UDC 622.831 DOI: https://doi.org/10.15407/geotm2022.163.016

THE UNLOADING ZONE AND ITS IMPACT ON THE SAFE MINING OF OUTBURST-HAZARDOUS COAL SEAMS

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Abstract. The development of outburst-hazardous coal seams is regulated by a number of normative documents that allow correct estimating of the parameters of the unloading zone in the face area part of the seam; therefore, there is no possibility of safe development of outburst-hazardous seams.

The purpose of the research is to substantiate the main parameters of the unloading zone, to clarify its parameters for the safe mining of outburst-hazardous coal seams.

Speaking about the actual hazard of gas-dynamic phenomena (GDP), as practice shows, none of the methods for predicting or assessing the size of the unloading zone, including the newly developed ones, can speak with 100% reliability about its implementation or its type. In the article, the author analyzes the results of determining the size of the unloading zone by various methods of controlling the effectiveness of the measures taken and the hazards of coal extraction in this zone. When discussing the results obtained, the definition of the unloading zone as a degassed part of the rock massif with destroyed or squeezed coal was formulated. As it is established, in this zone, it is possible to extract coal to a given depth without performing anti-outburst measures with the possibility of adjusting the size of the extraction by the depth of the unloading zone, taking into account the uneduced advance. The size of the unloading zone is determined by the settling time of the face, taking into account the stress-strain state (SSS), physical and mechanical properties (PMP), geological factors and the technology of massif destruction. The size of the unloading zone can be changed depending on the technological factor (extraction technology). For example, during fast extraction by a plough, the zone does not have time to form, i.e. when the plough (combine) either takes out a strip along the entire length of the long wall or cuts forward by 2-3 m.

The performed studies established the fact of formation of the unloaded zone in the face area part of the seam. The time interval of formation of the unloading zone is from 1 hour to 3 hours in case of mechanized coal extraction and up to 24 hours in case of blasting mining of coal, which is practically used in regulating the duration of technological processes. The unloading zone on outburst-hazardous seams varies from minimum sizes near zero to several meters.

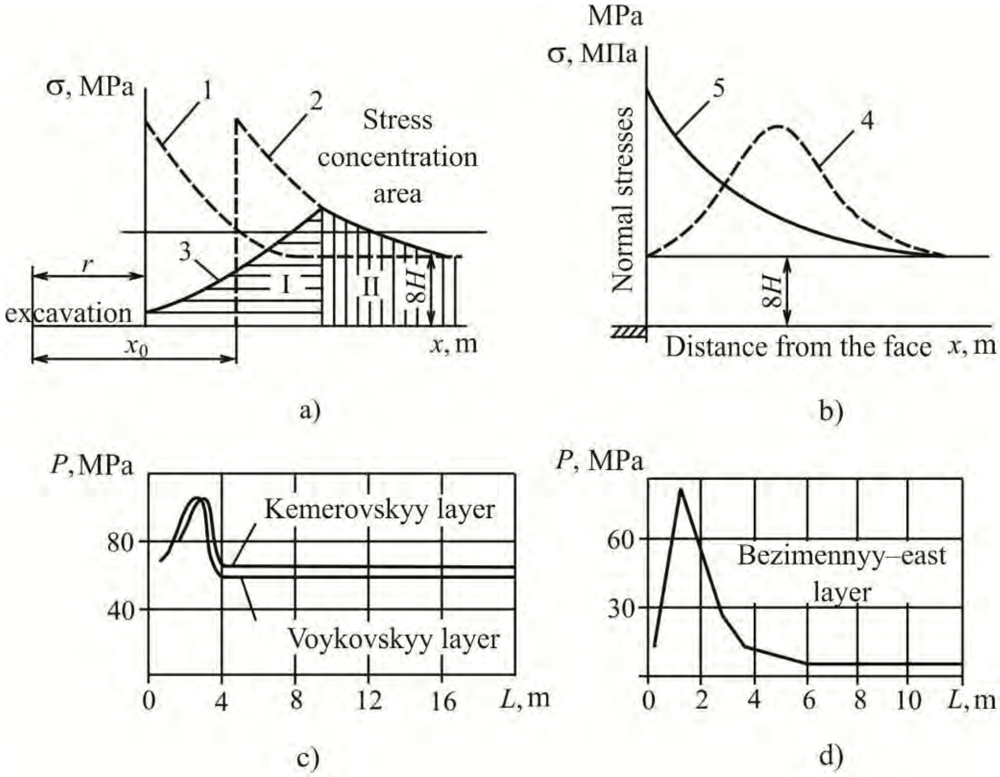
Keywords: outburst hazard, gas-bearing, unloading zone, coal seam, prediction, efficiency control.

1. Introduction

Many authors published in their works sheets on determining the unloading zone in the face part of the coal seam [1–20]. However, the described methods can mainly be used for laboratory studies of coal samples, and some of the authors did not apply their proposals to mine conditions.

According to the most known literature sources, a squeezing zone is formed ahead of the face [7, 9, 19]. It is known that while approaching the outcropped surface the stress state of the rock mass is redistributed. In this regard, there is a displacement of the formation towards the mined-out space. Deformation of coal in the plane of layering changes the sign and tensile deformation occurs in the coal seam along the line of extension of the seam strike. The implicit squeezing zone (in the rock mass) turns into the sudden squeezing zone. According to [1, 19], coal squeezing is the destruction and extrusion (cleavage) of coal into the face part and working under the influence of support pressure. An important issue is not the interpretation of the names of different zones in the face part of the coal seam, but the determination of the dimensions (areas) from the face to the depth of the massif during coal mining, within which gas-dynamic phenomena will not occur.

Let's consider the interpretation of the face part of the coal seam by different researchers. The research of V.V. Khodot [11] suggests that the stress state of a coal seam can be evaluated using two different functions: in the area of the boundary stress state I (Fig. 1a) - the function of the boundary state (curve 3), and in the area of the elastic state II (Fig. 1b) - the function of stress distribution around the cutout in the elastic setting (curve 2). Line I shows the distribution of stresses in the coal seam under the condition that the coal in the face part is an elastic body and does not collapse under the influence of increased stresses. The distribution of stresses arising near the breakage heading, according to [12], has the form (Fig. 1b), which is described by curve 5. The maximum load (curve 4) moves into the depth of the massif due to the destruction near the face.



x – distance from the outcropped seam, m; x_0 – size of the fictitious increase in the workings, m; P – indicators of pressure gauges, MPa; L – distance to the coalface, m

Figure 1 – Theoretical stress distribution (a, b) and stress measurements ahead of the face advancing (c, d)

From Figs. 1a and 1b it follows that zones of different stress levels can be formed ahead of the created (advancing) working: reduced stresses, increased stresses, and close to natural (primary) ones, which characterize the coal massif outside the zone of influence of mining operations.

Experimental observations of the manifestation of rock pressure in the zone of influence of the mine workings in Kuzbas [14] (Fig. 1c) and in Donbas [9, 15] (Fig. 1d) confirmed this distribution of stresses ahead of the face advancing.

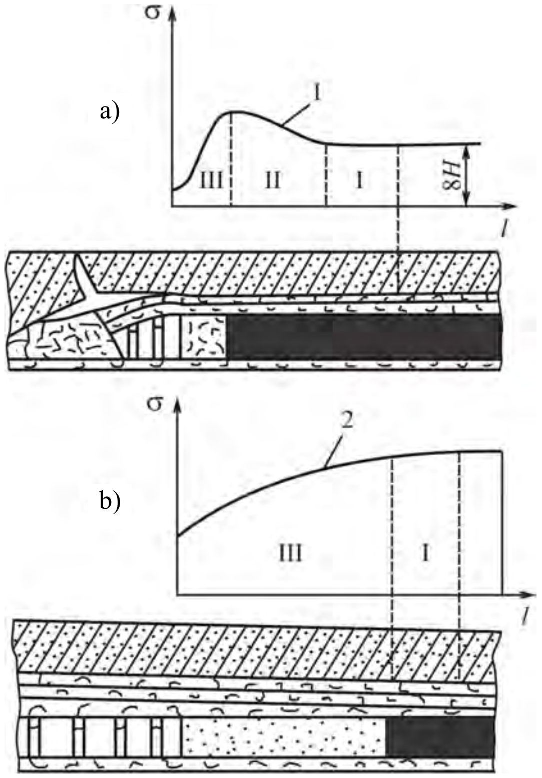
Similar results were obtained in the outburst-hazardous Smolianinovskii seam of mine No. 29 of the Donetskvuhillia plant [22], in steeply dipping mines in Donbas [23], and in the eastern regions of the former USSR [25] when studying the stress state in the face part of the seam by using hydraulic sensors. The highest intensity is also observed in the boreholes at the exit of the mud (borings) from the boreholes with a further decrease from the maximum value as the borehole deepens [24]. Acoustic methods [3, 6, 25] also established the presence (and sizes) in Donbas of characteristic zones of stress-strain state of the face part of the coal seam, which characterize the zones (areas) of pre-boundary and off-boundary deformations and allow to determine the size of squeezing, unloading zones and the position of the maximum support pressure. In all cases, the presence of a clearly expressed position of the maximum support pressure, at a distance of 1–8 m from the face in Donbas, 2–6 m in other basins is noted. In some cases, the position of the maximum support pressure is not clearly established in the preparatory workings.

The Institute for Physics of Mining Processes of the National Academy of Sciences of Ukraine developed the enterprise standard "Rules for determining the depth of the squeezing zone in coal mines" [26], which regulates the determination of the size of the squeezing zone in the breakage heading in flat coal seams. The methodology for determining the depth of the squeezing zone, which represents a part of the support pressure zone near the face surface, is based on the study of the compressive strength of coal samples

The size of the zone of influence of the preparatory workings on the stress state of the seam in the face part is 2.5–7.5 m at a seam thickness of 1.1–3.3 m and a depth of 280–380 m. An increase in the zone of influence for seams of greater thickness was established. The distance from the face to the zone of maximum stress was established for the breakage heading. It is 1.5–5.0 m. The thickness of seams in the study areas was 1.3–3.0 m, and the depth of work was 60–360 m. Minimum distances to the maximum stress zone of 1.5 m are set for the conditions of a 1.3 m thick coal seam at a depth of 90 m, and the maximum value is 6.0 m for a 2.5 m thick seam at a depth of 360 m. The above data indicate that the change in stresses in comparison with the natural conditions of the seam is more pronounced in the zone of influence of the breakage heading compared to the preparatory ones. Schematically, this is illustrated as follows (Fig. 2). The curves characterizing the stress distribution ahead of the heading (1) and preparatory (2) faces are constructed on the basis of the measured zones using hydraulic sensors. In area I, there are plastic deformations of the seam under the effect of additional loads caused by mining operations. Area II - elastic deformation of the seam. In it, the coal mass behaves as an elastic body.

In area III, due to coal extrusion towards the face, stresses are reduced. Here, the rock mass is broken down into separate blocks along the already existing numerous cracks. Preparatory workings, due to their small geometric dimensions, cannot be the cause of intensive displacement of the overlying roof rocks in comparison with the breakage heading, cannot lead to the absence of deformations ("hover") of the roof rocks and cannot create a load on the face area part of the massif. The convergence of the roof and sole rocks behind the preparatory workings is ten times less than behind the breakage heading [13]. Under these conditions, the coal massif, which does not have time to pass the stage of plastic and pseudoplastic deformation, enters the stage of intensive extrusion (squeezing) towards the face surface. This can only be explained by the presence of a zone of reduced stresses ahead of the face of the preparatory workings. Thus, it can be stated that there are zones different by the level of stresses ahead of the face advancing.

l – distance from the face, m; σ – stress, MPa;
1 – stress distribution ahead of the breakage heading; 2 – stress distribution ahead of the preparato-

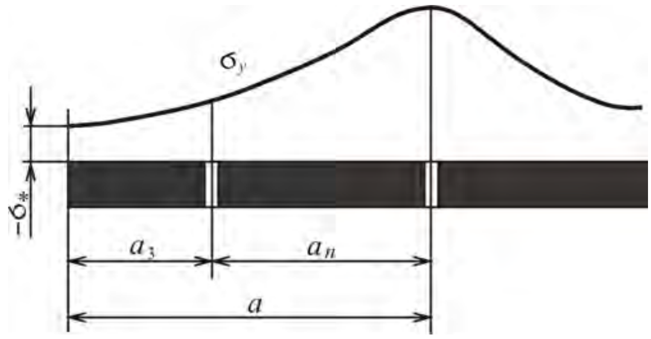


ry face; I – zone of plastic deformation of the seam; II – zone of elastic deformation of the seam; III – zone of stress reduction

Figure 2 – Schemes of stress distribution ahead of the breakage heading (a) and preparatory workings (b)

According to [27, 28], in the edge part of the coal seam, an outcrop zone is created, where deformations occur in the horizontal sections of the off-boundary diagrams (a_3 – the area near the outcrop, Fig. 3). This zone can occur as a result of natural squeezing during mining operations, and its size can be increased by the application of various special measures. The author [23] proposes it as a buffer zone. Behind it, on the falling sections of the off-boundary diagrams in the part of the face area zone a_n (Fig. 3), deformations occur, up to the maximum of the support pressure. Under natural conditions, the change of a_3 dimensions occurs due to changes in seam properties and loading conditions.

Some researchers propose a mechanism for changing the stress-strain state of the face area part of the coal seam in the process of face displacement. Thus, according to [14], when the face is displaced with a constant speed, there is a uniform movement of stress, gas permeability and gas pressure diagrams parallel to themselves in the direction of the face displacement. At the outcrop of the coal seam, there will be a uniform squeezing of coal and constant gas emission. That is, the situation will be dangerous, depending on the extent to which the occurrence of a gas-dynamic phenomenon is possible.



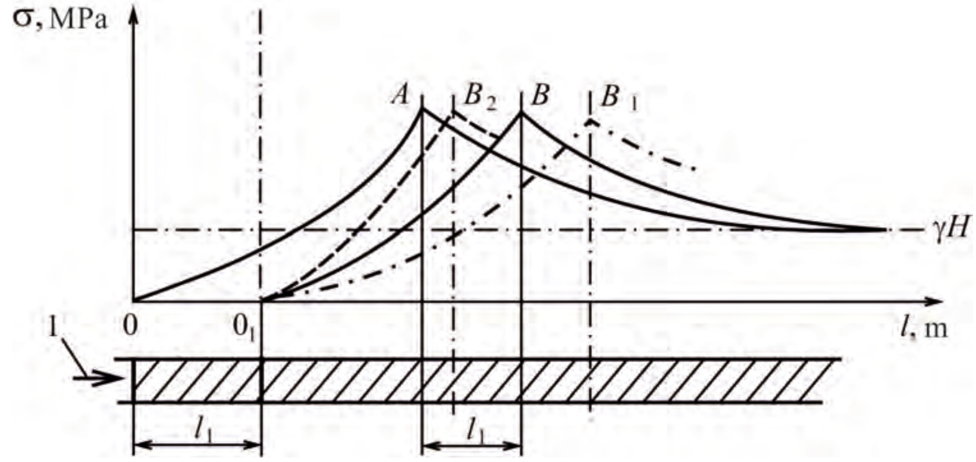
a – distance from the seam outcrop to the point of maximum support pressure;
- σ* – stress at the face edge; σ_y – normal stress

Figure 3 – Buffer zone (a_3) and deformation zone (a_n) in the face area part of the seam

In practice, the displacement of breakage heading and preparatory workings is carried out unevenly. With the explosive technology of coal extraction, there is an instant rejection of a part of the massif in the face part and redistribution of stresses, which proceed quickly (abruptly). Therefore, in such situations, stress redistribution occurs ahead of the face during the excavation period, which is illustrated in Fig. 4 [17]. In the process of excavation of coal (host rocks) by the value of *l*, the massif is deformed in the direction of the excavated space (workings) and the transition of stresses to the limiting state with the stress diagram O_1B_1 (Fig. 4) compared to the initial state with the diagram OA. During the rapid transition from one stress state to another, coal deformations do not have time to follow the stress changes and, the destructive effect of rock pressure on the seam is added by the work of destruction and displacement due to elastic recovery. The convergence of the host rocks significantly increases the friction at the contacts with the seams and prevents the deformation of the seam towards the workings. Stress diagram O_1B_2, due to coal layer fracture, however, returns to the position O_1B_1. Under some conditions (the ratio of the rate of coal destruction, the rate of convergence of the host rocks that simultaneously destroy and stuck the edge of the coal face, with a sufficiently high gas content of coal), the change in the stress state, which is characterized by the curves O_1B_1 and O_1B_2, can provoke a sudden outburst of coal and gas.

If the progressive-reverse displacement of the rock pressure diagram (from the position OA to O_1B_1 in Fig. 4, then – from O_1B_1 to O_1B_2) is quite smooth, there is a squeezing of coal and a smooth convergence of the host rocks. As a result of the dampening process of squeezing and changes in the rate of convergence of the host rocks, the stress diagram O_1B_2 returns to the position O_1B_1 parallel to OA, which exists before the coal extraction starts. Thus, the analysis shows that the main characteristics of the unloading zone are not clearly established.

The purpose of the research is to substantiate the main characteristics of unloading zone in the face area part of the coal seam to clarify the parameters of its use for the safe mining of outburst-hazardous coal seams.



1 – direction of displacement of the face; l – position of the face of the workings, m;
l_1 – the value of the displacement of the face, m; σ – vertical component of the stress state, MPa;
γH – inelastic state of the undisturbed massif

Figure 4 – Scheme of stress distribution ahead of the face in the process of coal extraction

Research methodology – the main objective of the research was to substantiate the main characteristics of the unloading zone in the face area part of the seam. Therefore, it was recommended to analyze the results of determining the size of the unloading zone, monitoring the efficiency and hazard of coal extraction in this zone. As a result of the discussion of the results obtained, it will be necessary to formulate the definition of the unloading zone.

2. Methods

Studies carried out in the conditions of the k_3 "Derezivka" seam - west, at the mine "Chervonyi Profintern" of the " Ordzhonikidzevuhillia" [14] establishes that there is a rolling drift ahead of the face, which is carried out by drilling and blasting in the mode of concussive blasting. The following zones are observed: a squeezing zone, which is characterized by a decrease in gas pressure measured through the wells from the previously drilled drift in the non-working seam k_{22} "Zolotarka", the size of the squeezing zone, in which there is no outburst of coal and gas during the explosion, ranged from 5 m to 8 m; a compression zone, extending from 2 m to 12 m and, then, a zone of the "undisturbed" massif. During concussive blasting, the squeezing and compression zones, preliminary coal and gas outburst, as a rule, were not sharply manifested. This is due to the lack of convergence of side rocks and the appearance of a deformation delay zone in the face area part of the seam. After the coal outburst, three different zones are again observed in the coal mass, which were described earlier. Studies of changes in the deformation (displacement) of the roof and base rocks in the depth of the massif and directly in the face area part of the preparatory workings showed that before the gas-dynamic phenomena that occurred during blasting, there are delays in deformation or their absence. With the face advance, there is an irregularity in the absolute values of deformations, which indicates the presence of different stresses in the face area part and in the depth of the massif. However, the experience of conducting mine experiments shows that there are several additional zones in the face area part of the coal seam, for example, some gas-impermeable zone of crushed coal, a zone where there is increased gas emission and other zones.

With the increase in the speed of the face advancement, especially with irregular changes in speed and especially when carrying out excavations (conducting coal operations) by drilling and blasting, there is a sudden redistribution of stresses, which can lead to the manifestation of gas-dynamic effects. The progressive-reverse character of the change in the rock pressure diagram is confirmed by the study of the deformation features of the squeezing zone in the face area part of the seam [18, 19]. The manifestation of seam unloading during its squeezing as a result of the formation of the face surface is determined by the change in the stress state in the face area part of the seam. In the process of coal extraction by various methods (except blasting), the squeezing zone is formed in a dynamic mode in the process of movement of the face into the depth of the coal massif. It was established [18] that the length of the squeezing zone in the dynamic mode (L_D) increases by 1.8–3.2 times compared to the squeezing zone in the static mode in similar mining and geological conditions. Besides, the presence of two modes of formation of the squeezing zone in the face area part of the seam causes a progressive-reverse displacement of the rock pressure diagram, which ultimately determines the length of the squeezing zone and the possibility of gas-dynamic effects during the next coal extraction.

The displacement of the rock pressure diagram by changing the size of the squeezing zone, unloading, distance to the maximum support pressure, stratification of roof rocks [6, 19, 20] in the breakage heading and preparatory workings was established experimentally. It is established that in the breakage heading during coal extraction by a combine, the maximum abrupt stratifications of roof rocks occurs at a considerable distance from the coal seam, and then they move to the contacts closer to the coal seam. After 2–2.5 hours, the parameters of the stress-strain state of the face area part are close to those obtained before coal extraction by the combine. The obtained results indicate a periodic wave-like change of parameters in the face area part of the massif. Ahead of the moving massif mining, during the combine advancing, the maximum abrupt interlayer deformations move to the contacts of layers more distant from the coal seam. At the same time, the stress diagram in the face area part becomes more flat, the squeezing zone increases, the unloading zone increases, and the maximum support pressure shifts to the depth of the massif. In 20–40 minutes after the passage of the combine (excavation of coal borings in the longwall), deformations begin to develop in the middle part of the detached roof thickness. The maximum support pressure returns to nearer to the face line. Due to the support pressure moving in the direction of the depth of the face and back to the face line, the coal seam is squeezed and degassed, and safe conditions are created for the extraction of the next strip of coal. At the entrance of the face into the outburst-hazardous zone there is a delay of deformations in the roof rocks, mainly at a distance of more than 10 m, the progressive-reverse movement of the maximum support pressure is reduced and completely stopped, the size of the unloading and squeezing zone is minimal

Similar results were obtained for preparatory workings [20, 28, 29]. The impact of the heading combine on the massif leads, at first, to an increase in the intensity of interlayer deformations in the contacts remote from the coal seam and a gradual movement of interlayer deformations to the contacts nearest to the coal seam. The maximum rock pressure moves deeper into the massif from the face, and then gradually moves nearer to the face. In the area hazardous by coal and gas outbursts, there is no displacement of the maximum rock pressure when coal is excavated by a combine, which leads to a delay of deformations [9, 19, 29].

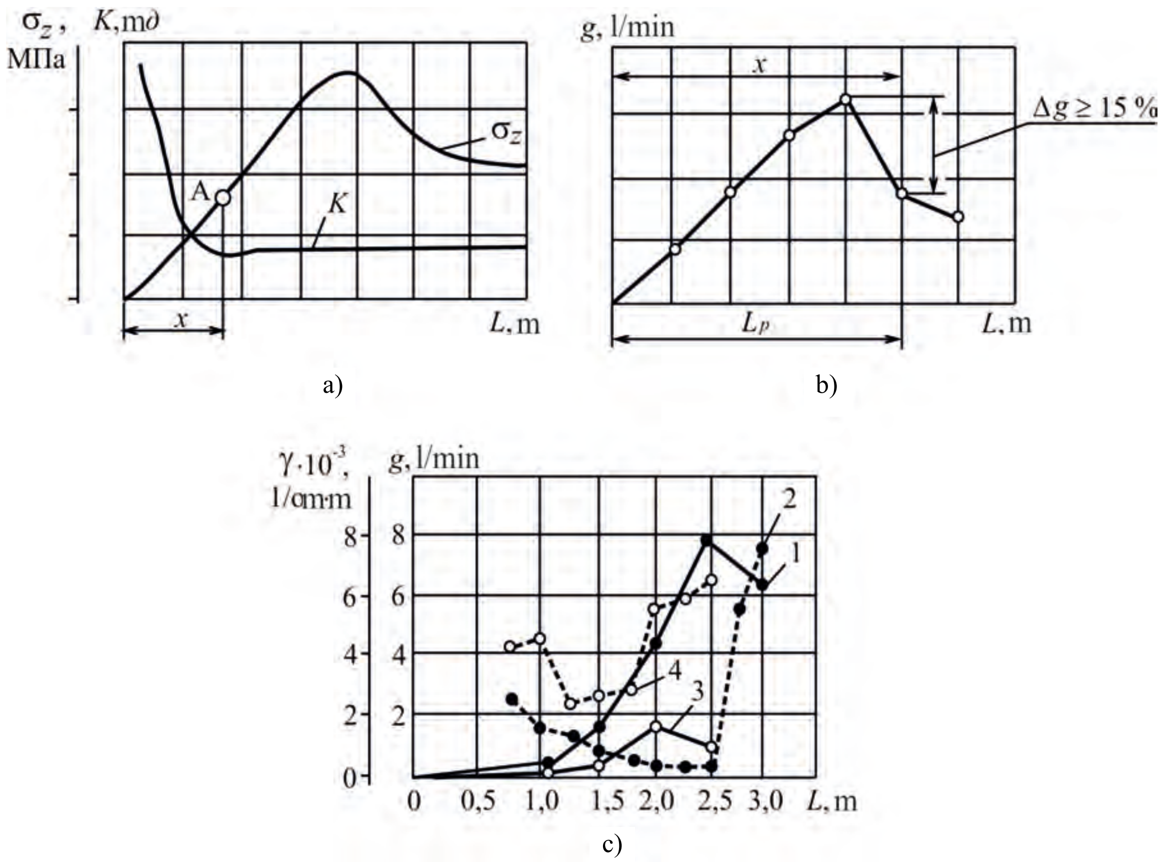
Based on the patterns of redistribution of normal stresses in the outskirts of the workings, the value of the unloaded zone a_0 can be determined by the formula [30]:

$$a_0 = a_m - 0,7 \frac{E_e}{M_{ss}} h, \qquad (1)$$

where a_m – distance to the maximum support pressure, m; E_e – modulus of elasticity of the host rocks, MPa; M_{ss} – stress-strain decline modulus, which takes into account the off-boundary characteristics of the coal seam, MPa; h – thickness of the coal seam, m.

Thus, for example, for the conditions of seam h_8 of the “Praskoviyevskii” at the mine named after the Newspaper “Socialist Donbas”, along with an increase in the depth of the seam development from 600 m to 1000 m, the size of the unloading zone according to the formula (2) increases from 1.1 m to 2.4 m. The above allows us to conclude that there are zones ahead of the face advancing (or stopped) differed by the level of intensity. There is a pronounced maximum of the support pressure for the heading faces, which exceeds the γH (normal level). For the preparatory face, there is an increase in the stress level from the minimum at the edge of the face to γH with the depth of the massif. In the process of excavation, the stress-strain state in the face area part of the formation can change over time. The change occurs both in quantitative terms and in spatial position relative to the face line. Control of changes in the stress-strain and gas-dynamic state should be carried out by methods of instrumental (experimental) measurements.

*On the permissible depth of safe coal extraction in the unloading zone***.** To control the presence of zones of different stress levels and the respective gas-dynamic state in the face area part of the seam, various methods were developed to determine them by the dynamics of gas emission [9, 19, 31]. Earlier it was determined that ahead of the moving face advancing under the action of rock pressure forces, there was a zone of inelastic deformations, the face area part of which was represented by squeezed cracked and partially degassed coal. Coal excavation within part of this zone is not accompanied by a sudden outburst. In the works of MacSRI, at one time, this zone was called a safe unloading zone. The established relationship of changes in the value of the plough of gas emission into the borehole with its deepening into the face area part of the massif (dynamics of gas emission), was the basis for determining the size of the unloading zone [25, 31]. The reason for the deepening into the insufficiently unloaded and degassed face area zone of the seam is the change in the character of gas emission (Fig. 5). The growth or stability of the gas emission rate is followed by its decrease. The size of the safe zone of unloading, coal excavation, within which there is no coal and gas emission, should be taken as the distance from the face to the depth of the massif, at which the growth or stationarity of the gas emission rate at interval measurements is replaced by a decrease by a certain value. The established regularity of changes in the rate of gas flow into the borehole drilled to the face area part of the seam in the direction from the face to the depth of the massif is confirmed by the work on the study of the stress state by electrometry (Fig. 5). It is found that with an increase in the level of tension there is a decrease in the rate of gas emission after its growth or stability. Similar results were obtained [14, 28, 29].



a) change in gas permeability of coal (K) as the stress level changes σ_Z ;
b) determination of the size of the zone by the dynamics of gas emission; c) change in the initial gas emission rate (1 – mine named after the Newspaper "Socialist Donbas", seam h_{10}; 3 – K.I. Pochenkov Mine, seam k_8) and electrical conductivity of coal (2 – seam h_{10} , 4 – seam k_8) along the length of the control borehole; g – value of the initial gas emission rate, l/min; $\Delta g \geq 15\%$ – the value of the decrease in the initial gas emission rate compared to the previous measurement, %; L – distance from the head of the face to the depth of the massif, m; L_p – safe unloading zone, m; x – distance from the face, m; A – a point characterized by σ_Z

Figure 5 – On the assessment of determining the size of the safe unloading zone by the dynamics of gas emission

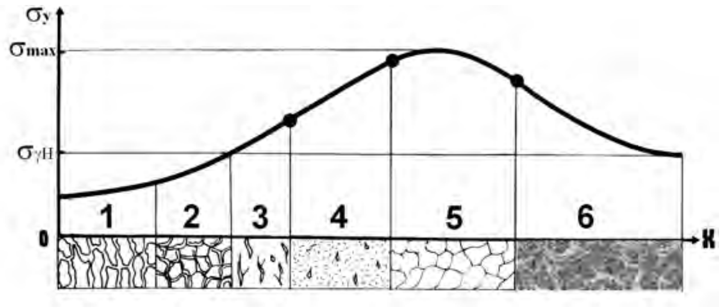
Comprehensive studies that were carried out in the longwall No 10 and in the 11th side drift of the seam h_4 of the mine “Hlyboka” of the Mine Administration “Socialist Donbas” [6] included the determination of volumetric deformations using hydraulic sensors, the amount of borings during drilling the holes, interval measurements of the initial gas emission rate, the propagation velocity of elastic waves, measurements of the parameters of the acoustic signal arising during drilling of the borehole (well). It is established that the size of the unloading zone, which is determined by the dynamics of gas emission, satisfactorily coincides with the data of changes in the stress state in the face area part of the seam, which are determined by the position of the maximum deformation, the maximum support pressure, the energy of the acoustic signal. Therefore, these data served as the basis for the development of an acoustic method for determining the size of the unloading zone, which is determined by the parameters of the acoustic signal arising during the drilling of the borehole (well) [3, 7, 10, 25]. Since 1973, various methods of controlling the outburst hazard based on the dynamics of the initial rate of gas emission into the borehole [33, 34] were used in the conditions of Donbas mines. The methods were included into the "Instructions ..." [10, 33, 34], and are used to this day.

3. Results and discussion

For giving further development to the previously mentioned approach of V.V. Khodot et al. (see Fig. 2) and the ideas of S.A. Khristianovich about the presence of zones of oriented cracks in the face area part of the coal seam, the M.S. Poljakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine developed a refined methodology for assessing the state of the massif in the face area part of the seam [15, 16] on the basis of analytical and experimental studies. By using this methodology, it is possible to describe the stress state of the massif, to estimate the structural changes of the coal seam and methane emissions in these zones of the face area part of the seam. The scheme of structural changes of the coal seam in the face area part is shown below (Fig. 6).

It should be noted that according to the above methodology of the IGTM of the NAS of Ukraine [15], the stress state in the face area part of the seam determines the order of six consecutive zones of the state of the carbonaceous massif. The most disturbed, in comparison with the zone of natural occurrence of the seam (zone 6), should be considered zones 1, 2, 3. Integration zone (4) is a zone of crushed gas-impermeable coal.

As a result of the analysis of the applied method of current prediction of outburst hazard by the initial rate of gas emission into the borehole [9, 10, 25, 33, 34], which has been used in the mines of Donbas since 1969, and the method of determining the size of the unloading zone [31], as well as the studies [35], a general method for determining the unloading zone and classifying the face area part of the seam as outburst hazardous or dangerous was developed. Coal extraction was allowed within the unloaded zone, reduced by at least 1 m of unreduced advance. In cases where the initial gas emission exceeded the critical value established for a given seam was determined at the boundary of the unloading zone, the face area part of the seam was considered outburst-hazardous and coal extraction was prohibited until additional safety measures were taken. This methodology was tested in the conditions of the mines of "Donetskvuhillia" and "Ordzhonokidzevuhillia", where its reliability was proved.



1 – zone of destroyed coal (squeezing zone); 2 – zone of developed filtration; 3 – zone of oriented cracks; 4 – zone of integration; 5 – zone of disintegration zone of loading; 6 – zone of natural occurrence of the seam; X – distance from the face to the depth of the massif, m; σ – total normal tensions (σ_{max} – maximum in the zone of support pressure; $\sigma_{\gamma H}$ – tension in the undisturbed massif zone)

Figure 6 – Scheme of structural changes in the coal seam in the face area part of the seam under normal distribution of rock pressure

The experience of applying the method of determining the size of the unloading zone by the dynamics of gas emission [19, 31] as a control of the excavation depth, has shown that in many cases the value of the decrease in the initial gas emission rate indicates, to a greater extent, changes in the stress state in the face area part of the coal seam and to a lesser extent, characterizes the danger of the presence of a outburst-hazardous situation. Additional studies proposed to take into account the gas factor by changed initial gas emission rate over time [32].

Earlier, the temporal factor was proposed to determine the zones of hazardous by different types of gas-dynamic phenomena (GDP) in the Eastern basins of the former USSR [36]. Regarding the change in the nature of gas emission into the borehole, it was proposed to determine the zones which are safe in terms of GDP and and in which sudden outburst and gas blower are possible. Moreover, the quantitative values - the time (interval) of measuring the initial gas emission rate and the degree of change in the absolute value of the initial gas emission rate over time - were not specified. The time factor for measuring the initial gas emission rate was used in the "Instruction..." [34], which was used when crossing steep coal seams. In the boreholes drilled into the coal seam through the rock blockage, a measuring chamber was formed and 2 minutes after the first initial determination of the initial gas emission rate g_n, the time criterion was calculated using the formula (3). The situation before the disclosure was assessed as outburst-hazardous at $K_v \geq 5$ and as not dangerous at $K_v < 5$. The temporal criterion K_v and its methodology are similar to those described above. The scope of its application was insignificant, and little is currently known about its application. The methods described above are intended to determine the size of the safe unloading zone by using the initial gas emission rate. Coal extraction is allowed within the safety unloading zone.

Based on the principles of determining the outburst-hazardous zones using the initial gas emission rate, there are known methods of current prediction developed in MacSRI [10, 33, 34, 37] and EastSRI [33, 34]. In the MacSRI method, face area zone was considered dangerous by coal and gas outburst when the measured initial gas emission rate was ≥ 5 l/min at a borehole depth of 3.0–3.5 m. The upper reliable limit for g_n and f (where g_n is the initial rate of gas emission from the control borehole; f is the strength of coal according to the scale of Prof. M. Protodyakonov) was determined taking into account that sudden coal outbursts did not occur at a coal strength coefficient above 0.8 p.o. and an initial gas emission rate was 10 l/min or less. Taking into account the double reserve, the value of 5 l/min is accepted as a safe value of gas emission for the conditions of all coal seams of Donbas. The expediency of this decision is confirmed by the absence of coal and gas emissions in the areas of outburst-hazardous single seams (more than 50 thousand measurements were made) and in protected areas (590 measurements), where, due to the presence of values of the initial gas emission rate of less than 5 l/min, sudden outburst of coal and gas did not occur [30].

If the measured data of the initial rate of gas emission into the borehole g_n is less than g_δ, which are established for this seam, the situation is assessed as not outburst hazardous. At shallow mining depths, where the value of rock pressure can be sufficient to break the coal, outburst occurs due to the participation of gas in the destruction and outburst of coal. At great depths, where the main factor of destruction is the rock pressure, the role of gas in outbursts is mainly reduced to the outburst of broken coal. However, the conditions of destruction depend on the deformation-strength properties of coal, which are essentially determined by the degree of its metamorphism (V^g). Therefore, the nature of the change in the initial gas emission rate (g_n) is due to both the depth of mining and the physical and mechanical properties of coal. According to the results of measurements of the initial rate of gas emission from boreholes in hazardous and safe zones of seams of different degrees of coal metamorphism, developed at depths from 300 to 1100 m, it is found that the safe value of the initial gas emission rate at V^g = 26% is 1.7 l/min at a depth of 1100 m and 3.8 l/min at a depth of 400 m. Values of the initial gas emission rate of 4.0 l/min and more were obtained for coal seams with volatile V^g yield from 4% to 20% at depths from 400 m to 1100 m and at $V^g \geq 30\%$ for depths from 400 m to 700 m. For other cases, the critical safety value of initial gas emission rate is from 1.7 l/min to less than 4.0 l/min. This can explain the presence of sudden coal and gas outbursts, which were accompanied by low gas emission, and the value of the initial gas emission rate measured according to the outburst hazard prediction was critical (5 l/min). However, this methodology was not widely used in the mines of Donbas. Obviously, it should have specified the areas of application depending on coal grades and depth of seam development. It is known that V^g (V^{daf}) is used in accordance with [34] at the yield of volatile substances from 9% to 29% and more. However, the highest probability of sudden coal and gas outburst occurs for coals with $V^{daf} \approx 19\%$ [38], and the lowest - at $V^{daf} \approx 4$ % and ≈ 34 %, depending on the significant yield of volatile substances and natural gas content. In the mines of Donbas, the current prediction of outburst hazard is carried out from the depth of 150–400 m. That is, in terms of the depth of development, this dependence features the possibility of limited application. The conclusion applied to all coal seams (threatening and dangerous due to sudden coal and gas outburst) to a depth of 3.5 m. In the case of the "safety" prediction, the following measurements were performed after not more than 2.0 m of advancement of the preparatory workings and 3.2 m of the breakage heading [33, 37, 39]. Then [10, 34] the value of the critical value of the initial gas emission rate g_n^0 was set to 4.0; 4.5; 5.0 l/min depending on the coal grade. According to [34], the value of the unreduced advance was not less than 1.5 m (for preparatory workings) and not less than 0.3 m (for breakage heading). In the SOU [10], it is noted that the prediction should be carried out after not more than 2.0 m of advancement of the working faces and not more than 2.7 m of advancement of the heading faces. To assess the changes in the gas-dynamic state of coal seams in the measured (undermined or overmined) areas, the value of the initial gas emission rate is used, which is determined by the chambers with a length of 0.5 m at interval (every 1 m) drilling of control boreholes [39]. Based on the obtained values of the initial gas emission rate, its average level and dispersion are calculated for each meter interval.

All described methods of determining the unloading zone and the current prediction of outburst hazard are currently carried out by the same devices for sealing boreholes and devices for determining the value of the initial gas emission rate, according to [10]. The difference in these methods is the fact of using the maximum measured value of the initial gas emission rate and measurement locations where other special methods of preventing sudden coal and gas outburst are not applied. The determination of the unloading zone is carried out by changing the interval measured values of the initial gas emission rate with the same drilling-measurement interval. Moreover, upon detection of the maximum gas emission and its decrease at the next interval, drilling-measurement is determined by the unloaded (safety) zone, and coal extraction is allowed within the unloaded zone, reduced by the value of unreduced advance. The size of the unloading zone can change within a wide range depending on the mining, geological and technical conditions. As it is established, the time interval for the formation of the unloading zone is from 1 hour to 3 hours at mechanized coal extraction and up to 24 hours at coal blasting, which is actually used to regulate the duration of technological processes [10]. The unloading zone on outburst-hazardous coal seams varies from the minimum size close to zero to several meters.

In practice, determination of the size of the unloading zone according to the dynamics of gas emission is performed both after the application of methods to prevent sudden coal and gas outburst (as a way to control efficiency) and without their application. Common in the mentioned methods is the determination of the permissible depth of excavation, the presence of a zone of unreduced advance (reserve) and considering of the face area part of the seam as dangerous in case of greater gas emission (current prediction), and small (non-technological) dimensions of the safe unloading zone (gas emission dynamics).

Based on the above discussion of the results obtained, it can be assumed that the unloading zone is a degassed part of the rock massif with broken (or squeezed) coal, in which:

1. It is possible to extract to a given depth without performing outburst protection measures.

2. It is possible to regulate the size of the extraction by the depth of the unloading zone with taking into account the unreduced advance.

3. The size of the unloading zone is determined by the settling time of the face with taking into account the stress-strain state (SSS), physical-mechanical properties (PMP), geological factors and technologies of massive destruction.

4. The size of the unloading zone may change depending on technological factor (extraction technology). For example, in the case of rapid plough extraction, the zone does not have time to form, i.e. when the plough (combine) either takes out a strip along the entire length of the longwall, or can cut forward by 2–3 m.

5. The unloading zone in outburst-hazardous coal seams varies from the minimum dimensions close to zero to several meters. It significantly decreases in zones of high rock pressure, counter-heading drivage, etc.

The author considers that it is possible to estimate the size of the unloading zone not only by using the method of estimation by the dynamics of the initial gas emission rate along the length of the control borehole or other normative method, but also by other new effective developed methods of prediction. At the same time, unfortunately, there is currently no way to predict the outburst hazard or estimate the size of the unloading zone that is unambiguously reliable, that is, that will necessarily determine whether the GDP will or will not occur. At the same time, it should be understood that the most important thing for practice is not to develop an effective anti-outburst measure, but to know clearly when and where it should be applied. In the process of developing new progressive methods of prediction outburst hazard, we can expect a significant increase in the volume of application of this methodology in the development of coal seams, as it significantly increases mobility and, most importantly, reduces the labor intensity of work in the face. Thus, in the future, it will be possible to significantly increase the productivity of coal mining, reduce its cost by reducing the cost of anti-outburst measures, downtime and a number of other factors.

4. Conclusions

1. All methods known in Ukraine for assessing the unloading zone concern only assessing the outburst hazard in the seam area, which is limited by the depth of the control borehole. Speaking about the hazard by types of GDP (in fact, about the possible real hazard), none of the methods for predicting or assessing the size of the unloading zone, including the new ones based on the analysis of amplitude-frequency characteristics when impacting the seam in any way, do not speak about GDP with 100% reliability.

2. The research established the fact of formation and gave a description of the unloaded zone in the face area part of the seam. The time interval for the formation of the unloading zone is from 1 hour to 3 hours during mechanized coal extraction and

up to 24 hours during coal blasting, which is practically used to regulate the duration of technological processes. The unloading zone in outburst-hazardous coal seams varies from the minimum dimensions close to zero to several meters. It significantly decreases in zones of high rock pressure, counter-heading drivage, etc.

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ЗОНА РОЗВАНТАЖЕННЯ І ЇЇ ВПЛИВ НА БЕЗПЕЧНЕ ВІДПРАЦЮВАННЯ ВИКИДОНЕБЕЗПЕЧНИХ ВУГІЛЬНИХ ПЛАСТІВ

Мінєєв С.П.

Анотація. Відпрацювання викидонебезпечних вугільних пластів регламентується низкою нормативних документів, які дозволяють коректно оцінювати параметри зони розвантаження в привибійної частини пласта, отже, немає можливості безпечної відпрацювання викидонебезпечних пластів.

Метою досліджень є обґрунтування основних параметрів зони розвантаження, уточнення її параметрів для безпечного відпрацювання викидонебезпечних вугільних пластів.

Говорячи про фактичну небезпеку реалізації газодинамічних явищ, то, як показує практика, жоден із методів прогнозу або оцінки величини зони розвантаження, включаючи і знову розроблені, не говорить зі 100% надійністю про його реалізацію або його вид. У статті проведено аналіз результатів визначення величини зони розвантаження різними методами контролю ефективності вживаних заходів та небезпеки виїмки вугілля у цій зоні. При обговоренні отриманих результатів сформульовано визначення зони розвантаження, як дегазованої частини гірського масиву з зруйнованим або віджатим вугіллям. Як встановлено, у цій зоні існує можливість виїмки вугілля на задану глибину без виконання противикидних заходів з можливістю регулювання величини виїмки глибиною зони розвантаження з урахуванням незнижуваного випередження. Величина зони розвантаження визначається часом відстою забою з урахуванням напружено-деформованого стану, фізико-механічних властивостей, геологічних факторів та технології руйнування масиву. Величина зони розвантаження може змінюватись залежно від технологічного фактора (технології виїмки). Наприклад, за швидкої виїмці стругом зона не встигає формуватися, тобто. коли струг (комбайн) або виймає смугу по всій довжині лави або зарубується вперед на 2-3 м.

Виконаними дослідженнями встановлено факт формування розвантаженої зони у привибійній частині пласта. Тимчасовий інтервал формування зони розвантаження становить від 1 до 3 годин при механізованому виїмці вугілля і до 24 годин при вибуховому відбиванні вугілля, що практично використовується при регламентації тривалості технологічних процесів. Зона розвантаження на викидонебезпечних пластах змінюється від мінімальних розмірів, близьких до нуля, до декількох метрів.

Ключові слова: викидонебезпека, газоносний, зона розвантаження, вугільний пласт, прогноз, контроль ефективності.