
A1	28.97	867.06	0.997	22.48
A2	23.02	980.57	0.996	20.35
A3-1	24.93	1091.75	0.996	18.79
A3-2	29.07	827.91	0.995	17.15
A3-3	31.38	932.37	0.996	15.83
A3-4	30.39	743.86	0.996	16.93

and to identify factors that could impact gas management and outburst risk.

Figure 12 presents a scatter plot comparing in-situ gas content (Q_T) with the Langmuir volume for the coal samples from the three seam sections. A strong positive correlation (Pearson's coefficient > 0.85) is observed between gas content and Langmuir volume. This suggests that higher sorption capacities correspond to higher gas content within coal seams.

The previous data show that the A3 seam section has the highest in-situ gas content (Q_T) and the highest sorption Langmuir volume. Conversely, the A2 seam section exhibits the lowest in-situ gas content and the lowest sorption capacity. These results further reinforce the positive correlation between in-situ gas content and gas sorption capacity.

The isotherm-based hysteresis also plays a critical role in understanding the relationship between gas content and sorption capacity. Figure 13 demonstrates this relationship, revealing a strong positive linear correlation (Pearson's coefficient > 0.9) between the Q_3 proportion and the degree of sorption hysteresis. As mentioned earlier, the A1 and A2 seam sections exhibit higher residual gas content (Q_3) compared to the A3 seam section, indicating greater difficulty in gas drainage. This observation corresponds to the relationship depicted in Fig. 13, where higher Q_3 proportions are associated with a higher sorption hysteresis degree. This suggests that the coal's pore structure, which influences the connectivity of pores and the trapping of gas within the coal matrix, contributes to the observed variations in gas content and sorption capacity. The results highlight the significance of considering the sorption hysteresis when assessing gas content and evaluating potential gas hazards in coal seams. The higher sorption hysteresis degree observed in the A1 and A2 seam sections, along with their higher residual gas content, indicates a greater potential for gas accumulation and increased gas-related risks.

In summary, the connection between coal seam gas content and gas sorption capacity is evident. Higher sorption capacities correspond to higher in-situ gas content in the coal seams, and variations in residual gas content can impact gas management strategies and outburst risk. Although Q_3 has a relatively small influence on coal and gas outbursts, it is important to consider its impact on ventilation management and gas emissions during coal extraction. Future

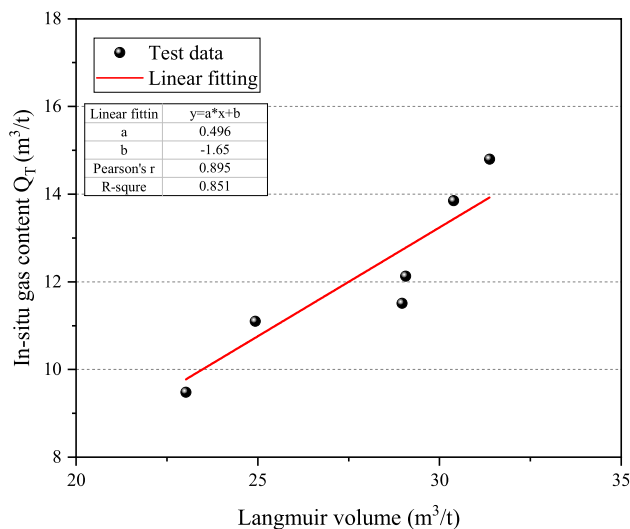


Fig. 12 The relationship between in-situ gas content and gas sorption capacity

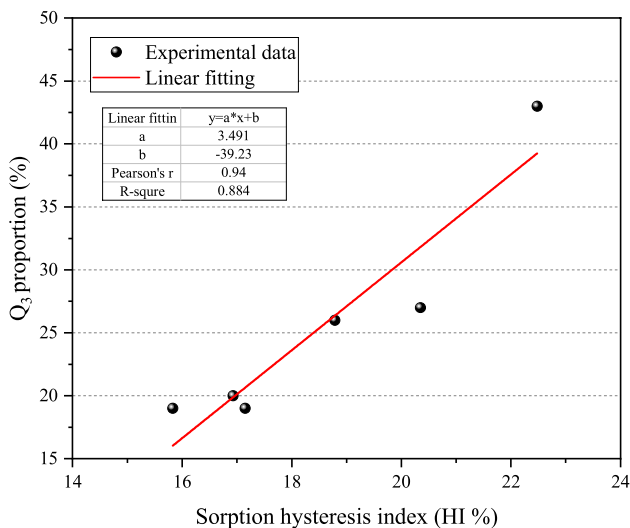


Fig. 13 The relationship between Q_3 proportion and sorption hysteresis

research plans include investigating the relationship between Q_3 and gas emissions, which will contribute to better management and control of the coal mining process. Understanding these relationships is crucial for developing effective gas drainage techniques and ensuring safe mining operations in coal mines with high gas content.

5 Conclusions

- (1) The direct rapid desorption method is effective and reliable for measuring in-situ coal seam gas content and composition, making it suitable for assessing coal seam gas content in the coal mining industry.
- (2) The in-situ gas content varies significantly among the A1, A2, and A3 seam sections. All sections exceeded Level 2 TLV, with the A3 section exhibiting the highest total gas content (Q_T) at 14.80 m³/t, and the A2 seam section having the lowest Q_T at 9.48 m³/t. This variation underscores the need for tailored gas drainage measures in each section.
- (3) Among the three gas components, Q_2 contributed the most to Q_T , with proportions ranging between 55% and 70%. Notably, the working section A3 indicated a higher outburst propensity than the A1 and A2 seam sections, due to its higher Q_1 and Q_2 gas contents and lower coal hardness f value.
- (4) A clear relationship between in-situ gas content and gas sorption capacity was observed, with higher sorption capacities corresponding to higher in-situ gas content. The A3 seam section demonstrated the strongest sorption capacity and lower sorption hysteresis. Conversely, the higher residual gas content (Q_3) and sorption hysteresis in the A1 and A2 seam sections indicated greater difficulty in gas drainage and lower gas drainage efficiency.

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