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THE IMPORTANCE OF THE GAS FACTOR IN THE OCCURRENCE OF SUDDEN OUTBURST OF COAL AND GAS

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The article examines the role of methane contained in coal in the mechanism of sudden outburst, because practice shows that the amount of methane released per ton of coal released into mining is several times and even tens of times higher than the natural gas content of the coal seam. Establishing the causes of sudden outbursts is necessary to reduce the risk of outbursts by influencing the stress state of a gas-saturated coal seam.

Keywords: sudden outburst of coal and gas, outburst hazard, gas content, gas release, gas saturation.

КӨМІР МЕН ГАЗДЫҢ КЕНЕТТЕН ШЫҒАРЫЛУЫНЫҢ ПАЙДА БОЛУЫНДАҒЫ ГАЗ ФАКТОРЫНЫҢ МАҢЫЗЫ

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Мақалада көмірдегі метанның кенеттен шығарылу механизміндегі рөлі қарастырылады, өйткені тәжірибе көрсеткендей, тау-кен қазбаға шығарылған көмірдің тоннасына бөлінетін метанның мөлшері көмір қабатының табиғи газдылығынан бірнеше есе, тіпті ондаған есе көп. Кенеттен шығарындылардың пайда болу себептерін анықтау газға қаныққан көмір қабатының кернеулі күйіне әсер ету арқылы шығарындылар қаупін азайту үшін қажет.

Туйін сөздер: көмір мен газдың кенеттен шығарылуы, шығарылу қаупі, газдылығы, газдың бөлінуі, газдың қанығуы.

ЗНАЧЕНИЕ ГАЗОВОГО ФАКТОРА В ВОЗНИКНОВЕНИИ ВНЕЗАПНОГО ВЫБРОСА УГЛЯ И ГАЗА

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В статье рассматривается роль содержащегося в угле метана в механизме возникновения внезапного выброса, потому как практика показывает, что количество выделившегося метана на тонну выброшенного в горную выработку угля в разы и даже десятки раз превышает природную газоносность угольного пласта. Установление причин проявления внезапных выбросов необходимо для снижения выбросоопасности путём воздействия на напряжённое состояние газонасыщенного угольного пласта.

Ключевые слова: внезапный выброс угля и газа, выбросоопасность, газоносность, газовыделение, газонасыщение.

Introduction. Although various technical measures have been developed to prevent sudden coal and gas outbursts, many remain insufficiently effective. Causes include poor understanding of seam structure, gas behavior, and cost-related limitations. Accurate prediction of hazardous areas, particularly in geologically disturbed zones, remains essential.

Methane emissions in coal mines have extremely negative social, technological, economic, and environmental impacts, as they increase the risk of methane-air mixture accumulation and explosions in both ventilated and unventilated workings. Such incidents often result in mass injuries and fatalities, as well as the destruction of mine support structures.

A global chronology of methane explosions with large numbers of fatalities is presented in Table 1.

Table 1 - Methane Explosions with Fatalities in Coal Mines (1962–2023)

Year	Country	Mine	Fatalities
1962	Germany	Luisenthal	299
1969	Mexico	Barroteran	300
1972	Rhodesia	Wankie	400
1975	India	Dhanbad	431
1979	Kazakhstan	Sokurskaya	72
1987	Ukraine	Chaykino	36
1990	Yugoslavia	Dobrinja	180
1992	Ukraine	Sukhodolska-Vostochnaya	63
1997	Russia	Zyryanovskaya	67
1997	Turkey	Armutcuk	217
2006	Kazakhstan	Lenin Mine (Shakhtinsk)	41
2007	Ukraine	AF Zasyadko Mine	106
2010	New Zealand	Pike River	29
2010	Russia	Raspadskaya	91
2013	China	Binxian	28
2014	Turkey	Soma	301
2015	Pakistan	Orakzai	45
2016	China	Chifeng	32
2020	China	Chongqing	23
2021	Kazakhstan	Abayskaya (Abay)	6
2022	Russia	Listvyazhnaya	51
2023	Kazakhstan	Kostyanko (Karaganda)	46

Currently, although various technical and technological measures have been developed to prevent the occurrence of sudden coal and gas outbursts, most of them have a number of shortcomings and are generally characterized by insufficient efficiency. The reasons for these

shortcomings are related both to the lack of information about the conditions of coal seams and the lack of knowledge about the nature of sudden outbursts themselves, as well as to the high complexity of implementation and high costs of the measures taken.

To ensure the safety of mining operations in coal seams that are dangerous and threatened by sudden coal and gas outbursts, it is necessary to predict the places of their possible occurrence (hazardous areas). Sudden coal and gas outbursts tend to occur in areas of geological disturbance. Of the 60 cases of sudden releases in the Karaganda coal basin, 23 were associated with fractured faults of the upwash type, 19 - with zones of small tectonic disturbances, 10 outbursts occurred in the zone of seam thickness changes (thinning or inflating), and 1 - in the zone of a sharp change in the seam hypsometry. The gas content of hazardous seams at the depth of coal and gas outbursts varies from 10.7 to 22.1 m^3/ t [1].

Therefore, in order to improve blowout prevention measures, it became necessary to conduct additional studies on the dynamics of gas release processes from rock massifs, to establish the regularities of the influence of gas factor on the nature of unloading ahead of the front of the advance of preparatory faces, in addition to a number of scientific publications available to the authors on this issue [2-4].

The sudden coal and gas outbursts that occurred at the mines of the Karaganda coal basin indicate that during their implementation, the amount of methane released per ton of coal released into production is several times and tens of times higher than the natural gas content of the coal seam. For example, the minimum value of gas release during outbursts (33.3 m^3/t) was recorded at the 3-bis mine, and the maximum value (859.4 m^3/t) was recorded at the Lenin mine. Of course, there is a question about the origin of the additional amount of methane released during outbursts. To get an answer to this question, it is necessary to know about the possible states of methane in coal and methods for determining the gas capacity of coal, on the basis of which the natural gas content of the seam can be determined.

Methane exists in coal in free, adsorbed, and absorbed states [5]. Absorbed methane plays a key role in outburst events. Zhekamukhov et al. [6] demonstrated that up to 90% of methane is retained in absorbed form. International research confirms that gas desorption and sudden decompression are major outburst triggers [10–13]. Studies in the Karaganda basin show that geological faults and seam anomalies significantly increase risk [1–3].

Research into the role of methane in sudden coal and gas outbursts has evolved significantly over the past decades, integrating geological, geomechanical, and thermodynamic perspectives. Early studies in the Soviet Union [5] and later international efforts [7] established that methane exists in coal in three states: free, adsorbed, and absorbed, each playing distinct roles in the accumulation and rapid release of gas during mining operations.

Methane States and Sorption Properties. Methane content in coal seams, or gas capacity, is a critical parameter affecting outburst hazard. As documented by Zhekamukhov et al. [6], the dominant portion of methane is retained in sorbed form, with up to 90% being absorbed into the coal matrix. This absorbed gas can transition into free gas under sudden decompression, making coal seams inherently unstable when disturbed.

Experimental studies (e.g., Yu et al., 2014) have shown that coal porosity and microfractures significantly enhance gas diffusion and desorption. Moreover, sorption capacity increases under pressure, and standard lab-based gas capacity measurements often underestimate real in-situ conditions due to the inability to reproduce underground stress states [6].

Geological Preconditions for Outbursts. Outburst events are strongly associated with tectonic disturbances, seam thickness variations, and fault zones, as shown in cataloged incidents from the Karaganda coal basin [1]. Approximately 70% of such events occurred in areas of structural instability, confirming findings by Tsai and Shontayev [2], who emphasized the need for continuous geomechanical monitoring and predictive modeling of hazardous zones.

International Research and Predictive Modelling.

Modern approaches employ numerical simulation of coal-gas systems (e.g., COMSOL, FLAC3D) to model stress redistribution and gas pressure evolution. Studies by Zhang et al. (2020) and Liu et al. (2018) demonstrated that gas desorption-induced softening and pore pressure changes are key triggers of instability in coal seams under mining stress.

According to Wang et al. (2016), the Rebinder effect—the weakening of coal under sorption-induced molecular interactions—further reduces tensile strength, making it susceptible to fragmentation under low pressure gradients. This aligns with the activation-energy-based fracture models used in the present study [7, 8].

Karaganda Basin in Global Context. The Karaganda coal basin has been recognized as one of the most methane-rich basins worldwide, with reserves exceeding 4.0 trillion m^3 and seam gas content reaching 25–40 m^3/t, according to Drizhd et al. [14, 15]. The relevance of degasification strategies used in the U.S. (e.g., Powder River Basin), Australia (e.g., Bowen Basin), and China (e.g., Qinshui Basin) are highly transferable to Kazakhstan' s context, as they rely on pre-mining drainage, multi-seam hydraulic fracturing, and in-situ monitoring networks.

Materials and methods. The study is based on analytical modeling of gas release mechanisms, fracture strength of coal, and sorption characteristics. Methane capacity is measured under laboratory and simulated field conditions. Strength models incorporate activation energy and pore-related weakening (Rebinder effect).

Methane in coal can be in a free state in cracks and pores, and sorbed. The latter is understood as an adsorbed gas (condensed on the surface of a solid substance of coal) and absorbed (as a solid solution in coal). In the case of absorption, the concept of "solid solution of embedding" is applicable to the methane-coal system, and the gas molecules embedded in the volume do not occupy voids in the crystal lattice, but vacancies in the solid. It is important to note that gas absorption increases the volume of coal, which undoubtedly leads to a decrease in its mechanical strength. When the equilibrium between different forms of methane state is disturbed, free gas is released in coal first, then adsorbed and finally absorbed. It is considered [5] that the share of gas in the free and adsorbed states is not more than 10% of the total methane content in the outburst-hazardous formations, and the main role in unleashing the release is assigned to gas in dissolved form.

The gas capacity of coals is determined in the laboratory by their sorption capacity. The natural gas content of coals of the Karaganda basin at the depth of outburst occurrence is in the range of 10.7-22.1 m^3/t. One gets the impression that coal seams contain more methane than can be "driven" into it in the laboratory, where gas absorption occurs only due to physical adsorption. Therefore, the determination of the natural gas content of coals according to existing methods does not reflect the real methane content in them, since it is impossible to change the volume of ultrapores and the sorption capacity of coals under laboratory conditions under the influence of mechanical pressure [6].

Based on the above, it follows that in order to understand the nature of sudden coal and gas outbursts, first of all, it is necessary to determine the conditions under which sorbed methane rapidly transitions from a supersaturated metastable state to a gas state in coal seams. Most researchers believe that the main factors of sudden methane outbursts are the stress state in the gas-saturated seam and the rapid discharge of these stresses, and coal crushing is the primary factor causing gas release. The stressed state of a gas-saturated coal seam is caused by the action of gravitational forces and the presence of sorbed methane in the coal. Under certain conditions, the potential of the gas-coal system reaches its maximum and becomes extremely unstable due-to the supersaturation of coal with dissolved gases, which can lead to a sudden outburst of coal and gas.

Outlier zones of the formation differ from non-outlier ones by the possibility of rapid transition of dissolved gases from supersaturated solution to free gas, and they are usually confined to areas of the formation with tectonically disturbed coal. However, the reasons for the relationship of such coal with intensive methane release and the mechanism of

release of gas absorbed in coal are not explained.

It was noted in [6] that intensive methane release is possible only if coal unloading is accompanied by its dispersion, the only mechanism of which is the explosion of gas bubbles embedded in the coal structure. When the formation is unloaded, gas bubbles located near pores or microcracks break the coal partition of the order of 10^{-3} cm in size, and gas release from the volume of crushed coal will occur in the order of 0.01-0.1 s. The condition for breaking the coal shell is reduced to the inequality:

$$p_s^* - p^2 \geq \alpha\sigma_k, \tag{1}$$

where p_s^* – initial gas pressure inside the bubbles, approximately equal to the rock pressure;

p^2 – pressure of the mixture of gas and coal particles;

σ_k – ultimate tensile strength of coal;

$$\alpha = \frac{1}{2}\left[\left(\sqrt[3]{\frac{4\pi}{3f_0}} - 1\right)^3\right] - 1, \tag{2}$$

where f_0 - porosity of coal.

Analysis of formulas (1) and (2) shows that an increase in porosity leads to a significant decrease in the critical values of rock pressure, at which a sudden outburst of coal and gas is possible. However, it is not clear, what the ultimate tensile strength is. If it is determined by standard laboratory tests, then its numerical value already takes porosity into account. The scale factor is also important in determining σ_k. On rock samples, their strength is significantly affected by structural defects (usually microcracks, pores commensurate with the size of the grains composing the rock). With a decrease in the size of coal to 10^{-3} cm, their strength will undoubtedly increase, since smaller defects will participate in the overvoltage of elementary bonds.

It is known [7] that the strength of a solid body can be represented as

$$\sigma = \frac{U_0'' - kT\ln\frac{\tau}{\tau_0}}{\gamma} \tag{3}$$

Where U_0'' – initial activation energy of destruction;

k – the Boltzmann constant;

T – absolute temperature of the test material;

τ – time to destruction of a solid (durability);

τ_0 – oscillation period of an atom in the crystal lattice;

$\gamma = q_{\text{str}}V_a$ – coefficient of the solid body structure;

q_{str} – coefficient that takes into account the overvoltage of elementary bonds due to the presence of structural defects in a solid (microcracks, pores, dislocations, etc.);

V_a – activation volume.

Let us consider the strength of coal in relation to particles of size 10^{-3} cm, which corresponds more to the mesoscopic level with a linear size of dislocation substructures $l \approx 0.01$–10 microns and is characterized by collective movement of dislocation structures. For gas-saturated coal, it is necessary to take into account the phenomenon of adsorption decrease in strength (Rebinder effect). It is caused by proppant pressure caused by sorption forces, i.e., forces of interaction between methane molecules and the coal surface. This circumstance can be taken into account by introducing an additional coefficient γ into the formula for finding the structure coefficient q_g, which takes into account the overvoltage of elementary bonds due to the proppant action of gas molecules. At the same time, the natural disturbance of fossil coals is the main factor in the softening effect of gas on coal.

Results and discussion. It was found [6] that during degassing of disturbed coals, their strength increases by $30 - 45\%$, therefore, the numerical value of q_g can be assumed to be $1.30 - 1.45$, so given $\sigma = \sigma_k$, equality (3) can be represented as

$$p_s^* - p_2 \geq \frac{U_0 - kT\ln\frac{\tau}{\tau_0}}{q_{str}\,q_g\,V_a} = A, \tag{4}$$

Determine the value of A by taking $U_0 = 0.64 \times 10^5$ J/mol, $\gamma = 0.0727(J/mol)/(kg/mm^2)$, $q_g = 1.35$, $\ln\tau = -5$ (according to experiments on the durability of hard coal); $\ln\tau_0 = 29.9$. The

calculation results show that at $T = 293^{\circ}$, the value of A is 30.5 MPa.

The value of rock pressure is defined as $\gamma_r H$ (γ_r is the average volume weight of overlying rocks, H is the depth from the surface). However, a reference pressure zone appears near the mine workings, in which the value of the rock pressure is 2–3 times greater than $\gamma_r H$. Taking the value of p_2 approximately equal to atmospheric, we obtain that the possibility of coal dispersion as a result of the explosion of methane bubbles during seam unloading can occur from a depth of $H = 500$ m (in calculations $\gamma_r = 2.0$ t/m^3). With an increase in the disturbance of coals, the structure coefficient increases, so inequality (4) can be performed at lower depths. Figure 1 highlights the correlation between gas content and depth in the Karaganda Basin, as well as its impact on methane saturation.

Figure 2 reveals the differences in methane outburst volumes across various mines, indicating the influence of geological conditions and previous degasification activities.

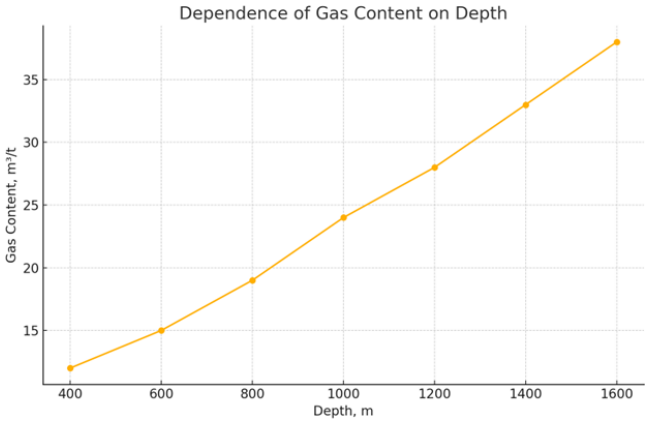


Fig.1 - Dependence of Gas Content on Depth in Karaganda Basin

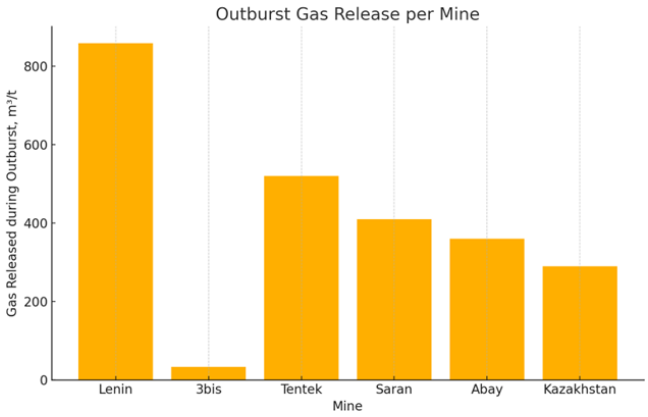


Fig.2 - Outburst Gas Release per Mine in Karaganda Basin

We investigate possible options for reducing the outburst hazard by influencing the parameters included in (3). A decrease in the temperature of coal in the outburst-hazardous zone leads to an increase in the threshold at which coal dispersion and gas release due to the diffusion mechanism are possible (Table 2).

Table 2 - Influence of coal temperature on the threshold stress (σ_k) for dispersion and gas release in the outburst - hazardous zone

Coal temperature, t°C	20	15	10	5	0
σ_k, MPa	30,5	41,0	51,50	62,1	72,6

Reducing the temperature of coal by 5°C leads to an increase in strength by about 10 MPa. When degassing a coal seam, the numerical values σ_k shown in Table 1 increase by a factor of 1.30-1.45.

Conclusion. The mechanism of sudden outbursts and the causes of their occurrence differ in the aggregate assessment of the participation of gas in them, the stress-strain state of the massif, as well as the physical, mechanical and physico-chemical properties of the intersected massif along the front of the mining operation.

Results show that coal porosity and methane saturation are directly correlated with the likelihood of sudden outbursts. Gas pressure at depths above 500 m can exceed critical strength thresholds.

Graphs in Figure 1 and Figure 2 illustrate this dependence.

At the same time, coal-sorbed methane plays a significant role in the implementation of a sudden outburst. With rapid stress relief in a gas-saturated coal seam, especially near or in the zone of tectonic disturbances characterized by the presence of disturbed coal bundles, this gas disperses coal with simultaneous avalanche-like methane release and removal of the destroyed rock mass in the bottom-hole part into the mine.

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