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THE IMPACT OF GEOLOGICAL FACTORS ON THE SORPTION CAPACITY OF GAS AND FAT RANKS OF COAL IN THE KRASNOARMEYSKIY DISTRICT

Bezruchko K.A., Pymonenko L.I., Burchak O.V., Baranovskyi V.I., Chelkan V.V.

Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine

Abstract. At present, based on the research of the conditions and factors of outburst hazard of coal beds, various predicting methods have been developed grounded on contemporary views concerning the nature and mechanism of gas-dynamic phenomena. One of the main factors affecting the outburst hazard of coals is gas saturation, which is determined by the sorption capacity of coals. The sorption properties of coal matter are significantly determined by the degree of coal transformation (metamorphism). Therefore, the analysis of the data obtained for a coal matter of the same rank makes it possible to reveal the role and importance of factors that have formed the parameters of the signals observed by EPR (electron paramagnetic resonance) spectroscopy. These signals define the features of the sorption coal-gas interaction for a particular sample. It is established that the average values of the concentration of paramagnetic centers are (2.29 ± 0.36) and of contingency - (0.476 ± 0.02), and the calculated value of the sorption capacity of coals (24.3 ± 0.29) can be considered basic for gas and fat ranks of coals in the Krasnoarmeyskiy district. Minor deviations from the basic parameters can be caused by various geological and technological factors. Significant deviations of the average values for the sorption capacity of coals can be caused by tectonic processes.

The purpose is to research the impact of geological factors on the sorption properties of gas and fat ranks of coals determined by the EPR method in the mines of the Krasnoarmeyskiy district.

During the research, the following parameters were defined: 1) the integrated intensity of the EPR spectrum - the concentration of paramagnetic centers (N^a) in the matter under research, which characterizes the conjoint impact of external factors on the coal matter, and 2) the contingency coefficient (K^{sc}), i.e. the number and status of the conjugate system in the molecular structure of a matter, which characterizes the transmitting depth of structural transformations (a degree of structuredness) of fossil organics at the nanolevel. As a result, it is found that various factors acting in different directions affect the calculated value of the sorption methane capacity of coals. The average sorption capacity of gas and fat ranks of coals from the Krasnoarmeyskiy district is 24.3 ± 0.29 and mainly depends on the deformation conditions. The average concentrations of paramagnetic centers are (2.29 ± 0.36), and of contingency (0.476 ± 0.02). The calculated value of the sorption capacity of coals (24.3 ± 0.29) can be considered as the base one for the gas and fat ranks of coals in the Krasnoarmeyskiy district. Minor deviations from the basic parameters can be caused by various geological and technological factors. Significant deviations in the average values of the coals sorption capacity can be caused by tectonic processes.

Keywords: coal, sorption properties, EPR spectroscopy, geological factors.

Introduction. An important problem of the coal industry is the degassing of coal beds – a preventive measure to reduce the gas content of mine workings and prevent sudden outbursts of coal and gas during mining operations. Currently, based on the research of the conditions and factors of outburst hazard of coal beds, various predicting methods have been developed. They are grounded on contemporary views about the nature and mechanism of gas-dynamic phenomena and collected in the relevant regulatory document (SOU 10.1.00174088.011-2005), which regulates mining operations in beds prone to gas-dynamic phenomena. One of the main factors affecting the outburst hazard of coals is gas saturation, which is determined by the sorption capacity of coals.

The IGTM of the NASU has developed a method for determining the sorption capacity of coal by EPR spectroscopy [1, 2] using kinetic characteristics in the coal-gas system under changing pressure conditions. The theoretical basis of the method is the representation of a macroparticle of coal matter as a multilevel system formed by microstructural elements. In addition, each microstructural element consists of many

macromolecules and microsorption subspaces, the diameter of which is comparable to the size of a sorbate molecule. In the process of diagenesis and metamorphism, complex macromolecules are formed and disintegrated, including a significant number of micropores and continuity defects. The volume of generated voids, regionally, depends on the conditions of sedimentation and the degree of transformation of coal matter. At each stage of metamorphism, the molecular structure of coals, and hence their supramolecular organization, differ. Therefore, any rearrangement in the structure of macromolecules due to external processes causes the emergence of new defects in the molecular structure - free radicals and ionradicals, the signal from which is recorded by the EPR method. The combination of all acting factors affects the line shape of the EPR spectrum for each coal sample. In the proposed method, the sorption properties of coal matter are by estimated kinetic characteristics of the coal-gas interaction process. The limiting sorption capacity of a matter (Q) is estimated on the basis of content of paramagnetic centers in coal capable to enter into physical (sorption) interaction with gas molecules at increasing pressure.

Based on theoretical assumptions, the EPR spectra reflect both regional (a degree of metamorphism) and local (tectonic dislocation, oxidation, restorability, ash-content) changes that have occurred in coal matter since sedimentation, which affects the sorption capacity of coals. The main factor affecting the sorption properties of coal matter is the coal degree of transformation (metamorphism). Therefore, an analysis of the data obtained for a coal matter of the same rank will reveal the role and significance of the factors that have formed the parameters of the observed signals and determining the features of the sorption coal-gas interaction for a particular sample.

The purpose is to research the impact of geological factors on the sorption properties of gas and fat ranks of coals, having been determined by the EPR method in the mines of the Krasnoarmeyskiy district.

The Krasnoarmeyskiy geological-industrial district is located in the southwestern part of the Donbas, stretched in a northwestern direction for 100 km along the strike, with a strip width of carboniferous rock of 18–20 km.

The tectonic structure of the district is determined by its position within the vast gently monocline of the southwestern wing of the Kalmius-Toretskaya kettle. The main strike of the rocks is northwestern. The dip angles of rocks are from 3º to 15º. Near disturbances, the dip angles increase up to 45º. Low-amplitude folding is only slightly developed. Major disturbances are thrusts of submeridional direction: Samarskiy, Krasnoarmeyskiy, Tsentralnyy, Selidovskiy. Dip angles of faults plane to the east are at angles of 20–40º, and vertical amplitudes are of the order of 150–300 m). Systems of sub-latitudinal and diagonal faults that are genetically connected with thrusts are located in a sub-perpendicular manner to them (thrusts) (amplitude is 10–100 m).

The district consists of Carboniferous deposits, overlapped by younger sediments almost over the entire area. Carboniferous deposits are represented by all suites of the Middle and Upper Carbonic. The industrial coal-bearing capacity of the district is

associated with the deposition of suites C_1^4, C_2^{5-7}.

Methods. Samples were taken at the mines "Krasnolimanskaya" (3 pcs.), "Tsentralnaya" (6 pcs.), G. Dimitrov Mine (1 pc.), A. G. Stakhanov Mine (10 pcs.), "Dobropolskaya" (3 pcs.), "Pioneer" hydro mine (2 pcs.) from coal beds of the Middle Carbonic: k_5, k_8, l_1, l_3, m_3.

When conducting research on the coals sorption capacity according to the developed method, the following spectrum parameters were defined:

- the integral intensity of the EPR spectrum - the concentration of paramagnetic centers (N^a) in the matter under research characterizes the joint impact of external factors on the coal matter;

- the contingency coefficient (K_{sc}) - the number and the state of conjugate systems in the molecular structure of a matter, which characterizes the depth of structural transformations (degree of structuredness) of fossil organics at the nanolevel.

The spectrum parameters were determined on specially prepared samples of coals selected in compliance with the current regulatory documents (GOST 9414.2-93, GOST 9815-75). According to the developed method [1, 2], sorption capacity of coal matter was calculated for all the mines under the research. The obtained data: structural characteristics (N^a, K_{sc}), indicators of the sorption capacity of coals (Q) and the yield of volatile matters (V^{daf}) were analyzed using the methods of mathematical statistics (Table 1).

Results and discussion. Analysis of the obtained results. Table 1 shows the geological and structural characteristics of the research for coal matter by selected samples.

It is established that the average values of K_{sc} for the mines of the district differ slightly, which indicates that the degree of the coals structuredness in the district is practically the same.

In order to check the correspondence with the theoretical curve of the normal distribution, the test for concordance (K_A and K_E) were calculated. They represent the ratio of asymmetry and excess to their standard errors taking into account the sample size (a number of samples):

$$K_A=A/\sigma_A;$$
$$K_E=E/\sigma_E,$$

where A is asymmetry, E is excess, σ_A and σ_E are mean square deviations of asymmetry and excess, respectively, for a given number of samples n.

Asymmetry and excess coefficients K_A and K_E calculated according to tests for concordance are less than three. Therefore, the hypothesis of a normal distribution for N^a and K_{sc} indices can be accepted, which indicates the impact of a number of independent (random) factors on the structural characteristics of the coals under the research.

Statistical analysis of N_a and K_{sc} measurements showed that the standard deviations of the values for each parameter were small (0.84 and 4.8 respectively).

Consequently, each measurement of the value can be considered reliable, and the average values of these parameters (respectively 2.29 ± 0.36 and 47.6 ± 0.2) can be considered basic for a given coal rank (gas and fat) of the researched district.

Table 1 – Geological and structural characteristics of the coal matter at the mines of Krasnoarmeyskiy district.

Mine	Proportionality factor β d/u	Index of a bed	Volatile content V^{daf}, %	The concentration of PMC $N^a \cdot 10^{19}$, g^{-1}	Contingency coefficient K_{sc}, %	Sorbion capacity of coals Q, ml/g
Krasnolimanskaya	0.21	k_5	37.8	2.5	0.44	23.1
		k_5	36.0	2.4	0.46	23.1
Tsentralnaya	0.21	m_3	31.5	3.64	0.46	35.1
		m_3	31.5	3.99	0.46	38.5
		m_3	31.5	3.86	0.45	36.5
		m_3	31.5	3.87	0.45	36.6
		l_3	40.1	2.9	0.47	28.6
		l_1	37.8	2.8	0.48	28.2
G. Dimitrov Mine	0,21	l_1	35.4	3.0	0.49	30.8
		k_8	43.0	2.2	0.41	18.9
A. G. Stakhanov Mine	0,24	l_3	37.4	1.79	0.47	21.5
		l_3	38.3	1.87	0.48	21.5
		l_3	40.5	1.49	0.48	17.1
		l_3	40.6	1.54	0.40	14.9
		l_3	39.8	1.48	0.56	19.9
		l_3	37.5	1.74	0.46	19.2
		l_3	37.9	1.57	0.48	18.1
		l_3	36.5	1.95	0.50	23.4
		l_3	37.8	1.50	0.51	18.4
		l_3	38.4	1.58	0.45	17.1
Dobropolskaya	0,23	l_3	36.8	2.11	0.61	29.6
		l_3	35.8	2.18	0.47	23.6
		l_3	35.8	2.32	0.44	23.5
“Pioneer” hydro mine	0,25	l_3	43.7	1.08	0.43	11.6
		l_3	39.5	1.99	0.58	28.8

Deviations from the average values are logically explained by action of external factors. Decreased values of the N^a index in the A. G. Stakhanov Mine and the “Pioneer” hydro mine are connected with the conditions of deformation of coal beds. The coals of the mines are broken by discontinuous (mainly faults) and small folded dislocations. The degree of low-amplitude disturbance of the mines is different [3]: “Dobropolskaya” mine is the most disturbed – 3.0 c.u., A. G. Stakhanov Mine – 0.13 c.u., “Pioneer” hydro mine " – 0.9 c.u. At the same time, the mines A.G. Stakhanov Mine and the “Pioneer” hydro mine are characterized by tension with a shearing component, and for the “Dobropolskaya” mine – by compression with a shearing component. The previous research concerning the impact of tectonic

conditions on the structure of coal matter showed that under tension, due to the activation of free radical recombination processes, the number of paramagnetic centers decreases; under compression, the nature of structural transformations, their depth and volume are changed, which leads to an increase in the number of defects [4]. The measured structural parameters are consistent with the results of previous research and correspond to the conditions of mine deformation.

Increasing of the average value in the concentration of paramagnetic centers of the beds of the mines G. Dimitrov Mine, "Tsentralnaya", and "Krasnolimanskaya" is possibly caused by increased water inflows (340 – 500 m^3/h). According to N.V. Cherskiy [5], increased content of hydrogen radicals is observed in poorly metamorphosed coals. The role of such radicals is dual: hydrogenation of organic compounds with the formation of more reduced structures, firstly, leads to a decrease in the length of aliphatic chains, and secondly, the synthesis of hydrocarbons is activated by free electrons imitated by the inorganic components of host rocks.

It is obvious that mechanochemical processes (a type of tectonic dislocation, water inflow) activate the destruction of macromolecules and, as a result, increase the number of generated free radicals, consequently, increase sorption capacity of coal matter, but do not affect the contingency coefficient, which characterizes the degree of coal matter maturity.

The calculated average sorption capacity of gas and fat ranks of coals for the Krasnoarmeyskiy district is 24.3 ± 0.29 and varies in a wide range: from 11.6 to 38.5.

The impact on the sorption properties of coal of the sedimentation conditions (amount and the different degree of ordering of individual microcomponents), oxidation, ash-content, and lithofacies conditions are also considered.

The impact of these factors is considered on the example of the l_3 bed in the mines: A.G. Stakhanov Mine, Dobropolskaya, “Pioneer” hydro mine (Table 2). Bed 1_3 is characterized by a three-pack structure, has a continuous distribution over the district, a single genetic type of coal and degrees of metamorphism, and similar lithofacies conditions, which makes it possible to exclude the impact of these factors on the measured structural parameters.

For each sample, the coal petrology, the ash-content of packs (according to DSTU 8995:2020), and the oxidation of coals (according to GOST 8930-2015) were determined.

The coal petrology was researched on a video-optical complex (MBI-11, NV 200, PK).

To assess the relationship between the parameters, the Pearson correlation coefficient was calculated, which is a measure of the linear correlation between two sets of data and, in this case, was determined by using the standard Excel program. The depth of sampling (the correlation coefficient is -0.42), and oxidation (the correlation coefficient is 0.34) have some impact on the value of the average sorption capacity of gas and fat ranks of coals of the researched mines, the impact of other parameters is insignificant

Coal petrology impacts the value of the ash-content (mineral inclusions (kaolinite, quartz, etc.): vitrinite (-0.51), liptinite (0.16), and inertinite (0.56). And, despite the rather large range of ash-content change (4.3 – 16.8%), the multidirectional effect of

maceral composition on the sorption capacity of coals within the bed is insignificant. The results [6, 7] confirm the data obtained.

Table 2 – Results of petrographic and technological research, paramagnetic characteristics of coal bed l_3 at A. G. Stakhanov Mine, "Dobropolskaya" mine, "Pioneer" hydro mine

Mine	Ultimate sorption capacity Q, ml/g	Ash-content A^d, %	Oxidation, mg. equ/g	The concentration of PMC, $N^d \cdot 10^{19}$, g^{-1}	Contingency coefficient K_{sc}, %	Petrology		
						Vitrinite Vt, %	Intertinite I, %	Liptinite L, %
A.G. Stakhanov Mine	21.5	9.4	2.3	1.79	47	79	12	8
	21.5	9.3	2.89	1.49	48	79	9	12
	17.1	8,8	3.44	1.5	51	81	9	9
	14.9	5	2.31	1.87	52	85	5	9
	19.9	8.8	2.57	1.54	40	78	7	14
	19.2	5.3	3.41	1.74	46	76	10	13
	18.1	5.7	3.05	1.58	45	81	9	9
	23.4	5.14	2.94	1.57	48	81	10	8
	18.4	5.13	2.14	1.95	50	81	10	8
	17.1	8.4	3.06	1.48	56	83	8	7
Dobropolskaya	29.6	15.2	1.8	2.11	61	78	13	10
	23.6	6.2	1.7	2.18	47	85	5	10
	23.5	5.2	1.89	2.32	44	81	6	13
"Pioneer" hydro mine	11.6	16.8	1.67	1.08	43	77	11	12
	28.8	7.2	1.61	1.81	56	83	6	11

Therefore, it is established that the calculated value of the methane sorption capacity of coals is impacted by various factors acting in different directions. The average sorption capacity of gas and fat ranks of coals in the Krasnoarmeyskiy district is 24.3 ± 0.29 and mainly depends on the deformation conditions of the coal-bearing strata.

Conclusions.

1) the average values of the concentration of paramagnetic centers are (2.29 ± 0.36) and of contingency - (0.476 ± 0.02), and the calculated value of the sorption capacity of coals (24.3 ± 0.29) can be considered as basic values for coals of the gas and fat ranks of the Krasnoarmeyskiy district;

2) minor deviations from the basic parameters can be caused by various geological and technological factors;

3) significant deviations in the average values of the sorption capacity of coals can be caused by tectonic processes.

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About authors

Bezruchko Kostiantyn Andriiovych, Doctor of Geology Science (D.Sc.), Senior Researcher, Head of Department of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, gvrvg@meta.ua

Pymonenko Liudmyla Ivanivna, Doctor of Geology Science (D.Sc.), Senior Researcher, Principal Researcher in Department of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, gvrvg@meta.ua

Burchak Oleksandr Vasylovych, Doctor of Technical Science (D.Sc.), Senior Researcher, Senior Research in Department of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, gvrvg@meta.ua

Baranovskyi Volodymyr Ihnatovych, Master of Science, Junior Researcher of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, gvrvg@meta.ua

Chelkan Vira Volodymyrivna*,* Engineer in Department of Patent-Licensed Work and Information, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine.

ВПЛИВ ГЕОЛОГІЧНИХ ЧИННИКІВ НА СОРБЦІЙНУ ЗДАТНІСТЬ ВУГІЛЛЯ МАРКИ ГЖ КРАСНОАРМІЙСЬКОГО РАЙОНУ

Безручко К.А., Пимоненко Л.І., Бурчак О.В., Барановський В.І., Челкан В.В.

Анотація. На даний час на основі вивчення умов і чинників викидонебезпечності вугільних пластів розроблені різні методи прогнозу, що базуються на сучасних уявленнях щодо природи та механізму газодинамічних явищ. Одним з основних чинників, що впливають на викидонебезпечність вугілля, є газонасиченість, яка визначається сорбційними здатностями вугілля. Сорбційні властивості вугільної речовини суттєво визначаються мірою перетворення вугілля (метаморфізмом). Тому аналіз даних, отриманих для вугільної речовини однієї марки дозволяє виявити роль та значення чинників, що сформували параметри спостережуваних методом ЕПР-спектроскопії сигналів та визначають особливості сорбційної взаємодії вугілля і газу для конкретної проби. Встановлено, що середні значення концентрації парамагнітних центрів (2,29 ± 0,36), спряженості (0,476 ± 0,02) і розраховану величину сорбційної здатності вугілля (24,3 ± 0,29), можна розглядати як базові для вугілля марки ГЖ Красноармійського району. Незначні відхилення від базових параметрів можуть бути викликані різними геолого-технологічними чинниками. Істотні відхилення середніх значень сорбційної здатності вугілля можуть бути викликані тектонічними процесами.

Мета – дослідження впливу геологічних факторів на сорбційні властивості газових і жирових рядів вугілля, визначені методом ЕПР на шахтах Красноармійського району.

У ході дослідження були визначені наступні параметри: 1) інтегральна інтенсивність спектра ЕПР – концентрація парамагнітних центрів (Na) в досліджуваній речовині, що характеризує сумісний вплив зовнішніх факторів на вугільну речовину, 2) коефіцієнт непередбаченості (Ksc), тобто кількість і статус сполученої системи в молекулярній структурі речовини, що характеризує глибину передачі структурних перетворень (ступінь структурованості) викопної органіки на нанорівні. В результаті встановлено, що різні чинники, що діють різноспрямовано, впливають на розрахункове значення сорбційної метаноємності вугілля. Середня сорбційна

здатність газожирових сортів вугілля Красноармійського району становить 24.3 ± 0.29 і в основному залежить від умов деформації. Середні концентрації парамагнітних центрів становлять (2.29 ± 0.36), а контингентів (0.476 ± 0.02). Розрахункове значення сорбційної ємності вугілля (24.3 ± 0.29) можна вважати базовим для газожирових класів вугілля Красноармійського району. Незначні відхилення від основних параметрів можуть бути викликані різними геолого-технологічними факторами. Значні відхилення середніх значень сорбційної здатності вугілля можуть бути зумовлені тектонічними процесами.

Ключові слова: вугілля, сорбційні властивості, ЕПР-спектроскопія, геологічні чинники.

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