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A METHOD FOR PREVENTING METHANE EXPLOSIONS WHEN MINING GAS-SATURATED COAL SEAMS

Purpose. The research is aimed at improving the methods for preventing coal dust-methane explosions during cutting-loading machine operation when mining coal seams with gas-dynamic phenomena (GDP).

Methodology. When performing the research, basic methods of mathematical and physical modeling, bench experimentation, as well as methods for processing the results of laboratory and industrial studies in the EXCEL and MATHCAD environment were used. Measurement of the dynamic parameters of the cavitation flow of the liquid (frequency and range of pressure auto-oscillations) was carried out using the ДДІ-20 sensor. The signal through the АЦП-12 analog-to-digital converter was sent to the hardware and software complex based on the Athlon-800 PC with the "DASYLAB" and "GEMIS WIN" software.

Findings. A method for combating explosions of dust-methane mixture has been developed. A generator of cavitation self-oscillations of the mine flushing fluid pressure is used to automatically destroy and remove clogging from the nozzle channels of the irrigation system. Simultaneously with the supply of the water-air mixture directly to the broken coal mass, the coal dust-methane mixture, formed in stagnant zones near the face, is sucked in by a perforated pipeline and sent through a non-perforated pipeline outside the cutting-loading machine boundaries in the direction of the mine working ventilation flow.

Originality. The use of cavitation generators in the irrigation system of cutting-loading machines in the process of rock breaking to prevent coal dust-methane explosions has been scientifically substantiated. Functional dependence has been determined of amplitude and frequency of the flushing fluid self-oscillations periodically created at the outlet of the cavitation generator on the boost pressure, which periodically occurs as the nozzle channels are clogged with destruction products of mine water supply system and rocks. The automatic destruction and subsequent removal of clogging from the nozzle channels is performed by high-frequency self-oscillations of the flushing fluid, the pressure of which at maximum amplitude and frequency values exceeds the ultimate compressive strength of the debris particles.

Practical value. The improved complex method can ensure uninterrupted operation of the irrigation system nozzles and significantly reduce the probability of the coal dust-methane mixture explosion in the places of broken gas-saturated coal accumulation during cutting-loading machine operation. It also increases the safety of mining operations when mining coal seams.

Keywords: *cutting-loading machine, coal dust, methane, cavitation generator*

Introduction. A significant number of Ukrainian coal mines are explosion-hazardous ones due to coal dust explosiveness and are over-categorized in terms of methane gas and sudden coal-gas outbursts into the extraction working [1, 2]. Methane explosions and ignitions account for 96 % of the total number of accidents that occur due to dust-gas regime violations in coal mines. Even local methane ignitions can lead to large explosions of dust-gas-air mixtures and, as a result, to large human casualties, material and financial losses [3]. The technology of underground coal mining has changed significantly over the past period, which has had a negative impact on the risk factors of gas and coal dust explosions [4, 5]. This is evidenced by a number of fatal accidents that occurred in 2007–2008 in mines of the post-Soviet space: Ulianovska, Yuvileina (Russia), Krasnolymanska, A. F. Zasyadko

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(Ukraine), Abayska (Kazakhstan), etc. [6]. A fairly large number of accidents caused by methane and coal dust explosions are recorded in mines in the People's Republic of China (PRC): only in recent years – more than 30 powerful explosions that resulted in the deaths of many miners.

Up to 1.5 % of local methane ignitions during the operation of cutting machines in extraction workings turn into developed explosions, and 20 % of ignitions during the operation of tunneling machines in preparatory workings turn into methane and coal dust explosions. About 87 % of coal dust explosions in mines were initiated by methane explosions or ignitions. The situation is similar abroad. In South Africa, during coal mass breaking, about 70 % of methane ignitions occur, and in the United States – up to 50 % of cases of its ignition [3].

When mining seams that are prone to gas-dynamic phenomena (volatile matter yield is 15 % or more), in the faces of extraction workings in places of increased methane release (yield), both free and bound (sorbed) [6, 7], local coal dust-methane accumulations may be formed. In poorly ventilated stagnant zones, for example, directly in the places of accumulation of broken gas-saturated coal or a coal-rock mixture with the release of a coal dust-methane mixture, coal dust-methane concentration can reach 2 % or more [8, 9].

A critical factor that can enhance the explosion effect for coal dust-methane mixture and oxygen is the limited space in hard-to-ventilate stagnant zones. When the coal dust-methane mixture is in a confined space, the pressure and temperature rise rapidly due to combustion. This increase in pressure can lead to an explosion, generating a powerful shock wave that can cause significant damage to people and surrounding equipment.

The intensity of dust formation during coal mining depends on many rock factors (physical-chemical properties, moisture content, etc.), as well as on the method of their breaking (mining technology). In mine workings driven by cutting-loading machines, the working body of which is an intensive source of dust during the mechanical coal-rock breaking, coal dust is formed 2.5–6.5 times as much as when using the drilling-blasting method [1]. Coal dust increases the gas-air mixture explosion power, which leads to a significant increase in the number of miners killed.

Practice shows that providing reliable dust explosion protection is a complex organizational-technical task, the solution of which depends on an objective assessment of explosion hazard factors. The main of them are:

1. Lower concentration limit of deposited dust explosive capacity. It is expressed by dependence (obtained by Makeevka Research Institute for Mining Safety in an experimental gallery) [10]

$$\delta = A_{\exp}\left[\frac{k_1}{V_r} - k_2 n\right],$$

where δ is the lower concentration limit of deposited dust explosive capacity, g/m^3; $A_{\exp}$, k_1, k_2 are experimental coefficients for the experimental gallery are 25.08; 22.71; 0.69, respectively; V_r is the volatile matter yield, %; n is the methane content in the mine working, %.

2. Mass of dust deposited per unit surface of the mine working and mining equipment.

3. Methods of precautionary measures to prevent the formation of explosive methane concentrations.

Methods for localizing dust-gas-air mixture explosions. The source of ignition of methane, as well as hybrid mixtures (for example, in coal mines, methane-air, coal dust – air, coal dust and pyrite dust) can be static electricity. When combined, hybrid mixtures can form explosion-hazardous mixtures, although the concentration of each component is below the flame propagation limit [11, 12].

Recently, about one in five to seven methane and coal dust explosions has been caused by frictional sparking. In the process of friction of the cutters against pyrite inclusions compared to sandstone, frictional sparking can ignite not only methane, but also coal dust. The pyrite dust cloud by the time of burning is tens of times longer than the time of existence of the hot trace that appears when the cutters interact with sandstone. Red-hot pyrite dust particles burn in the air within tenths of a second. The time required to prepare the explosive medium (induction period) is measured in milliseconds. The lower induction period for coal dust is 40 ms, and for methane – 2 ms. The induction period is significantly influenced by the volatile matter yield, which changes during the coal metamorphism process. As the degree of metamorphism increases, the coal dust induction period increases depending on coal ash content. Methane ignitions and explosions with severe consequences as a result of frictional sparking of the cutting-loading machine actuators against the host rocks with pyrite inclusion cause large material damage [4, 13].

Literature review. In the process of mechanized rock breaking during tunneling and mining operations, various methods and devices are used to prevent the formation and local accumulation of methane on the road near the cutting-loading machine [4, 12].

For example, the erosion of local methane accumulations is used, which is achieved by increasing the air flow velocity in the extraction working (up to 0.05 m/s) [8, 14]. However, the air flow along the mine working, even increased, does not ventilate such places in the mine working as the coal seam face and the spaces under the augers of the cutting-loading machine working body, where local methane accumulations can occur.

In addition, local methane accumulations near the cutting-loading machine during its operation can be eroded by redistributing the air flow moving along the cutting-loading machine. To do this, a portion of the air flow mixed with water is fed into the space between the cutting-loading machine body and the coal seam using a double-jet water-air ejector. The ejector is rigidly mounted on the body of the cutting-loading machine behind the augers of its working body at a distance of 0.3–0.4 m [15, 16]. However, this technical solution also does not irrigate such places as coal seam faces and spaces under the augers of the cutting-loading machine working body. This can also lead to a methane explosion due to its local accumulation.

According to the "Wetting agent for coal dust suppression" method, which is used to prevent coal dust-methane explosions, water is taken from the mine water supply system and the pressure of the taken water is increased using a water pump. Then this water is fed into the irrigation main of the cutting-loading machine, mixed with liquid wetting additives and this mixture is sprayed with nozzles directly at the place of coal breaking by the cutting-loading machine actuator [17, 18]. However, the limited capacity of water with liquid wetting additives cannot affect the amount of methane released from open coal fractures during coal breaking. This can lead to ignition and explosion of methane released during coal mining [19, 20].

Another way to prevent coal dust-methane explosions is to spray a mixture of water and liquid wetting additives. It consists of devices for taking water from the mine water supply system, increasing the pressure of the withdrawn water using a water pump and supplying this water to the irrigation main of the cutting-loading machine. Water under high pressure is passed through the dispenser with the addition of liquid wetting additives in various proportions. This mixture is used by spraying it directly at the place of coal breaking by the actuator [21, 22]. The technical disadvantage of this method is the complexity of the equipment and its maintenance, as well as the high cost of operations for broken coal irrigation.

In the "Method for preventing coal dust-methane explosions," water saturated with inert gas is sprayed. This method involves taking water from the mine water supply system, increasing the pressure of the withdrawn water using a water pump, and supplying this water to the irrigation main of the cutting-loading machine. This water is used by spraying with nozzles directly at the place of coal breaking by the cutting-loading machine actuator [22]. The water is saturated under pressure with an inert gas, such as nitrogen or carbon dioxide, before it is fed into the pumping unit. After that, the water saturated with inert gas is sprayed in the nozzle cone at the nozzle outlet at a given solid angle [23]. The spot from the gas mixture spray cone is directed both to the cutter of the cutting-loading machine working body and to the face surface behind the cutter [24]. This method requires creating two pipelines moving together with the cutting-loading machine to supply water and nitrogen/carbon dioxide, which complicates the technology.

"Pneumohydraulic irrigation system" is designed to prevent coal dust in order to neutralize it by irrigating it with an air-water mixture. For this purpose, two-component (liquid-gas) nozzles are used, which are supplied with air and water through separate pipelines. Under pressure, they are directed into the space under both augers of the cutting-loading machine working body and into the face of the coal seam directly to the broken coal mass [18]. The disadvantage of the "Pneumohydraulic irrigation system", when used in mine conditions for dust suppression and prevention of methane explosions on the cutting-loading machine actuator, is also the need to create two pipelines for water and compressed air supply moving together with the cutting-loading machine. Moreover, additional maintenance is required and the cost of using compressed air increases.

The next device implements the "Method for eroding local methane accumulations near a coal shearer, equipped with two augers and a scraper conveyor". This method consists of a cutting-loading machine and a double-jet ejector. The water-air mixture of the double-jet ejector is directed under pressure into the space under both augers of the cutting-loading machine working body and into the face of the coal seam directly to the broken coal mass in the process of loading it onto the scraper conveyor [25, 26]. The disadvantage of the device is that the eroded coal dust-methane mixture is not completely removed and not directed into the air flow. This is due to the lack of equipment for removing (suction) of the coal dust-methane mixture formed during the breaking of a gas-saturated coal seam from the space, bounded by extraction working roof, its face and bottom.

Thus, modern methods do not fully provide guaranteed explosion protection and are not effective enough in terms of reducing dustiness in mining faces. The reasons for this situation are not only organizational and economic. It is necessary to recognize the influence of objective factors, such as an increase in the load on the mining face and the transition at some mines to mining of lower horizons with increased methane emissions. In view of the above, the degree of technical sophistication of new mining machines is determined by the extent to which their anti-explosive equipment ensures the level of explosion safety of the process of coal-rock mass breaking. This circumstance necessitates the improvement of anti-explosion methods, measures and equipment of mining machines in order to reduce the number of developed gas and coal dust explosions in mine workings. To date, the relevance of this problem has not been lost, since no effective practical solution has yet been found.

The purpose is to improve the method and equipment of a cutting-loading machine to prevent coal dust-methane explosions during its operation in a gas-saturated coal seam.

Methods. Source of ignition of coal dust-methane-air medium in mines can be frictional sparking. The cause of methane and coal dust ignition (explosions) is associated with a high-temperature "spot" of frictional contact between the cutter and the rock. The process of frictional contact between the tool and the rock, as well as frictional sparking, is a subject of serious and long-term study in most coal-mining countries. The main results of such studies are as follows [26]. It has been found that the probability of coal dust ignition during friction is almost equal to one at a load per cutter of 1 to 3 MPa and above. The more intense the load, the faster the ignition occurs. Moreover, the number of working cutters does not influence the probability of ignition.

During friction against sandstone, the coal dust explosion was observed when 2.7 % or more of methane was added to the dust-air mixture. With a lower methane content, no dust explosions were recorded.

Studies have revealed differences in the coal dust-methane ignition as a result of friction of cutters against pyrite inclusions and sandstone. When the actuator cutter

rubs against pyrite, a halo of flammable pyrite dust cloud is generated at a distance of 0.1–0.2 m from the cutter, and sometimes even closer. The length of the flame torch reaches 0.4 m with its diameter of 0.1–0.2 m. The ejected pyrite dust particles are heated by a cutter to a temperature of 350–400 °C, entering the air, ignite and burn within 0.2–0.3 seconds. This indicates a significant energy and action of an ignition source of a long duration, sufficient to ignite not only methane but also coal dust. This indicates that dust explosion protection measures against friction ignition source should be applied not only in gas mines, but also in mines hazardous for coal dust explosions.

Explosion-proof operation of the tool and minimal dust emission during coal or rock breaking are ensured using high-pressure irrigation of rocks by supplying water jets directly to the contact zone of the tool with the mass to be broken.

Previously, to eliminate the possibility of methane ignition, developments were primarily aimed at creating effective irrigation systems to prevent the possibility of coal dust-methane mixture ignition. The efficiency was achieved by supplying water jets to each cutter of the actuator (from the back to the cutter trace), increasing the jet pressure (3 MPa and more), and increasing the reliability of irrigation systems by diluting them internally. Studies by many scientists have determined that the prevention of methane and coal dust ignitions/explosions during the operation of mining and tunneling machines in a rock mass with sandstones with strength $f = 8$ and more according to Prof. Protodyakonov's scale and with pyrite inclusions with a sulfur content of more than 35 % is provided by explosion-proof irrigation with water consumption of at least $3.33 \cdot 10^{-5}$ m^3/s per cutter at a pressure of at least 4 MPa, which is regulated by safety rules. Three types of actuators with water-jet devices are distinguished based on application conditions and design parameters. The first type is low-pressure (up to 4 MPa) water irrigation of the cutters with a minimum water consumption of $3.33 \cdot 10^{-5}$ m^3/s per cutter. The second type is water irrigation of the cutters at a mean pressure of 15–20 MPa (high-pressure irrigation) with a water consumption of $66.67 \cdot 10^{-5}$ m^3/s per cutter. The third type of device (hydromechanical method of coal and rock breaking) uses compact high-speed water jets under a pressure of 30–100 MPa or more. The hydromechanical method of breaking is based on the combined impact on the rock mass by a high-speed water jet with surfactant and a mechanical tool of chipping or cutting action [27, 28]. The efficiency of the hydromechanical method is determined by efficiency of its mechanical and hydraulic components. When designing actuators with water-jet devices of the third type, it is planned to eliminate dust and spark formation, reduce cutter wear, and increase the productivity of mining and tunneling machines without increasing the specified power of the actuator engines.

It should be noted that at present, the efficiency of external and internal low-pressure irrigation systems has reached its maximum, and the residual air dust content remains at the level of 20 %, which does not provide guaranteed explosion protection and is not effective enough in terms of reducing dust content in mining faces. Further increase in spraying power is impractical, because the broken rock mass will be over-moistened, the liquid will be carried into the working zone, and the bottomhole space will be water-flooded.

Compared to low-pressure irrigation systems, high-pressure internal irrigation systems (systems of the second type) have a higher efficiency with the supply of water jets with a pressure of 10–20 MPa to the cutter trace. Jet spraying is provided by jet-forming nozzles, increased pressure and increased outflow rate. This results in more intensive air ejection and increased methane removal from the cutting zone. Increased water flow rate helps to bind explosion-hazardous dust of fine fractions and reduce the possibility of its penetration into the lungs.

However, although high-pressure irrigation has some advantages, a greater effect of dust suppression and explosion protection of cutting-loading machines can be achieved with the hydromechanical combined method of coal breaking using compact water jets under a pressure of about 30 MPa. Foreign experience of using thin high-pressure water jets for cutting rocks also confirms the effectiveness of hydro-jet technologies in mining. At the same time, during the operation of cutting-loading machines with hydromechanical actuators, it has been found that in a number of cases high-pressure hoses ruptured and, as a result, injured miners. The location of high-pressure pumping units in the drift leads to certain pressure losses and a 5–10 % increase in total energy consumed for breaking.

For the above reasons, the practical use of both high-pressure irrigation and the hydromechanical combined method does not allow us to exclude the related injuries to miners, material and economic losses.

Thus, it can be concluded that the low-pressure irrigation method by supplying water from the mine water supply system to the irrigation main of the cutting-loading machine under pressure of 2–5 MPa is safer, and therefore more promising for irrigating broken rock while conducting preparatory and extraction workings. But the nozzles for spraying the flushing fluid have flow channels with diameters not exceeding 1 mm, and the mine water used for spraying contains solid particles larger than 1 mm. During one day of cutting-loading machine operation, the nozzles are completely clogged with destruction products of mine water supply system and rocks [22]. This can lead to the cessation of irrigation water supply to the rock cutting zone and, as a consequence, to frictional sparking, provoking an ignition of both methane and coal dust.

Given the above, the authors of the paper propose a method for preventing clogging of nozzle channels by destroying it with cavitation self-oscillations of the flushing fluid high-frequency pressure [29, 30]. In addition, based on the working conditions in hard-to-ventilate stagnant zones of extraction working faces, the developed technology should reduce the probability of gas-air mixture and coal dust explosions during the cutting-loading machine operation, while the equipment should be of the lowest labor intensity and cost.

The research is based on the task of improving the method and devices for preventing coal dust-methane explosions during the cutting-loading machine operation in a gas-saturated coal seam by means of additional equipment of a cutting-loading machine with a double-jet water-air ejector: generator of cavitation self-oscillations of the flushing fluid high-frequency pressure to destroy nozzle clogging, as well as a suction fan, an inlet perforated pipeline and an outlet non-perforated pipeline, which allows ensuring a technical result — a significant reduction in methane concentration (up to 2 %, in accordance with the Safety Rules in Coal Mines [8]) in the airspace, bounded by extraction working roof, its face and bottom, as well as reduced probability of the coal dust-methane mixture explosion during the cutting-loading machine operation by taking this mixture from the extraction working face and directing it towards the ventilation flow movement of the extraction working outside the cutting-loading machine boundaries.

Research results. The task set is solved in the following way. A cavitation oscillation generator is used to prevent clogging of the nozzle channels of the cutting-loading machine irrigation system by destroying it with cavitation self-oscillations of the flushing fluid high-frequency pressure. Its calculation scheme is shown in Fig. 1.

The destruction and subsequent removal of clogging from the nozzle channels is performed using high-frequency self-oscillations of the flushing fluid, the maximum pressure values of which exceed the ultimate compressive strength of the debris particles. The amplitude of self-oscillations of the flushing fluid pressure is calculated using the following formula

$$\left|\delta P_1\right| = \rho \cdot v_{cr}^2 (2\pi)^2 Sh_m^2 \frac{I_d}{\sqrt{1+\dfrac{(2\pi)^2 \cdot v_{cr}^2 \cdot I_d^2 \cdot F_2^2}{l_k^2 \cdot c^2}}} \cdot \frac{\left|\delta V_k\right|}{l_k^2},$$

where ρ is the fluid strength; Sh_m is the Strouhal number; δV_k is the current value of the detached cavern part volume, m^3; l_k is the cavitation cavern length, m; c is the sound velocity in a fluid, m/s; F_2 is the outlet section area of the generator diffuser, m^2; I_d is the inertial resistance coefficient of the oscillation generator diffuser part, m^{-1}, located between the newly settled cavern and the diffuser outlet, is determined by the formula

$$I_d = \frac{1}{\pi \cdot \mathrm{tg}\dfrac{\beta}{2}} \cdot \left[\frac{1}{r_{cr} + l_k \cdot \mathrm{tg}\dfrac{\beta}{2}} - \frac{1}{r_{cr} + l_d \cdot \mathrm{tg}\dfrac{\beta}{2}}\right],$$

where l_d is an axial length of the generator diffuser, m; β is the diffuser opening angle, deg.; r_{cr} is the radius of the generator critical section, m.

The self-oscillation frequency is calculated by the formula

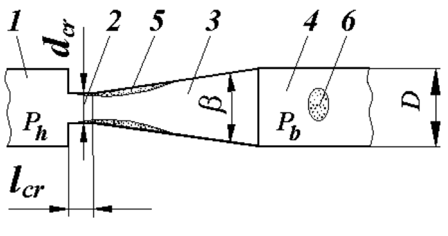

Fig. 1. Cavitation oscillation generator schematic diagram:
1 — inlet pipeline; 2 — confusor; 3 — diffuser; 4 — outlet pipeline; 5 — cavitation zone; 6 — detached part of cavern; d_{cr} — critical section diameter; D — outlet pipeline diameter; l_k — confusor length; β — diffuser opening angle; P_b — boost pressure; P_h — injection pressure

$$f = \frac{v_{cr} \cdot \mathrm{tg}\dfrac{\beta}{2}}{r_{cr}\sqrt{\mu}} \cdot \left(1 - \sqrt{1 - P_b/P_h}\right),$$

where β is a diffuser opening angle, deg.; P_b is the boost pressure, MPa; P_h is injection pressure, MPa; v_{cr} is fluid velocity in the generator critical section, m/s; μ is the generator consumption factor; r_{cr} is the radius of the generator critical section, m.

In the laboratory conditions of the M. S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine, bench studies have been conducted to determine the parameters of fluid pressure oscillation amplitude at the outlet of the cavitation oscillation generator GK-2.5 with a critical section of d_{cr} = 2.5 mm, diffuser opening angle of β = 25° and a post-diffuser channel with a length of $L = 100d_{cr}$.

Fig. 2 shows the dependence of the self-oscillation amplitude ΔP on the boost pressure P_b at a flushing fluid consumption of $Q = 0.65 \cdot 10^{-3}$ m^3/s (35 l/min) and a head pressure of P_h = 10 MPa.

Fig. 3 shows the dependence of the frequency f on the boost pressure P_b at a consumption Q = 35 l/min and P_h = 10 MPa

The automatic destruction and subsequent removal of clogging from the nozzle channels of the cutting-loading machine irrigation system during its operation is achieved by high-frequency flushing fluid self-oscillations, the pressure of which at maximum amplitude and frequency values exceeds the ultimate compressive strength of the debris particles.

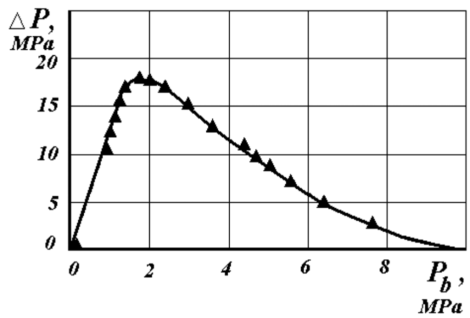

Fig. 2. Dependence of ΔP on the boost pressure P_b at a consumption $Q = 0.65 \cdot 10^{-3}$ (39 l/min) and P_h = 10 MPa

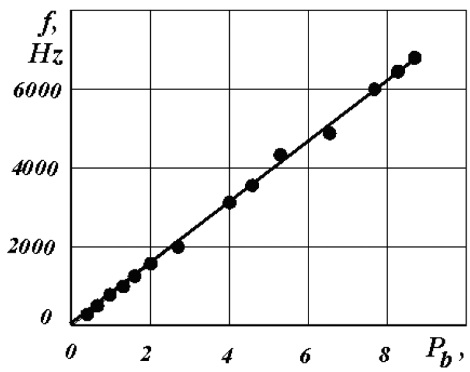

Fig. 3. Dependence of the frequency f on the boost pressure P_b at a consumption $Q = 0.65 \cdot 10^{-3}$ (39 l/min) and P_h = 10 MPa

In the method for preventing coal dust explosions by irrigation, water is taken from the mine water supply system while the cutting-loading machine is working in a gas-saturated coal seam. The water pump increases its pressure to a value of at least 2 MPa and supplies it to the nozzle channels of the irrigation system of the cutting-loading machine working body to spray water with nozzles directly at the place of coal breaking by the cutting-loading machine working body. After the water pump increases the pressure, the water is preliminarily passed through a cavitation generator with a critical section diameter of at least 3 mm before it is supplied to the nozzle channels. As clogging accumulates in the nozzle channels and the boost pressure reaches half of the head pressure, the cavitation generator is automatically activated and begins to create cavitation oscillations in water pressure. The maximum values of the amplitude and frequency of the flushing water pressure self-oscillations increase at least twice, destroying clogging and cleaning the nozzle channels of the cutting-loading machine irrigation system.

Fig. 4 shows a technological scheme of the extraction working equipment for implementing a method for preventing coal dust explosions by irrigation during the cutting-loading machine operation.

The method is performed as follows. The equipment for irrigation of the working body *2* of the cutting-loading machine is assembled in the mining face 1 in accordance with the scheme in Fig. 1. Then, water from the mine water supply system *3* is directed to the suction line *4* of hydraulic pump *5* to increase its pressure. From the hydraulic pump *5*, water under a pressure of at least 2 MPa is directed through the pressure line *6* through the cavitation generator *7* with a critical section diameter of at least 3 mm (so that the destruction products of water supply system and rocks with a size of 2–3 mm do not clog the critical section of the cavitation generator *7*) and through the post-diffuser *8* into the nozzle channels *9* to irrigate the cutting-loading machine cutter *10*, broken coal *11* and coal dust *12*. As clogging accumulates, the opening in the nozzle channels *6* decreases, thereby creating a boost pressure. When the boost pressure reaches half of the head pressure, the cavitation generator *7* is automatically activated and conditions are created for its optimal operating mode (maximum frequency and amplitude of pressure self-oscillations). Pulsed water pressure, the maximum values of which are increased at least twice, destroys clogging with destruction products of water supply system and rocks and cleans the nozzle channels *6*, which ensures continuous cooling of cutter *10* of the cutting-loading machine actuator and high-quality irrigation of the broken coal *11* and coal dust *12*, which reduces the probability of methane and coal dust *12* explosions.

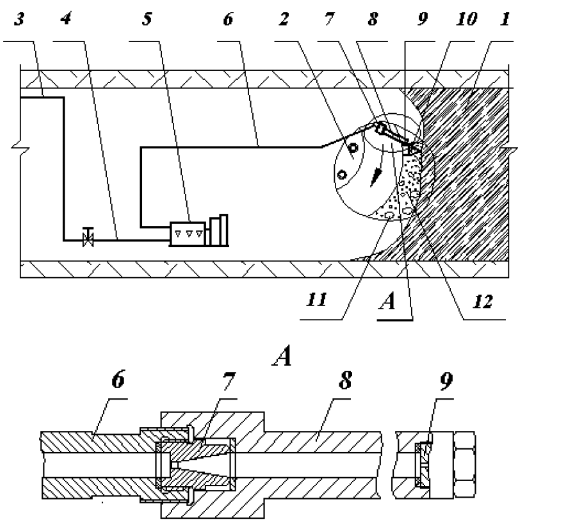

Fig. 4. Technological scheme of the extraction working equipment for implementing a method for preventing coal dust explosions by irrigation during the cutting-loading machine operation:

1 – extraction working; 2 – cutting-loading machine working body; 3 – mine water supply system; 4 – pump suction line; 5 – hydraulic pump; 6 – pump pressure line; 7 – cavitation generator; 8 – post-diffuser; 9 – nozzle; 10 – cutter of the cutting-loading machine working body; 11 – broken coal; 12 – coal dust

The use of a cavitation generator for water pressure oscillations in the cutting-loading machine irrigation system, when breaking rock automatically and without the use of manual labor, as the nozzle channels become clogged, cleans them. This reduces maintenance costs for the irrigation system and ensures its uninterrupted operation, while reducing the probability of broken rock-coal dust explosions and increasing the safety of mining operations in coal seams prone to gas-dynamic phenomena.

In addition, in an improved method, simultaneously with the supply of the water-air mixture directly to the broken coal mass near the face, the resulting coal dust-methane mixture is removed from the space, bounded by extraction working roof, its face and bottom. The removed coal dust-methane mixture is directed towards the ventilation flow movement of the extraction working outside the cutting-loading machine boundaries. The equipment consists of a cutting-loading machine with two augers, one of which is mounted on its movable boom, and a double-jet ejector, the water-air mixture of which is sent directly to the broken coal mass on the ground near the extraction working face. The cutting-loading machine is additionally equipped with a suction fan, an inlet perforated pipeline, and an outlet non-perforated pipeline, which are rigidly mounted on the cutting-loading machine movable boom. The inlet perforated pipeline is placed above the broken coal mass in the space, bounded by extraction working roof, its face and bottom, and is connected to the suction fan inlet. A non-perforated pipeline is placed in the flow that ventilates the extraction working, towards its movement with coal dust-methane mixture outside the cutting-loading machine boundaries, and is connected to the suction fan outlet.

The essence of the improved method and equipment of the cutting-loading machine is explained in the drawings. Fig. 5 shows a technological scheme of the extraction working equipment for implementing the technology of preventing coal dust-methane explosions during the cutting-loading machine operation with equipment placed on its body when mining coal seams prone to gas-dynamic phenomena.

To implement an improved method for preventing coal dust-methane explosions, the cutting-loading machine *1* with a movable boom *2* and augers *3* and *4*, a double-jet water-air ejector *5* and a scraper conveyor *6*

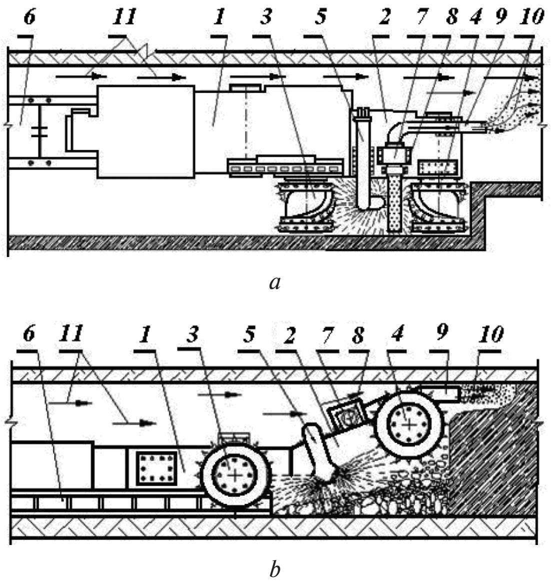

Fig. 5. Technological scheme of the extraction working equipment for implementing the improved technology of preventing coal dust-methane explosions during the cutting-loading machine operation with equipment placed on its body:

a — top view; b — view of the longitudinal mine working section; 1 — cutting-loading machine; 2 — movable boom of the cutting-loading machine; 3 and 4 — cutting-loading machine augers; 5 — double-jet water-air ejector; 6 — scraper conveyor; 7 — suction fan; 8 — inlet perforated pipeline; 9 — outlet non-perforated pipeline; 10 — selected coal dust-methane mixture; 11 — ventilation flow of the extraction working

is additionally equipped with a suction fan *7*, an inlet perforated pipeline *8* and an outlet non-perforated pipeline *9*. The suction fan *7* is rigidly mounted on the top of the movable boom of the cutting-loading machine *1*. The inlet perforated pipeline *8* is placed in the space, bounded by extraction working roof, its face and bottom, and is connected to the suction fan *7*. And the outlet non-perforated pipeline *9* is connected to the suction fan *7* and directed into the air flow *11*, which moves on the road of the cutting-loading machine *1*, towards the ventilation flow movement of the extraction working *11* outside the cutting-loading machine *1* boundaries.

The water-air mixture, which is supplied under pressure by a double-jet ejector, cools the cutters of the working body and ensures effective wetting of the cutting zone, creating a non-combustion atmosphere. In this case, the coal dust-methane mixture that accumulates in poorly ventilated stagnant zones is sucked in by the inlet perforated pipeline located above the broken gas-saturated coal or a coal-rock mixture, thereby effectively preventing possible ignition. When irrigating with a pressurized water-air mixture, due to the large droplet activity and high cooling potential, the water demand is greatly reduced compared to pure water irrigation. At the same time, the maximum values of water consumption and pressure are individually selected for individual machine types. An improved complex method involves simultaneous supply of water-air mixture (with a minimum consumption of 2×10^{-5} m^3/s and an average pressure of 15–20 MPa) directly to the broken coal mass for wetting and to the cutters of the working body for their cooling, as well as suction of the coal dust-methane mixture created during the cutting-loading machine operation in a gas-saturated coal seam through the inlet perforated pipeline, which makes it possible to effectively prevent coal dust-methane explosions.

Conclusions. The use of cavitation generators in the irrigation system of cutting-loading machines in the process of rock breaking to prevent coal dust-methane explosions has been scientifically substantiated. Functional dependence has been determined of amplitude and frequency of the flushing fluid self-oscillations periodically created at the outlet of the cavitation generator on the boost pressure, which periodically occurs as the nozzle channels are clogged with destruction products of mine water supply system and rocks. The automatic destruction and subsequent removal of clogging from the nozzle channels are performed by high-frequency self-oscillations of the flushing fluid, the pressure of which at maximum amplitude and frequency values exceeds the ultimate compressive strength of the debris particles.

An improved complex method for preventing coal dust-methane explosions during the cutting-loading machine operation in a gas-saturated coal seam provides high efficiency while controlling local coal dust-methane accumulations in poorly ventilated stagnant zones, due to irrigation of the broken coal mass with water-air mixture and simultaneous removal of the created coal dust-methane mixture from the mine working face and its direction towards movement of the mine working ventilation flow outside the cutting-loading machine boundaries. The design of the equipment is simple, reliable, and suitable for operation in underground conditions, while the costs of installation and maintenance are minimal.

Thus, the use of an improved method for preventing coal dust-methane explosions, as well as the cutting-loading machine equipment developed for this purpose, can significantly reduce not only the methane concentration in the air space, bounded by extraction working roof, its face and bottom, but also the probability of coal dust-methane mixture explosion during the cutting-loading machine operation, thereby increasing the safety of mining operations when mining coal seams prone to gas-dynamic phenomena.

At the same time, research has found that most methane and coal dust explosions occur due to frictional sparking. During the cutting-loading machine operation, frictional sparking occurs mainly due to insufficient fluid supply to the places of contact between the cutting tool and the rock containing pyrite and hard sandstone inclusions. Therefore, the use of a method to prevent clogging of nozzle channels by destroying it with cavitation self-oscillations of the flushing fluid high-frequency pressure will significantly increase the service life and efficiency of the nozzles.

Nevertheless, the authors of the paper consider it expedient to direct further research in the field of ensuring explosion safety in coal mines to develop improved methods and devices for preventing frictional sparking by supplying the flushing fluid directly to the zone of sparking occurrence.

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Спосіб боротьби із вибухами метану при розробці газонасичених вугільних пластів

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Мета. Удосконалення способів боротьби із вибухами вугільного пилу й метану у процесі роботи видобувного комбайна при розробці вугільних пластів із газо-динамічними явищами.

Методика. При виконанні досліджень застосовувалися базові методики математичного й фізичного моделювання, стендового експериментування, а також прийоми обробки результатів лабораторних і промислових досліджень у середовищі EXCEL і MATHCAD. Вимірювання динамічних параметрів кавітаційної течії рідини (частоти й розмаху автоколивань тиску) проводилося за допомогою датчика ДДІ-20. Сигнал через аналогово-цифровий перетворювач АЦП-12 надходив до апаратно-програмного комплексу на базі ПЕВМ Athlon-800 із програмним забезпеченням «DASYLAB» і «GEMIS WIN».

Результати. Розроблено спосіб боротьби із вибухами пилометанової суміші. Для автоматичного руйнування й видалення засмічення у каналах форсунок зрошуваної системи застосовується генератор кавітаційних автоколивань тиску шахтної промивної рідини. Одночасно із подачею водоповітряної суміші безпосередньо до зруйнованої маси вугілля, пилометанова суміш, що утворюється в застійних зонах біля вибою, засмоктується перфорованим трубопроводом і направляється по неперфорованому трубопроводу за межі видобувного комбайну в напрямку руху вентиляційного потоку гірничої виробки.

Наукова новизна. Науково обґрунтоване застосування кавітаційних генераторів у системі зрошення гірничих комбайнів у процесі руйнування гірських порід для боротьби із вибухами вугільного пилу й метану. Встановлена функціональна залежність періодично створених на виході із генератора кавітації амплітуди й частоти автоколивань промивної рідини від підпірного тиску, що періодично створюється у міру накопичення засмічення каналів форсунок продуктами руйнування шахтного водогону й гірських порід. Автоматичне руйнування й наступне видалення засмічення із каналів форсунок здійснюється високочастотними автоколиваннями промивної рідини, величина тиску якої за максимальних значень амплітуди й частоти перевищує межу міцності частинок сміття на стиск.

Практична значимість. Удосконалений комплексний спосіб може забезпечити безперебійну роботу форсунок зрошуваної системи та значно зменшити ймовірність вибуху пилометанової суміші у місцях накопичення зруйнованого газонасиченого вугілля в процесі роботи видобувного комбайна. Також він підвищує безпеку гірничих робіт при розробці вугільних пластів, схильних до газодинамічних явищ.

Ключові слова: *видобувний комбайн, вугільний пил, метан, кавітаційний генератор*

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