BİTLİS EREN ÜNİVERSİTESİ
FEN BİLİMLERİ DERGİSİ

ISSN: 2147-3129 / e-ISSN: 2147-3188

Article Type : Research Article
Received : September 26, 2024
Revised : February 27, 2025
Accepted : March 17, 2025
DOI : 10.17798/bitlisfen.1556667

Year : 2025
Volume : 14
Issue : 1
Pages : 129-148

ON THE GAS ADSORPTION & DESORPTION CHARACTERISTICS FOR SOME TURKISH LIGNITES IN TERMS OF COAL QUALITY PARAMETERS

Mehmet Bilen [1*], Sait Kızgut [1]

[1] *Zonguldak Bülent Ecevit University, Department of Mining Engineering, Zonguldak Türkiye*

*** Corresponding Author:** *mehmetubilen@yandex.com*

ABSTRACT

Gas sorption capacity in coals is a well-researched topic, yet the complexity of experimental setups often limits detailed reporting. Understanding coal gas adsorption and seam gas content is essential for predicting and preventing mine gas outbursts and explosions. Therefore, characterizing coal samples based on their adsorption capacities is crucial. This study explores the adsorption of nitrogen, carbon dioxide, and methane across different coals and plots isotherms to assess the impact of gas type, pressure, and coal quality parameters. Results indicate that methane can adsorb even at low pressures in the Dursunbey sample, while higher pressures are required for carbon dioxide and nitrogen. The study also finds a strong correlation between Langmuir volume and ash percentage on an original basis, with nitrogen showing the highest correlation ($R^2 = 0.7$), followed by methane ($R^2 = 0.69$). Carbon dioxide, however, exhibits a weaker correlation ($R^2 = 0.44$).

Keywords: Adsorption-desorption, Coal, Proximate analysis, Lignite, Ash, Moisture, Methane

1 INTRODUCTION

The gases formed in the coals are first dissolved on the surfaces by adsorption and in cases where the gas pressure is high, they dissolve in the water in the structure of the coal and are trapped and accumulate in the pores and cracks. It can be said that adsorption is the most effective mechanism for gas accumulation in coal.

Determining the gas adsorption or gas holding capacity of coal is critical to the safe conduct of mining operations. Gas adsorption to coal directly affects the stability of underground mines, the release of harmful gases and the environmental impact of coal mining operations. By determining the gas adsorption characteristics of coals and understanding the importance of this issue, effective safety measures and sustainable mining practices will be easier and faster. The gases formed in coals are first adsorbed on the surfaces through adsorption. In cases where the gas pressure to which the coal is exposed is high, the gas dissolved in the water in the coal structure is trapped in the pores and cracks in the coal structure. Gases are found in coal beds as both adsorbed and free gases [1]. Gases can also be compressed in pore spaces, condensed as solid or liquid, dissolved in the coal structure or adsorbed on surfaces [2]. Coal contains gases, mostly methane, due to biogenic and thermogenic processes that occur during coalification [3], and as a result, these gases are stored in coal seams [4]. The water solubility of gases decreases with increasing temperature and increases with increasing pressure.

Pores are openings or voids of various shapes and sizes in the matrix of a coal. These voids are either closed and isolated from other pores or connected to other pores [5]. Pores are categorized into 3 groups according to their size [6] [7] [8].

-Micro pores (pores smaller than 2 nm in size in coals with carbon content between 85-91%),

-Transitional (meso) pores (pores between 2-50 nm in size in coals with carbon content between 75-84%),

-Macropores (pores larger than 50 nm in size in coals with carbon content below 75%).

Young coals have high moisture content and porosity. As the carbon content in coal increases, porosity decreases and reaches its lowest value around 85% carbon. The average porosity of lignite is between 27-35%. Coals with high porosity are more easily oxidized and emit more volatiles under temperature. The distribution of pores in a coal matrix, adsorbed gas molecules and the types of cracks in the coal are given in Figure 1 [5] [7].

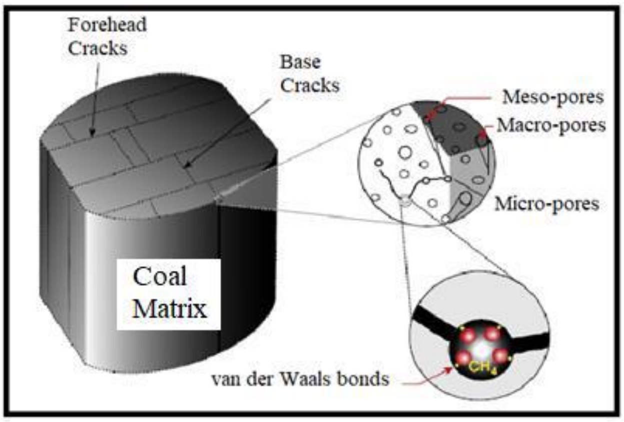


Figure 1. A cross-section of the clastic system and molecular internal structure of coal [7].

Gas adsorption on coal is influenced by the specific properties of the coal. Studies have confirmed that coal condition and coal type, as well as moisture content, ash yield, mineral content, and coal pore distribution have effects on adsorption. According to Perera et al. [9], gas adsorption in coal is determined by various factors, including the properties of the coal seam (such as composition, moisture content, temperature, and pressure) as well as the characteristics of the adsorbed gas. A detailed review of these studies showed that the degree of coal metamorphism [10], pressure [11], temperature [12], pore space, ash, moisture [13] and burial depth [14] greatly affect the coal-CH_4 adsorption process. Adsorption pressure contributes significantly to the gas adsorption process to coal, but the development of the adsorption process varies in the same pressure gradient [15]. In terms of CH_4 adsorption on coal under the influence of temperature, it is generally believed that the adsorption amount gradually decreases with the increase in temperature. Zhang et al. [16] confirmed through variable temperature adsorption experiments that the adsorption capacity of coal is inversely proportional to temperature. Charrière et al. [17] studied the sorption properties of bituminous coals for CO_2 and CH_4 in the temperature range of 283.15-333.15°K and found that increasing temperature shortens the time to reach sorption equilibrium [18]. Han vd. [19] investigated the adsorption properties of CO_2 and CH_4 on coal samples with six different particle sizes ranging from 0.063 to 3 mm and showed that the adsorption capacity of coal samples for single component gases weakens as the particle size increases [18].

Previous investigations, such as those by Florentin [20], have highlighted the dependency of adsorption-desorption characteristics on particle size, gas type, and temperature. In this study, proximate analyses and adsorption-desorption experiments were conducted on lignite samples to evaluate their gas retention properties. Langmuir isotherms and parameters were determined for CO_2, CH_4, and N_2, and their relationships with coal quality parameters were analyzed to assess implications for methane recovery, coalbed methane extraction, and CO_2 sequestration.

2 MATERIAL AND METHOD

In the experimental studies, coal samples were collected from eight different enterprises in Türkiye, namely Saray, Dursunbey, Milas-Ekizköy, Yatağan, Çayırhan, Ilgın, Ermenek, and Gürmin-Merzifon, the locations of which are presented in Figure 2. These samples were subjected to detailed analysis to assess their properties. In terms of sample preparation, collected samples were crushed and screened to have samples under the sieve size of 18 mm, i.e. -18 mm. In order to be better clear in this context, samples analyzed in terms of the adsorption desorption experiments have %100 undersize fraction of 18 mm. In addition, samples have not been objected to any dehumidification process, i.e. they are not oven nor air dried. They are the run of mine samples from the mines collected from each location as mentioned in Figure 2.

Figure 2. Geolocation map showing the regions of the samples used in the study.

2.1 Proximate Analyzes

Proximate analyses of the coal samples were meticulously carried out following the guidelines of the relevant standards. These analyses included moisture content determination (ASTM D3173), ash content measurement (ASTM D3174), volatile matter determination (ASTM D3175), calculation of fixed carbon content, total sulfur content analysis (ASTM D3177), and calorific value assessment (ASTM D5865). Each parameter was evaluated with precision to ensure accurate characterization of the coal samples' physical and chemical properties, providing a comprehensive understanding of their quality and usability.

2.2 Adsorption and Desorption Experiments

Adsorption and desorption experiments were carried out in the schematic experimental setup given in Figure 3 (previously described in the study of Bilen [21] and Bilen and Kizgut [22].

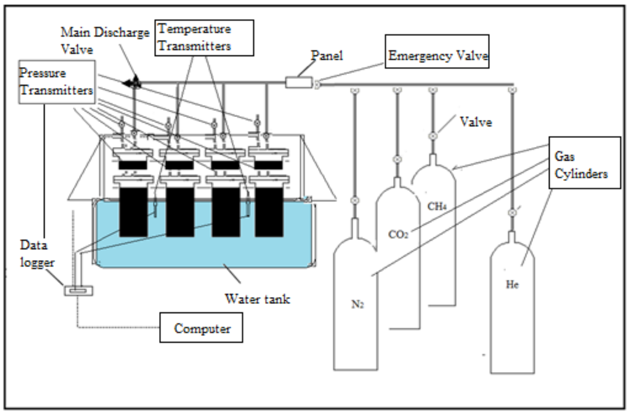
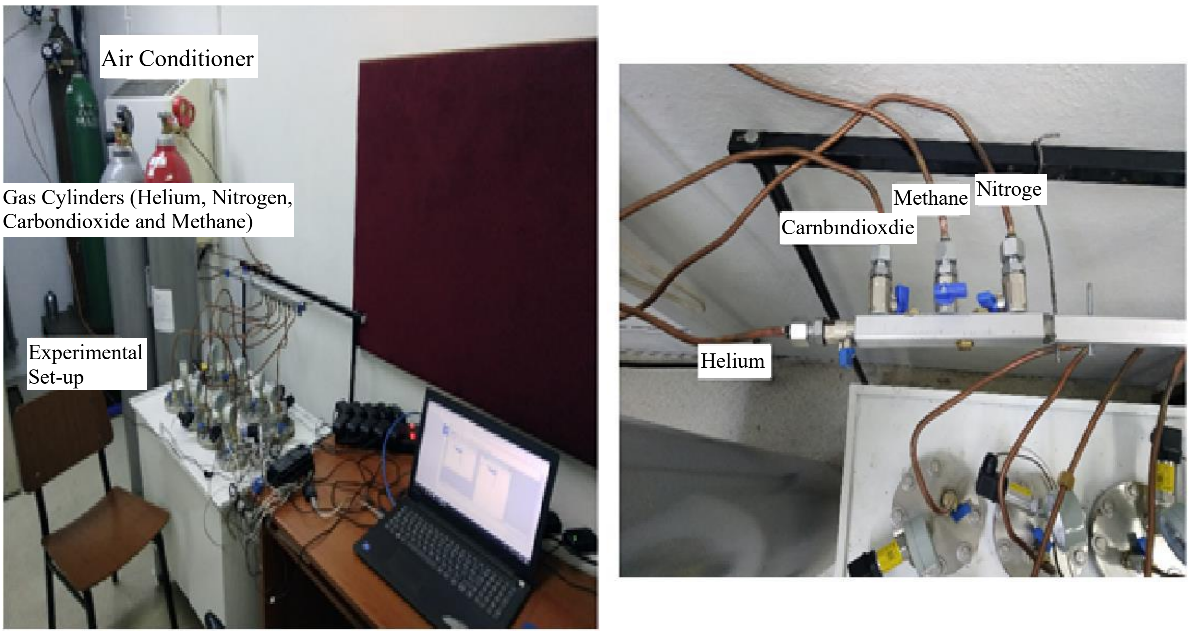


Figure 3. Schematized experimental set-up.

The temperature effect in the adsorption process is quite high, so two temperature sensors (Pt100) embedded in the water bath are supplied and connected to the analog converter. A visual of the laboratory where the adsorption and desorption experiments were carried out is presented in Figure 4.



a) **b)**

Figure 4. A visual of the laboratory where adsorption & desorption experiments were performed, (a) complete experimental set-up, (b) each gas connection and valves.

The adsorption-desorption experiments were conducted under controlled laboratory conditions, with temperature fluctuations maintained within ±0.5°C. Humidity was also monitored and controlled to prevent any unintended variations in coal moisture content. The calibration of the pressure sensors and gas flow meters was performed using standard calibration gases, ensuring accuracy in gas adsorption measurements.

The selection of a -18 mm sample size was based on industry-standard procedures for adsorption-desorption studies, ensuring uniformity in particle size distribution while preventing excessive fragmentation, which could alter surface area and pore structure. The constant temperature of 20°C was chosen to maintain consistency with previous studies and to reflect typical underground coal mine conditions where adsorption occurs.

3 RESULTS AND DISCUSSION

Proximate analysis results of lignite samples are given in Table 1 and Table 2. The experimentally obtained CH_4, CO_2 and N_2 gas adsorption & desorption graphs of the studied coal samples are given in Figure 5 - Figure 12.

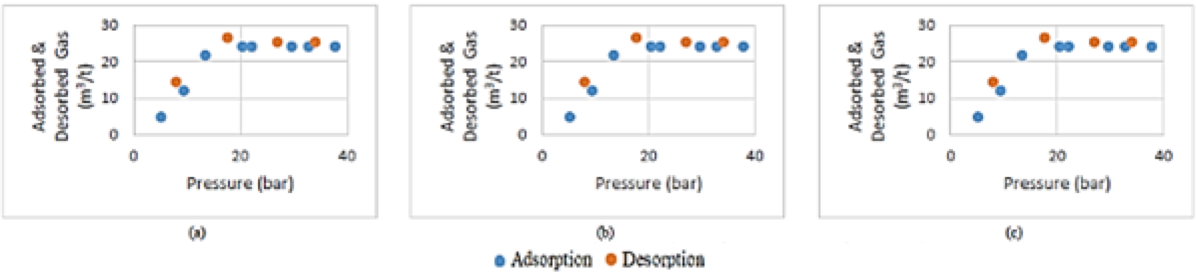


Figure 5. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Çayırhan sample.

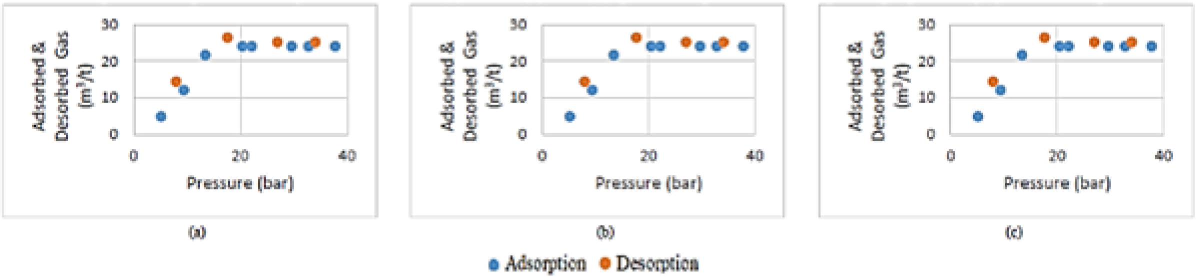
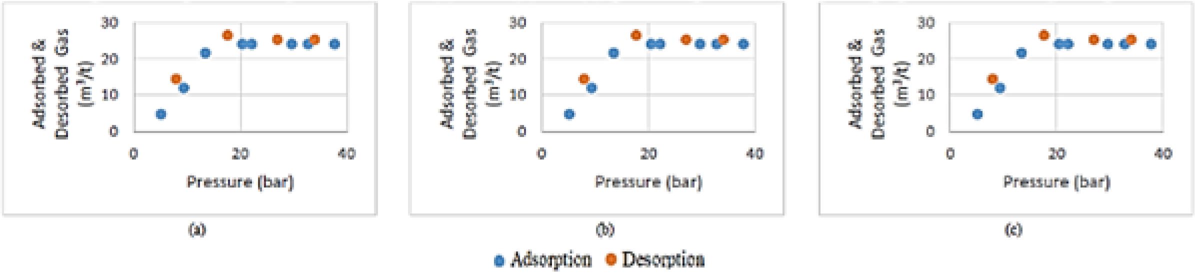
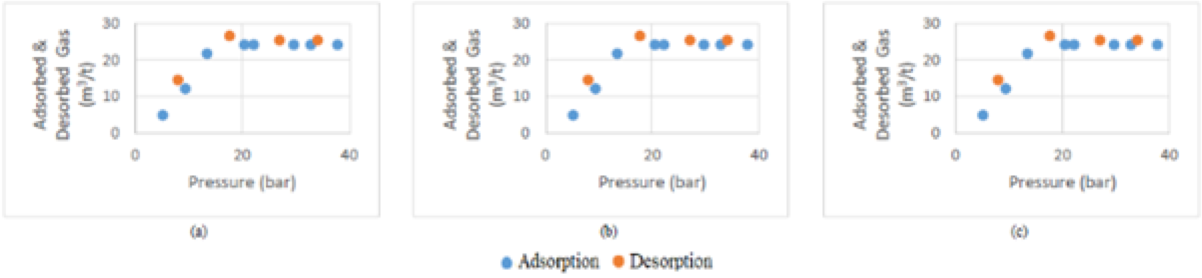


Figure 6. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Dursunbey sample.



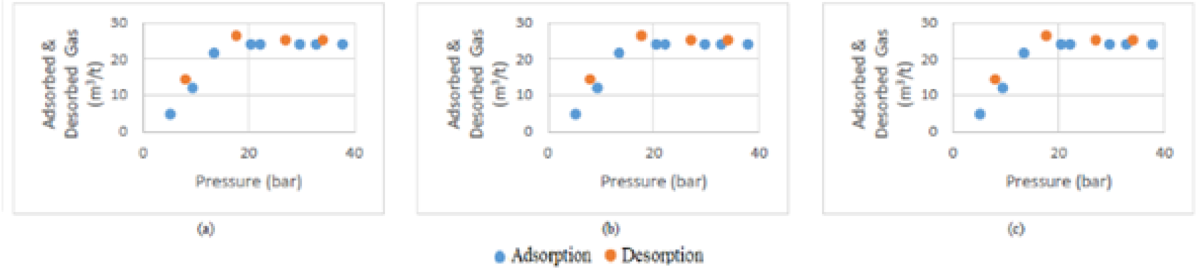
(a) (b) (c)

Figure 7. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Ermenek sample.



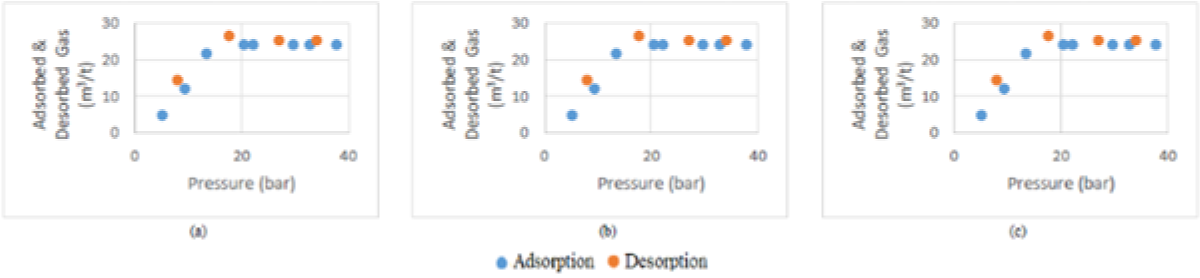
(a) (b) (c)

Figure 8. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Gürmin-Merzifon sample.



(a) (b) (c)

Figure 9. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Ilgın sample.



(a) (b) (c)

Figure 10. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Milas Ekizköy sample.

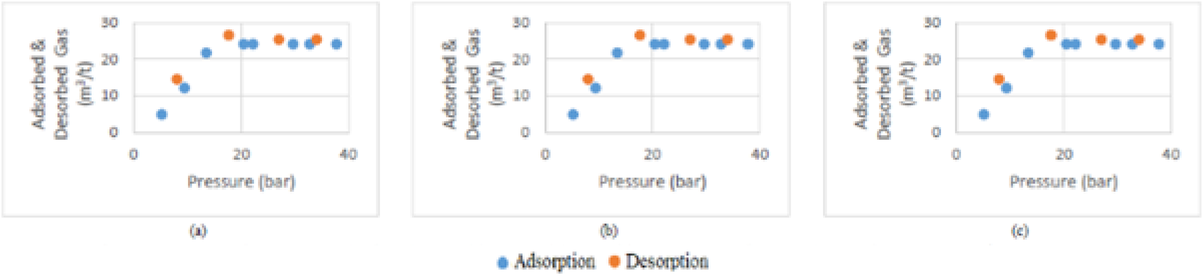


Figure 11. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Saray sample.

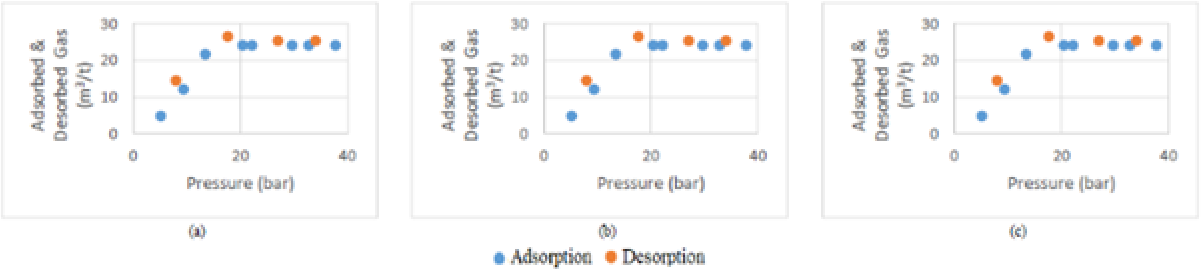


Figure 12. Experimentally obtained a) CO_2 b) CH_4, c) N_2 gas adsorption & desorption graphs of Yatağan sample.

Table 1. Proximate analysis results of the Saray, Dursunbey, Milas-Ekizköy and Yatağan coded lignite samples.

Analysis	**Saray**		**Dursunbey**		**Milas-Ekizköy**		**Yatağan**	
	Original Basis	**Dry Basis**	**Original Basis**	**Dry Basis**	**Original Basis**	**Dry Basis**	**Original Basis**	**Dry Basis**
Total Moisture (%)	43.52	-	8.76	-	30.92	-	26.32	-
Ash (%)	8.21	14.53	22.68	24.86	9.03	13.07	11.77	15.97
Volatile Matter (%)	27.09	47.96	33.02	36.19	34.89	50.51	38.78	52.63
Fixed Carbon (%)	21.19	37.51	35.54	38.95	25.16	36.42	23.14	31.40
Total Sulfur (%)	2.26	4.01	5.47	6.00	3.18	4.60	2.58	3.50
Upper Calorific Value (kcal/kg)	2936	5198	4731	5185	3614	5231	3657	4963
Lower Calorific Value (kcal/kg)	2801	4960	4551	4988	3438	4978	3466	4705

Table 2. Proximate analysis results of the lignite samples coded Çayırhan, Ilgın, Ermenek and Gürmin-Merzifon.

Analysis	**Çayırhan**		**Ilgın**		**Ermenek**		**Gürmin-Merzifon**	
	Original Basis	**Dry Basis**	**Original Basis**	**Dry Basis**	**Original Basis**	**Dry Basis**	**Original Basis**	**Dry Basis**
Total Moisture (%)	26.74	-	38.32	-	16.32	-	2.14	-
Ash (%)	19.52	26.64	23.91	38.77	22.07	26.37	44.06	45.02
Volatile Matter (%)	28.29	38.62	30.06	48.73	33.04	39.48	28.29	28.91
Fixed Carbon (%)	28.38	38.74	7.71	12.50	28.58	34.15	25.51	26.07
Total Sulfur (%)	3.41	4.66	3.48	5.65	3.86	4.61	2.65	2.71
Upper Calorific Value (kcal/kg)	3601	4915	2024	3282	3867	4621	3521	3598
Lower Calorific Value (kcal/kg)	3449	4708	1894	3071	3703	3703	3361	3435

3.1 Langmuir Isotherms and Langmuir Parameters

In this section, Langmuir isotherms were drawn on a coal sample using Equation 1 and Langmuir parameters were found. For this purpose, data obtained from adsorption experiments were used. Langmuir curves were not drawn due to the low number of pressure stages (4 pressure values, 8, 16, 24, 32 bar) for the desorption process. According to this equation, a linear line is obtained if P/V is plotted against P. The slope of the line gives 1/Vm and the point where it intersects the ordinate gives 1/(bVm).

$$\frac{P}{V} = \frac{P_L}{V_L} + \frac{P}{V_L} \tag{1}$$

where

P: Pressure , V: Volume , PL: Langmuir Pressure, VL: Langmuir Volume

In the context of Langmuir isotherms:

• Vm: This represents the maximum adsorption capacity of the material, which is the theoretical volume of gas that the coal sample can adsorb under ideal conditions when the adsorption sites are fully saturated. It is often referred to as the Langmuir volume VL in studies.

- bVm: This term combines the Langmuir volume (Vm) with the Langmuir affinity constant (b), which describes the strength of the interaction between the gas molecules and the adsorption sites on the coal surface. The parameter bbb is inversely proportional to the Langmuir pressure (PL) and is a measure of how easily the gas is adsorbed onto the coal. The term bVm thus reflects the product of the maximum adsorption capacity and the affinity constant, contributing to the adsorption equilibrium behavior. As an example, Langmuir linear curve of Çayırhan sample for nitrogen gas is given in Figure 13.

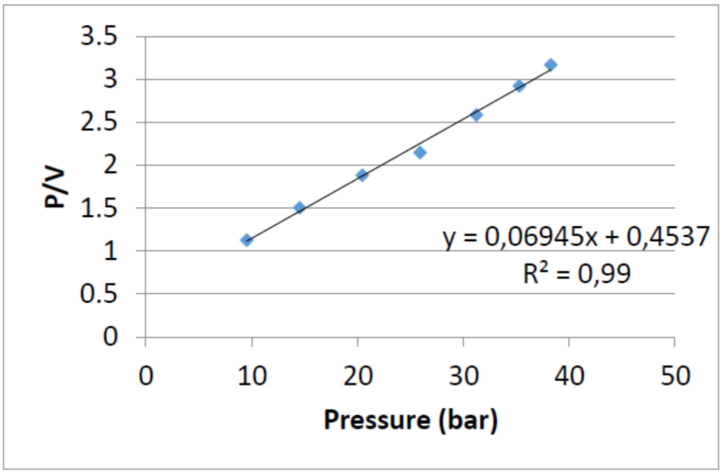


Figure 13. Çayırhan Example Langmuir Linear Curve (Nitrogen).

According to Figure 13, the slope (1/Vm) was found to be 0.0695 and the point intersecting the ordinate (1/bVm) was found to be 0.4537. Accordingly, the 1/b value was found as 6.534, while the b value was determined as 0.153. Accordingly, if 1/bVm is considered as PL/VL, and 1/Vm is considered as 1/VL, PL and VL are easily found. For the Çayırhan sample, the PL value was 6.53 bar and the VL value was 14.4 m^3/t. Similarly, Langmuir parameters of nitrogen, carbon dioxide and methane gases of studied lignite samples were found and tabulated (Table 3).

Table 3. Langmuir Parameters, P_L and V_L.

Samples	**Nitrogen**		**Carbondioxide**		**Methane**	
	P_L (bar)	**V_L (m^3/t)**	**P_L (bar)**	**V_L (m^3/t)**	**P_L (bar)**	**V_L (m^3/t)**
Çayırhan	6.53	14.40	9.21	31.47	8.76	21.48
Dursunbey	10.32	15.79	16.08	38.89	5.53	19.90
Ermenek	1.12	12.14	3.81	27.89	3.61	19.56
Gürmin-Merzifon	3.73	7.72	3.15	17.18	6.83	13.52
Ilgın	1.23	11.89	5.79	30.59	9.40	22.25
Milas-Ekizköy	2.86	14.39	4.81	28.96	4.14	20.88
Saray	4.21	16.02	11.54	38.54	16.42	27.17
Yatağan	2.80	13.53	4.45	28.53	6.34	20.73

When the Langmuir parameters obtained for nitrogen gas were examined, it was determined that the VL and PL values of the Dursunbey sample were the highest among all samples. This is also true for carbon dioxide gas. However, when Langmuir parameters of methane gas are examined, it is seen that the VL value of the Dursunbey sample is not the highest among the samples, while the Saray sample has the highest PL value and the Ilgın sample has the highest VL value. With a maximum adsorbing amount of approximately 20 m^3/t (VL for methane gas), the pores of the Dursunbey sample with a volume of approximately 10 m3 per ton are filled with methane gas at 5.5 bar levels. This value is the lowest among the methane gas PL values after Ermenek and Milas Ekizköy samples. These values can be explained by the methane gas adsorption susceptibility of the samples (methane gas affinity). When the petrographical analysis results are examined, the vitrinite percentages of Dursunbey, Ermenek and Milas Ekizköy samples are 78% and above (Dursunbey 85%, Ermenek 78% and Milas Ekizköy 86%). Dursunbey, one of the examples, has come to the fore in recent years in our country as a place where methane gas-related accidents have occurred. The high methane adsorption capacity of this sample and the low PL (pressure equivalent to half the Langmuir volume) value, which is one of the Langmuir parameters, and the difference in PL and VL values for a single methane gas compared to other gases necessitate a separate evaluation of the Dursunbey sample regarding methane gas. The differences in the coal matrix (pore structure) of the aforementioned Dursunbey sample are also suitable for the methane gas adsorption process. It is thought that the coal matrix and the changes in the coal matrix by adsorption (swelling in the coal matrix) are effective in this process. Pillalamarry et al. [23] stated that they saw a negative correlation between diffusion coefficients and pressures at pressure values below 35 bar. This shows that the methane moves freely in the coal matrix with the pressure drop and the diffusion coefficient is high at low pressures. For the Dursunbey sample, the low methane gas PL value compared to the high nitrogen and carbon dioxide gas PL values shows that the diffusion coefficient is higher for this sample at low pressures. It can be said that for Ermenek coals with the lowest PL value (for methane gas), the diffusion coefficient of methane gas is high at low pressures. In our country, there have been accidents related to methane gas in the coals of the Ermenek basin in the past years, resulting in loss of life.

When the adsorption process and Langmuir parameters were examined carefully, different capacities were determined depending on the structural differences of the coals and the gas type, and different Langmuir pressure and volume values were determined as parameters. However, the point to be noted here is that the maximum amount of methane gas adsorption of lignite samples varies between 13 and 23 m^3 per ton. This value was determined as the lowest in Gürmin Merzifon sample (13.52 m^3/t) and the highest in Ilgın sample (22.25 m^3/t). However, VL values alone are not sufficient for the evaluation of the methane gas adsorption of the samples. Samples with both high VL values and low PL values can be considered as examples that may cause problems in terms of methane gas. For example, Dursunbey Ermenek and Milas Milas– Ekizköy samples stand out in this sense as both their Langmuir pressures are low and their Langmuir volumes are around 20 m^3/t. Among the samples, it was determined that Saray sample had the highest PL and VL values in terms of methane gas. Although this indicates that methane gas is adsorbed at high pressures, the high Langmuir volume indicates that the Saray sample may be the subject of alternative studies such as underground coal gasification and obtaining methane from the coal bed, as well as traditional coal mining. When evaluated from this point of view, the replacement of carbon dioxide and methane seems possible for the Saray example compared to methane gas (low carbon dioxide gas PL value).

Gürmin Merzifon sample (VL=7.7 m^3/t) was determined as having the lowest nitrogen gas adsorption (in terms of VL value). The PL value of Gürmin Merzifon sample was determined as 3.7 bar. In terms of PL value, the lowest value was determined in the Ermenek sample. The PL and VL values for nitrogen gas in this example are 1.12 bar and 12.14 m^3/t, respectively. When nitrogen gas is considered, the Dursunbey sample has the highest PL value (10.32 bar), while the Saray sample has the highest VL (16.02 m^3/t). Considering the nitrogen adsorption values, the porosity of the samples can be commented on. Since the molecular diameter of nitrogen gas is 1.55 A°, when the adsorbed amount (on mole basis) is considered, correlations can be made between the porosity and the surface areas of the samples. It is understood that the surface areas of the Saray and Dursunbey samples, which have the highest Langmuir volume, are larger than the other samples. Likewise, it can be said that the structures of Dursunbey and Saray examples, which have more surface areas, are more porous than the other examples. Both surface area and porosity of Gürmin Merzifon sample are less than other samples.

The Saray sample exhibits the highest methane Langmuir parameters (PL = 16.42 bar and VL = 27.17 m^3/t), along with significant nitrogen and carbon dioxide adsorption capacities (PL = 4.21 bar and VL = 16.02 m^3/t for nitrogen; PL = 11.54 bar and VL = 38.54 m^3/t for carbon dioxide), correlating with its high total moisture content (43.52%). In contrast, Gürmin-Merzifon has the lowest moisture content (2.14%), accompanied by the lowest methane adsorption capacity (PL = 6.83 bar and VL = 13.52 m^3/t) and relatively low values for nitrogen (PL = 3.73 bar and VL = 7.72 m^3/t) and carbon dioxide (PL = 3.15 bar and VL = 17.18 m^3/t). Meanwhile, Dursunbey stands out with the highest carbon dioxide adsorption parameters (PL = 16.08 bar and VL = 38.89 m^3/t) and also shows notable adsorption for nitrogen (PL = 10.32 bar and VL = 15.79 m^3/t) and methane (PL = 5.53 bar and VL = 19.90 m^3/t), despite having the lowest moisture content among the samples (8.76%). On the other hand, Ilgın shows strong methane adsorption (PL = 9.40 bar and VL = 22.25 m^3/t), while its nitrogen and carbon dioxide adsorption capacities are moderate (PL = 1.23 bar and VL = 11.89 m^3/t for nitrogen; PL = 5.79 bar and VL = 30.59 m^3/t for carbon dioxide). These results highlight the varying adsorption behaviors and moisture contents of the lignite samples.

When the parameters obtained for carbon dioxide gas adsorption were evaluated, the highest PL and VL values were determined for the Dursunbey sample (PL=16.1 bar and VL =38.9 m^3/t). Similarly, the lowest PL and VL values for carbon dioxide gas were determined in the Gürmin Merzifon sample (PL=3.2 bar and VL =17.2 m^3/t). Information can be obtained for applications such as carbon dioxide gas adsorption capacities and carbon dioxide storage. In this context, the example of Gurmin Merzifon is the example where carbon dioxide can be stored at the lowest pressures. Similarly, Dursunbey has the highest carbon dioxide adsorption capacity. The Dursunbey example is considered as an example that has the potential to be evaluated in terms of underground coal gasification, obtaining methane from coal beds and carbon dioxide storage.

The findings related to the Dursunbey sample indicate a significant risk associated with methane desorption under pressure drops. The high methane adsorption capacity (VL = 19.90 m^3/t) and the relatively low Langmuir pressure (PL = 5.53 bar) suggest that methane is readily stored within the coal matrix but can also be rapidly released when pressure decreases. This characteristic increases the likelihood of sudden gas emissions, which is a critical hazard in underground coal mining. The history of methane-related incidents in the Dursunbey region aligns with these findings, emphasizing the necessity for proactive gas drainage and monitoring systems to mitigate the risk of outbursts. Additionally, the differences in Langmuir parameters among the studied samples highlight the role of coal matrix composition and porosity in governing methane desorption behavior, reinforcing the need for site-specific risk assessments in mining operations.

3.2 Interrelationships Between Langmuir Parameters and Coal Quality Parameters

In this section, the coal quality parameters and the Langmuir parameters obtained will be compared and the test results will be correlated.

In addition, possible relationships between the results of the proximate analysis of coal samples and Langmuir parameters were similarly investigated. The relationships between the results of the proximate analysis of the coal samples and the Langmuir parameters gave more significant (with higher correlation coefficient) results than the relationships between the analysis results on the dry basis and these parameters. In all data, coal ash and fixed carbon content are given according to the original basis. In this context, the most significant results were obtained for each sample and gas between Langmuir volume and ash. These relationships between Langmuir volumes and ash are given in Figure 14, Figure 15 and Figure 16.

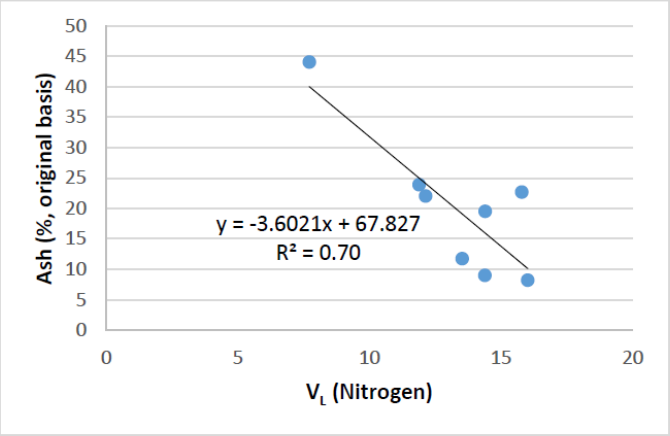


Figure 14. Relationship between Langmuir parameter V_L (Nitrogen) and Ash (%, on original basis).

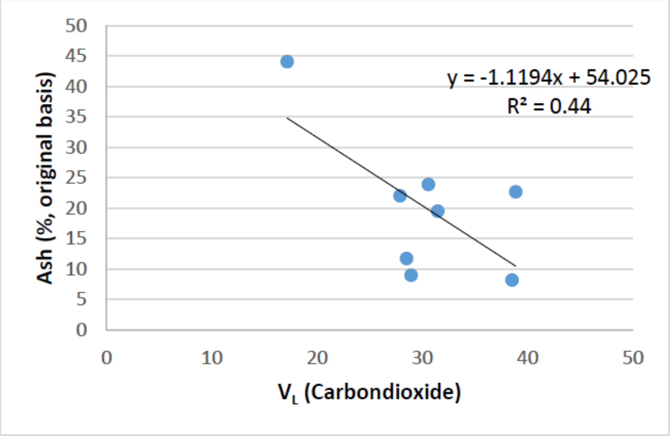


Figure 15. Relationship between Langmuir parameter V_L (Carbon Dioxide) and Ash (%, on original basis).

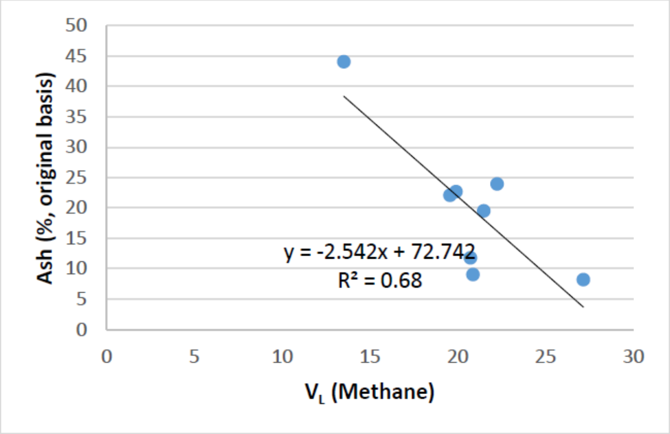


Figure 16. Relationship between Langmuir parameter V_L (Methane) and Ash (%, on original basis).

According to Figure 14-Figure 16, it was observed that Langmuir volumes increased as the ash percentages of the samples decreased. In particular, the relationship between the Langmuir volume results of nitrogen gas and ash has the highest correlation coefficient (R^2=0.7) observed in this context. Similarly, a similar correlation (R^2=0.69) was observed between Langmuir volumes of methane gas and ash. Another of these relationships, the Langmuir volume of carbon dioxide gas, did not show a significant relationship as expected, and a correlation of 0.44 (R^2=0.44) was observed between ash and Langmuir volume (VL).

Similarly, Langmuir pressure and proximate analysis results were compared, and here the relations of nitrogen gas with fixed carbon carbon dioxide and methane gas with total sulfur were relatively more significant (higher correlation coefficient) than other analysis results. has given. These aforementioned relationships are presented in Figure 17, Figure 18 and Figure 19, respectively.

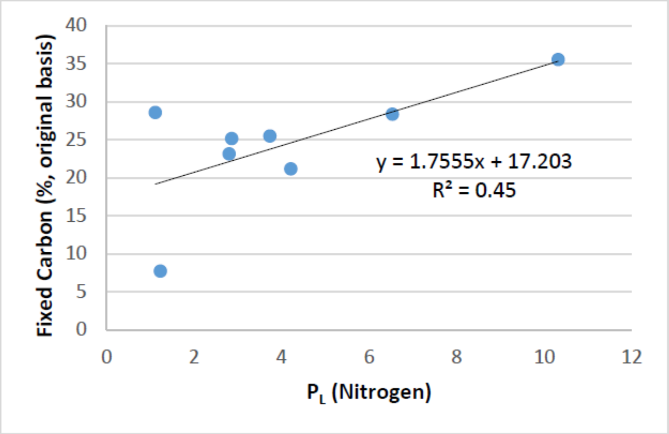


Figure 17. Relationship between Langmuir parameter PL (Nitrogen) and Fixed Carbon (%, on original basis).

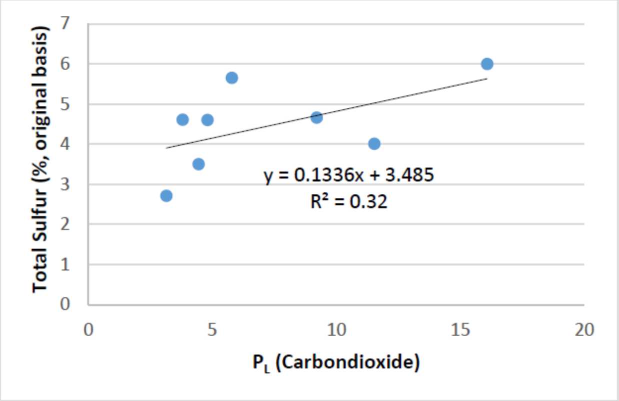


Figure 18. Relationship between Langmuir parameter PL (Carbon Dioxide) and Total Sulfur (%, on original basis).

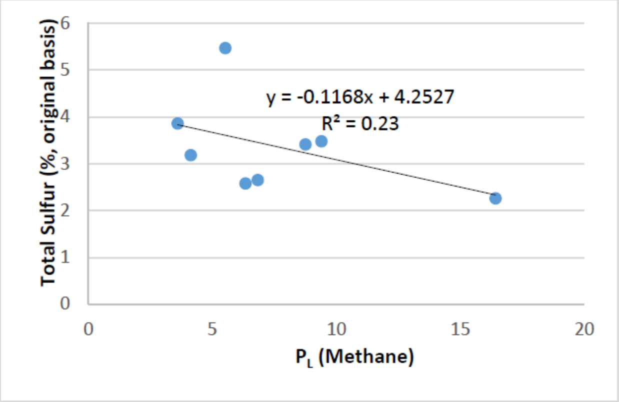


Figure 19. Relationship between Langmuir parameter PL (Methane) and Total Sulfur (%, on original basis).

In this context (Figure 17-Figure 19), the best relationship was observed between nitrogen gas Langmuir pressure and fixed carbon. An increase in Langmuir pressure (nitrogen) was observed as the fixed carbon values increased in the samples examined. The results obtained in this context, Duda et al. [24], a U-shaped relationship with fixed carbon has been evaluated by many researchers [25] [26] [27]. Therefore, it has been seen in the relatively results that the nonlinear (Figure 17) relationship with the carbon content is consistent with the literature and that the Langmuir pressure first decreases and then increases with the increase of the carbon content. When the gas adsorption amounts to the coals are evaluated (m^3/t), it has been observed that carbon dioxide gas has the highest, nitrogen gas the lowest and methane has values between them. In addition, the adsorption amounts of methane gas at different temperatures were compared in the literature [9] [28], but since the temperature was kept constant at 20 °C (293 °K) in this study, a comparison could not be made with the result stated in the literature. However, there was no need for experimental evidence in this sense, since it would not be difficult to predict that the amount of adsorption will decrease with (increasing) temperature and that the gases attached to the pores will be released to the environment more with temperature. In the literature, ash percentages and carbon dioxide adsorbed volumes were compared and it was observed that increasing ash amount decreased the adsorbed amount of carbon dioxide gas. A similar relationship (Langmuir volumes and ash percentages) is given in Figure 14, Figure 15 and Figure 16. According to these relations given, Langmuir volumes (the volume of gas to be adsorbed at maximum pressure) were found to be high when ash was low and low when high. The Langmuir volume values of the coal samples with high ash content were determined as low, and the result was obtained which is in line with the literature. Again, a similar study was conducted on South Wales coals belonging to methane gas adsorption [29] [30]. In literature it was shown that high adsorbed volume (methane) when ash is 1.99% and low adsorbed volume (methane) when ash is 90.27%. In our samples, the maximum volumes of methane gas (VL) to be adsorbed significantly decrease with the increase in the amount of ash. This obtained relationship (Figure 16) has a correlation coefficient of 0.68 (R^2=0.68) and is considered to be significant when compared with the literature.

The presence or absence of these relationships will be decided more clearly by increasing the number of samples. However, differing associations and varying correlation coefficients in different gases will make it possible to make inferences about which parameters are effective in the gas adsorption desorption process to these coals.

4 CONCLUSION AND SUGGESTIONS

This study provides valuable insights into the adsorption and desorption characteristics of nitrogen, carbon dioxide, and methane in lignite samples, aligning with findings in the existing literature. The results indicate that carbon dioxide exhibits the highest adsorption and desorption capacity at all pressure levels, while methane surpasses nitrogen in adsorption capacity, except at low pressures. These findings emphasize the importance of understanding gas behavior in coal seams, particularly in relation to safety risks and resource utilization.

From an industrial perspective, the characterization of Langmuir parameters in the studied lignite samples offers practical implications for both methane management and carbon dioxide sequestration. The potential for methane recovery from coal seams presents an opportunity to enhance energy production while simultaneously reducing greenhouse gas emissions. At the same time, identifying coal seams with high CO_2 adsorption capacity supports sustainable carbon storage initiatives. These insights could inform industry stakeholders, including mining companies and regulatory bodies, in optimizing gas drainage strategies and developing more effective safety protocols in underground mining operations.

To enhance workplace safety, mining companies should integrate site-specific gas monitoring systems that account for variations in methane desorption behavior, particularly in regions like Dursunbey, where low Langmuir pressure values indicate a higher risk of sudden methane release. Proactive gas drainage, ventilation improvements, and continuous monitoring should be prioritized to mitigate explosion hazards. Additionally, policymakers should consider the potential of lignite-based carbon sequestration projects in climate action plans, leveraging coal seams for long-term CO_2 storage.

For researchers, future studies should focus on refining the predictive modeling of gas adsorption and desorption under varying geological conditions. Expanding experimental datasets, incorporating petrographic analyses, and conducting field-scale trials will further validate the applicability of these findings in real-world mining environments. Moreover, interdisciplinary collaborations between mining engineers, geologists, and environmental scientists will be crucial in translating laboratory-scale insights into actionable strategies for sustainable resource management.

Ultimately, this study provides a foundation for both improving safety in coal mining and advancing cleaner energy initiatives. By integrating these findings into industrial practices and policy frameworks, the coal sector can move toward more efficient, sustainable, and safer resource extraction and utilization.

Acknowledgements

Authors of this study would like to thank to BAP Coordinatorship of Zonguldak Bülent Ecevit University for their support under the project “Investigation of Gas Adsorption and Desorption Properties of Some Coals” with project number “2018-98150330-02”.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

Contributions of the Authors

Mehmet Bilen: Writing - review & editing, Formal analysis, Investigation, Data curation

Sait Kizgut: Conceptualization, Methodology, Validation.

REFERENCES

[1]. L. Qi, X. Tang, Z. Wang and X. Peng, "Pore characterization of different types of coal from coal and gas outburst disaster sites using low temperature nitrogen adsorption approach". *International Journal of Mining Science and Technology*, 2017, 27(2), 371-377. http://dx.doi.org/10.1016/j.ijmst.2017.01.005

[2]. P.J. Crosdale, B.B. Beamish and M. Valix, "Coalbed methane sorption related to coal composition". *International Journal of Coal Geology,* 1998, 35(1-4), 147-158. https://doi.org/10.1016/S0166-5162(97)00015-3

[3]. R. Susilawati, J.S. Esterle, S.D. Golding and T.E. Mares, "Microbial methane potential for the South Sumatra Basin coal: Formation water screening and coal substrate bioavailability". *Energy Procedia*, 2015, 65, 282-291. https://doi.org/10.1016/j.egypro.2015.01.051

[4]. S. Harpalani and S. Ouyang, "A new laboratory technique to estimate gas diffusion characteristics of coal". 1999, U.S. Mine Ventilation Symposium. 4.

[5]. R.M. Flores, "Coal and coalbed gas: Fueling the future". First Edition. ISBN: 9780123969729, Elsevier, USA. 2014.

[6]. M. M. Dubinin, "The potential theory of adsorption of gas". *Chemical Reviews*, 1969, 60(13), 235-241.

[7]. O. Esen, "Investigation of Gas Content, Gas Adsorption Capacity and Gas Flow Properties of the Coal Seams in the Soma Coal Basin, Turkey. Ph.D. Dissertation. İstanbul Technical University, Graduate school of natural and applied science, 2021.

[8]. R.A. Schraufnagel and P.S. Schafer, "The Success of Coalbed Methane". Edited By: J. L. Saulsberry, P.S. Schafer, and R.A. Schraufnagel, A Guide To Coalbed Methane Reservoir Engineering (s. 343). 1996, Chicago, Illinois, U.S.A. Printed in the U.S.A. GRI: Gas Research Institute.

[9]. M.S.A. Perera, P.G. Ranjith, S.K. Choi, D. Airey and P. Weniger, "Estimation of Gas Adsorption Capacity in Coal: A review and an analytical study". *International Journal of Coal Preparation and Utilization.* 2012, 32(1), 25-55. https://doi.org/10.1080/19392699.2011.614298

[10]. A.S. Ranathunga, M.S.A. Perera, P.G. Ranjith, T.D. Rathnaweera and X.G. Zhang, "Effect of coal rank on CO_2 adsorption induced coal matrix swelling with different CO_2 properties and reservoir depths". *Energy & Fuel*s, 2017, 31(5), 5297-5305. https://doi.org/10.1021/acs.energyfuels.6b03321

[11]. B.V. Krooss, F. Van Bergen, Y. Gensterblum, N. Siemons, H.J.M. Pagnier and P. David, "High-pressure methane and carbon dioxide adsorption on dry and moisture-equilibrated Pennsylvanian coals". *International Journal of Coal Geology*, 2002, 51(2), 69-92. https://doi.org/10.1016/S0166-5162(02)00078-2

[12]. T.F. Rexer, M.J. Benham, A.C. Aplin and K.M. Thomas, "Methane adsorption on shale under simulated geological temperature and pressure conditions". *Energy & Fuels*, 2013, 27(6), 3099-3109. https://doi.org/10.1021/ef400381v

[13]. C.R. Clarkson, and R.M. Bustin, “Binary gas adsorption/desorption isotherms: effect of moisture and coal composition upon carbon dioxide selectivity over methane”. *International Journal of Coal Geology*, 2000, 42(4), 241-271. https://doi.org/10.1016/S0166-5162(99)00032-4

[14]. X. Liu, D. Song, X. He, Z. Wang, M. Zeng, and K. Deng, "Nanopore structure of deep-burial coals explored by AFM." *Fuel*, 2019, 246, 9-17. https://doi.org/10.1016/j.fuel.2019.02.090

[15]. L. Xu, Z. Xinghua and C. Xiuzhi, “Study on adsorption capacity of coal based on low-temperature nitrogen absorption and high-pressure adsorption”. *Safety in Coal Mines*, 2009, 40(5), 9-11.

[16]. Z.G. Zhang, D. Zhao, C.H. Zhang, Y. Chen and C. Tang, “Isothermal adsorption/desorption characteristics of soft coal at different temperatures”. J Liaoning Tech University, 2021, 40, 510-7. https://doi.org/10.11956/j.%20issn.1008-0562.2021.06.005

[17]. D. Charrière, Z. Pokryszka, and P. Behra, “Effect of pressure and temperature on diffusion of CO_2 and CH_4 into coal from the Lorraine basin (France)”. *International Journal of Coal Geology*, 2010, 81(4), 373-380. https://doi.org/10.1016/j.coal.2009.03.007

[18]. J. Jia, H. Song and P. Jia, “Molecular Simulation of Methane Adsorption Properties of Coal Samples with Different Coal Rank Superposition States”. *ACS Omega*, 2023, 8(3), 3461-3469. https://doi.org/10.1021/acsomega.2c07471.

[19]. F. Han, A. Busch, B.M. Krooss, Z. Liu and J. Yang “CH_4 and CO_2 sorption isotherms and kinetics for different size fractions of two coals”. *Fuel*, 2013, 108, 137-142. https://doi.org/10.1016/j.fuel.2011.12.014

[20]. R.M.M. “Florentin Characterisation of the parameters influencing the storage and drainage of gas”. PhD thesis, The University of Wollongong School of Civil, Mining and Environmental Engineering, 2012, 320 s.

[21]. Bilen, M. “Investigation of gas retention and release properties in lignites”. PhD thesis, Zonguldak Bülent Ecevit University). 2019. Retrieved from https://acikbilim.yok.gov.tr/bitstream/handle/20.500.12812/253331/yokAcikBilim_10278664.pdf?isAllowed=y&sequence=-1

[22]. M. Bilen, and S. Kizgut, “Investigation of gas adsorption and desorption characteristics for some Turkish lignites in terms of coal petrographic properties”. *International Journal of Oil, Gas and Coal Technology*, 2023, 34(1), 68-95. https://doi.org/10.1504/IJOGCT.2023.133537

[23]. M. Pillalamarry, S. Harpalani and S. Liu, “Gas diffusion behavior of coal and its impact on production from coalbed methane reservoirs”. *International Journal of Coal Geology*, 2011, 86(4), 342-348. https://doi.org/10.1016/j.coal.2011.03.007

[24]. J.M. Duda, J. Duda, A. Nodzenski and J. Lakatos, “Absorption and Adsorption of Methane and Carbon Dioxide in Hard Coal and Active Carbon”. *Langmuir*, 2000, 16(12), 5458-5466. https://doi.org/10.1021/la991515a

[25]. M. Faiz, A. Saghaf, N. Sherwood and I. Wang, “The influence of petrological properties and burial history on coal seam methane reservoir characterisation, Sydney Basin, Australia”. *International Journal of Coal Geology,* 2007, 70(1-3), 193-208. https://doi.org/10.1016/j.coal.2006.02.012

[26]. P.B. Hirsch, “X-ray scattering from coals. Proceedings of the Royal Society”, London, 1954, 226, 143-169.

[27]. D.H. Moffat and K.E. Weale, “Sorption by coal of methane at high pressures”. *Fuel*, 1955, 34, 449-462.

[28]. R.M. Bustin and C.R. Clarkson, “Geological controls on coal bed methane reservoir capacity and gas content”. *International Journal of Coal Geology*, 1998, 38(1-2), 3-26. https://doi.org/10.1016/S0166-5162(98)00030-5

[29]. G.R.R. Barker-Read and S.A. Radchenko, “The relationshio between the pore structure of coal and gas dynamic behaviour of coal seams”. Mining Science and Technology, 1989, 8, 109-131. https://doi.org/10.1016/S0167-9031(89)90521-5

[30]. M. Tshifhiwa, “Effects of carbon dioxide storage in coal on the physical and chemical properties of coal”. (PhD Thesis). Faculty of Engineering and the Built Environment, University of the Witwatersrand. 2012.