https://doi.org/10.18321/cpc426

Localization of explosion pulses in a closed space in coal mines

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АННОТАЦИЯ

The data on the prospect of using an artificial high pressure water barrier as a method of localizing the explosion impulse in the confined space of tunnels and mines are presented. The explosion impulse and the process of its decay in interaction with water fog have been studied. In the course of field research, an explosion was simulated in the shock installation, and a method for its localization was developed using four water screens (barriers). The water screen was created using a system of ring-shaped water distribution headers with high pressure nozzles installed in a circle. Hexogen was used as an explosive. Experiments on localization of explosions were carried out on the base of the «Grigol Tsulukidze Mining Institute of Georgia» in Tbilisi, Georgia, together with the research group of the Faculty of Chemistry and Chemical Technology of al Farabi Kazakh National University and the Institute of Combustion Problems. The influence of the water barrier on the process of shock wave attenuation at 3 points of overvoltage of the section is established. The test results showed that the average values of the overpressure in the three sections were reduced by 38.8%, 26.67% and 19.2%, respectively. The action of the shock wave occurs according to an exponential function, and all other wave changes along any other trajectory on the plane of h – t change are described by a single time dependence.

Key words: explosion localization, shock wave, water screen (barrier, screen), water fog.

1. Introduction

In Kazakhstan, more than 110 million tons of coal are mined per year, one of the mining methods is a closed mine method [1]. The main problem of coal mining by the closed method is the accumulation of a gas-dust mixture of methane and coal dust in the space of the mine. Naturally, during the production process, the likelihood of gas accumulation increases, this gas-dust mixture is highly flammable. Every year in the global coal industry, a huge number of accidents associated with the ignition of methane mixtures are recorded [2].

Preventing gas accumulation in a mine is a complex organizational and technological task that requires the involvement of the scientific community in this problem. Today, researchers are looking for ways to localize the explosion in the mine space. There are various localization methods, including the creation of powder and water barriers in the path of the shock wave and flame front [3-5].

In coal mines and other industrial facilities, various automatic explosion containment systems are used, having a similar design. These systems consist of an explosion identification module (optical sensor and an electrical device that generates a trigger signal) and an explosion energy absorber containing an explosion suppressor dispenser and a device for ejecting material into the protected environment [6-8]. They are widely used in mines, for example, in Ukraine (AVP-1), Germany (BVS), Great Britain (Graviner), Russia (ASVP-LV), etc.

Research has been carried out to develop a dust explosion protection system at industrial facilities and factories producing chemicals,

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plastics, textiles, pulp and paper, pharmaceuticals and milling operations [9-10].

In this regard, it is of interest to study the prospects for using an artificial high pressure water barrier as a method of localizing an explosion in a confined space.

2. Experimental part

A number of studies on the localization of explosions were carried out on the base of the «Grigol Tsulukidze Mining Institute of Georgia» in Tbilisi, Georgia, together with the research group of the Faculty of Chemistry and Chemical Technology of al-Farabi Kazakh National University and the Institute of Combustion Problems.

During the study, an explosion of 10 g of hexogen was carried out in a 5-section shock unit (Fig. 1), a 4-step water barrier was created in the path of the shock wave and the flame front. The water barrier created by a special ring-shaped system of high-pressure injectors, consisting of four protective screens, allows you to localize the explosion site in a fraction of a second, cutting off the paths of the flame to spread. Each section was also equipped with electronic sensors and devices for data collection.

The experiments were carried out on a special installation, which is a shock tube 10 m long, 500 mm in diameter, and 8 mm thick (Fig. 2). The shock tube consists of a blast chamber/tube and nine separate sections/tubes connected in series. Also, the shock pipe has a dosed water supply system, pumps, pipelines, manifolds and nozzles for creating water mist. The nozzles are equipped with spray nozzles of three different models from 260-400 microns, allowing you to change the size of droplets in the fog at different stages of the experiment.

Thanks to the prefabricated structure, it is possible to arrange a different number of sections and thus create several protective screens.

An annular water distribution manifold with a diameter of 500 mm, consists of 8 nozzles, with a nozzle (atomizer) size of 260-400 microns, connected in a single chain, directed towards the center and connected to a single water source. When activated, the system creates an almost evenly distributed water mist in the shock tube. As the water pressure increases, the nozzles create droplets of different diameters.

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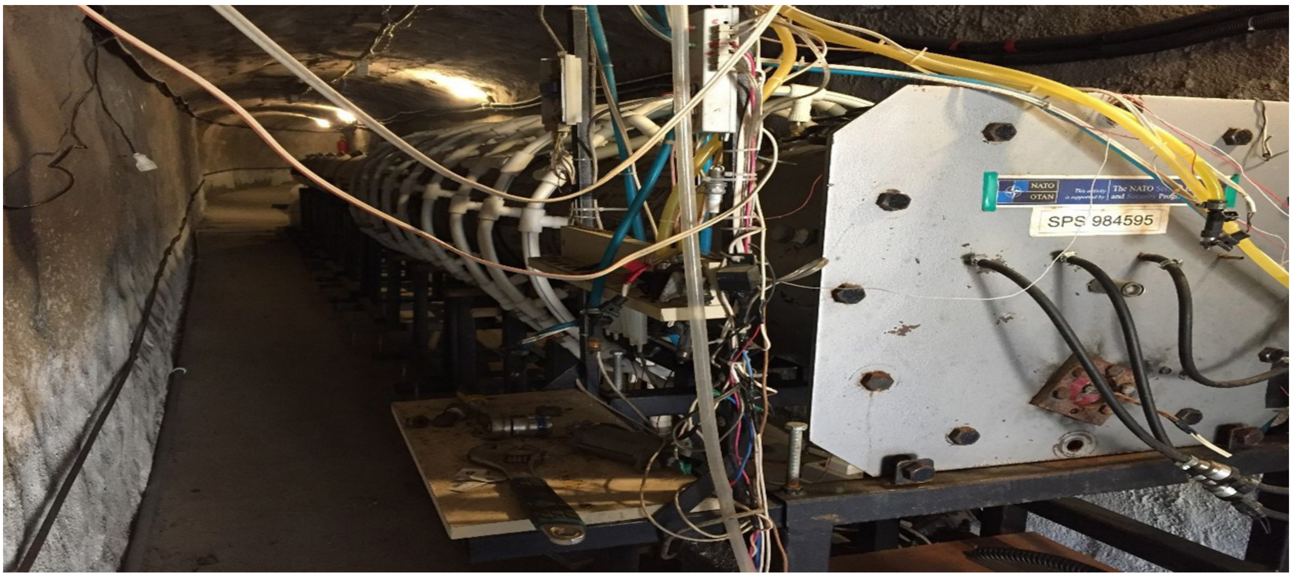

Fig. 1. Experimental sectional drum set.

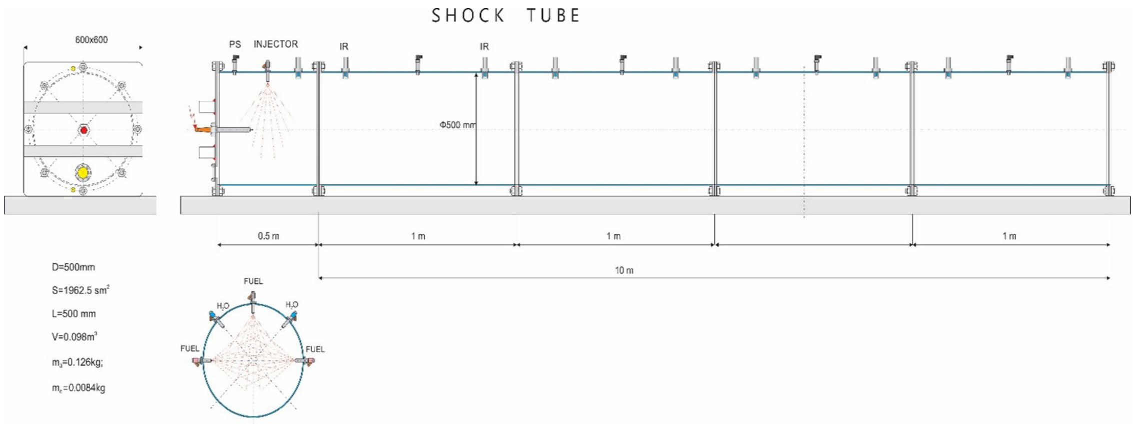

Fig. 2. Scheme of an experimental sectional drum kit.

center and connected to a single water source. When activated, the system creates an almost evenly distributed water mist in the shock tube. As the water pressure increases, the nozzles create droplets of different diameters.

To achieve the set goal of the study, a set of methods was used, including the analysis and generalization of data obtained from devices and sensors installed on the experimental pipe, and tracking the explosion process, and its attenuation, when interacting with dispersed water screens (barriers). During the experiment, the possibilities of water screens created at a pressure of 7.5 bar were investigated.

3. Results and discussion

In the process of research, a spherical hexogen charge with a mass of 10 g was placed in the explosion chamber of the shock tube, with a detonation speed of 7500 m/s. Initiation was carried out using an electric current. Each section was supplied with water at different pressures, creating a high-density water mist to create a barrier in the path of the front of the flame and incandescent particles.

The initiation of the explosion in the shock chamber is synchronized with the dispersed water supply system. The process control module has the following functions:

- provides information about the current state of the experiment;
- transmits commands regarding the amount of water to be supplied to the chamber and plugs in accordance with the specific purpose of the experiment;
- controls the time intervals of the water supply;
- sends a command regarding the moment of water supply in the tube and initiation of an explosion in the shock chamber;
- saves data obtained from previous experiments.

The control module controls it in two modes: test and experimental. Test mode allows you to check the system performance before starting the experiment.

In a closed space without a water barrier (Fig. 3), during and after the explosion, phenomena of the following kind occur: a shock wave, followed by a flame front with a high temperature and incandescent particles (explosion products) moving at high speed.

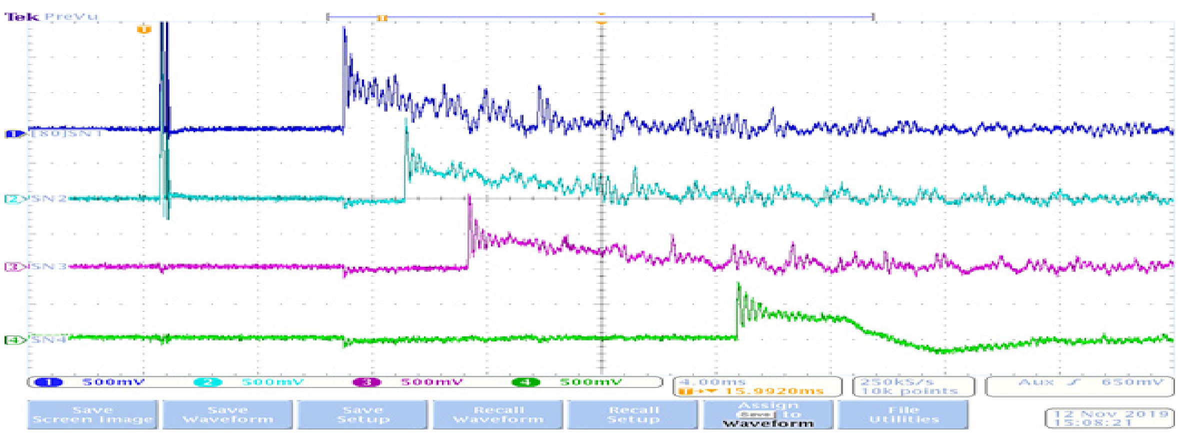

Fig. 3. Shock wave action without water barrier.

On the way of movement, a shock wave, colliding with an artificial water fog (water-air screen), overvoltage is formed at the points of collision, and the explosion energy is absorbed by water, in connection with which the process of transition of the water barrier to the gas-air phase (evaporation) occurs. When exposed to several screens, the initial energy of the explosion is completely extinguished (Fig. 4).

Figure 4 shows that as a result of the interaction of counterpropagating rarefaction waves, negative pressures are generated in the wave. This is possible only for condensed substances – solids and liquids, in gases, of course, negative pressures are impossible; as the pressure approaches zero, the flow velocity also tends to zero.

Taking into account the mutual influence of the diagrams (Figs. 2 and 3) distance-time and pressure-mass velocity for the case of interaction of two symmetrical counter waves of a shock wave and a water absorption wave, a dust-air mixture of explosive particles is rarefied. In this region, the overpressure values and the mass velocity along the pipe are not constant and change along the flow. In this case, the further flow of the shock wave is already simple waves until their secondary interaction with the second absorption wave and until complete extinction.

As shown in figs. 2 and 3, 4 hexogen charge initiations were performed. For the first time, the explosion in the shock chamber was carried out without turning on the water supply to all three sections, the data obtained are summarized in Table 1.

As can be seen from Table 1, the excess pressure in the pipe decreases from 38.8 to 19.2%. The attenuation of the shock wave and the flame front requires an explanation of the physico-chemical phenomena and thermodynamic processes that occur during the interaction of the screen and shock waves.

To discuss experiments with shock waves, it suffices to consider the one-dimensional motion of explosive particles, since it is in this setting, which is the simplest for analysis, that most measurements are carried out. Since the registration of the kinematic parameters of the shock-wave process in a condensed medium is carried out, as a rule, for the selected material sections of the sample, it is convenient to analyze the wave processes in the substantial Lagrange coordinates [11] associated with matter. We will use the spatial coordinate x as the Lagrangian coordinate h.

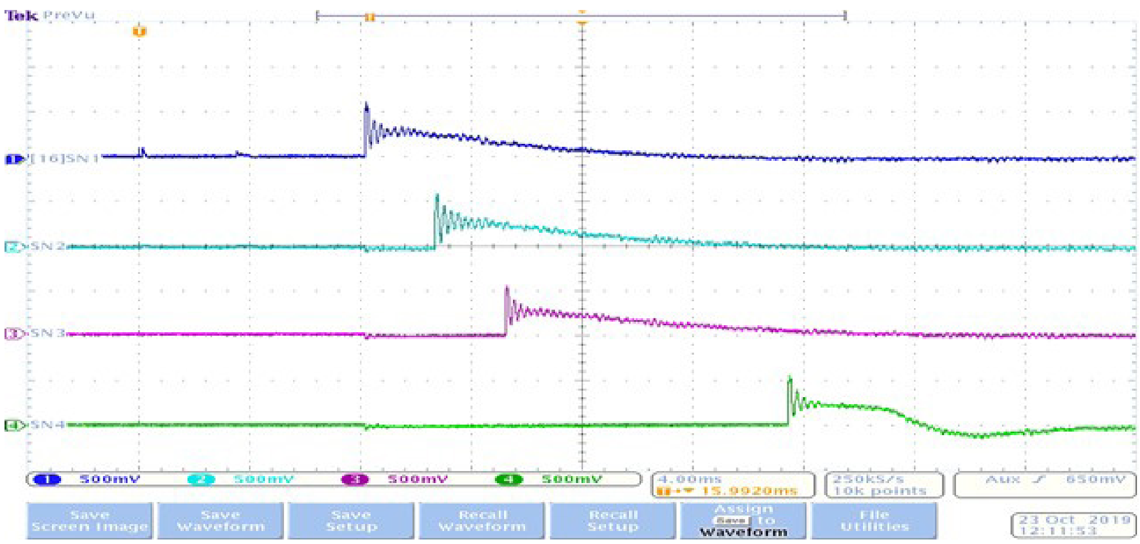

Fig. 4. Shock wave action at 7.5 bar water pressure in three sections.

Table.1. Average values of overpressure

№	7.5 BAR	I sensor (kPa)	II sensor (kPa)	III sensor (kPa)
1	I, II, III (section) without water	527,6	575,625	524,8
2	I, II, III (section)	349,43	422	422,744
3	Percentage difference, %	38,8%	26,67%	19,2%

Particles of explosive at the initial moment of time are determined by the following expression [6]:

$$h = \int_o^x pdx / p_o, \frac{dh}{dx}\Big|_t = \frac{p}{p_0} \quad (1)$$

where ρ_0, ρ – pressure values at time t_0 and at time t, respectively. Partial derivatives with respect to time t and coordinate h will be denoted as ∂/∂t=(∂/∂t)_h and ∂/∂h=(∂/∂h)_t; the derivatives of the function f along certain trajectories in the h-t plane are expressed by the relations:

$$\frac{df}{dt} = \frac{df}{dt} + \frac{df}{dh}\frac{dh}{dt}, \frac{df}{dh} = \frac{df}{dh} + \frac{df}{dt} / \frac{dh}{dt}. \quad (2)$$

where dh/dt – slope of the selected path. Calculations of the partial derivatives of the change in the excess pressure coefficient from the distance h = 2–10 m and time and time t = 7.5–8 ms without the presence of water are determined by the following expressions:

$$K = 131,9 = \frac{dp}{dt_{t=8}} + \frac{dp}{dh_{h=2}} \cdot \frac{dh}{dt}, \int_2^4 \frac{dp}{dt}\Big|_{t=8} \quad (3)$$

$$K = 153,5 = \frac{dp}{dt_{t=7,5}} + \frac{dp}{dh_{h=4}} \cdot \frac{dh}{dt} \quad (3.1)$$

$$K = 131,2 = \frac{dp}{dt_{t=8}} + \frac{dp}{dh_{h=10}} \cdot \frac{dh}{dt} \quad (3.2)$$

Further, three explosions were carried out at a water pressure of 7.5 bar, and when all 3 sections of the percussion unit were turned on.

Calculations of the partial derivatives of the change in the excess pressure coefficient for all three sections depending on the distance of damping of the shock wave h, m and time t, ms with water barriers are given in the following parameters:

I, II, III section:

$$K = 88,37 = \frac{dp}{dt_{t=10}} + \frac{dp}{dt} \cdot \frac{dh}{dt_{h=2}}, \int_2^4 \frac{dp}{dt}\Big|_{t=10} \quad (4)$$

$$K = 79,39 = \frac{dp}{dt_{t=12}} + \frac{dp}{dt} \cdot \frac{dh}{dt_{h=4}} \quad (4.1)$$

$$K = 75,95 = \frac{dp}{dt_{t=11,2}} + \frac{dp}{dt} \cdot \frac{dh}{dt_{h=10}} \quad (4.2)$$

In order to obtain reproducible results, three additional experiments were carried out and the averaged results of changes in the parameters of the shock wave pressure are summarized in Table 2.

The explosion impulse was calculated by the formula:

$$I = \frac{Pt}{2} \quad (5)$$

where P – overpressure of explosion products, kPa; t – final action time corresponding to the moment of reaching the water barrier, ms.

As can be seen from Table 2, on the basis of the results obtained, the following can be stated: the movement of the dust-air mixture, at which there is an excess pressure drop, is a simple or traveling wave. In a simple wave, before being blocked by a water barrier, the pressure passes through a maximum of 153.5 kPa at sensor II, and all other wave changes along any other trajectory on the plane of h–t change are described by a single dependence (1).

It was also experimentally established that under conditions when the distance of the air space between the explosion chamber and the fog is 1 m, the coefficient of reduction of the overpressure is 1.5-1.6 times higher than under conditions when the water fog is created in direct contact with the explosion chamber. This can be explained by various mechanisms of energy extinguishing near the charge zone, where overvoltages develop under the action of gaseous explosion products, and in the zone where shock waves are generated.

During the field studies, an explosion was simulated in the shock installation, and a method for its localization was developed using four water screens (barriers). The water screen was created using a system of ring-shaped water distribution headers with high pressure nozzles installed in

Table 2. Change in the coefficient of overpressure of the shock wave

Experience №	Section	Pressure (kPa)			Time (ms)		
		I sensor	II sensor	III sensor	I sensor	II sensor	III sensor
1	Without water	131,9	153.5	131.2	8	7.5	8
2	I, II, III (section)	88.37	79.39	75.95	10	12	11.2
3	I, II, III (section)	65.95	75.49	74.57	6.4	10.4	10.4
4	I, II, III (section)	80.46	76.79	75.95	10.4	10.4	12
5	I, II, III (section) Average of three experiments	78.26	77.22	75.49	8.93	10.93	11.2

a circle. Hexogen was used as an explosive. The influence of the water barrier on the process of shock wave attenuation at 3 points of overvoltage of the section is established. The test results showed that the average values of excess pressure in the three sections were reduced by 38.8%, 26.67% and 19.2%, respectively. The action of the shock wave occurs according to an exponential function, and all other wave changes along any other trajectory on the plane of h – t change are described by a single time dependence.

4. Conclusion

The data on the prospect of using an artificial high-pressure water barrier as a method of localization of the explosion pulse in the confined space of tunnels and mines are presented. The explosion pulse and the process of its attenuation during interaction with water mist are studied. The influence of the water barrier on the process of shock wave attenuation at 3 points of overvoltage of the section is established.

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Локализация импульсов взрыва в замкнутом пространстве в шахтах по добыче угля

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Аннотация

Представлены данные по перспективе использования искусственного водного барьера высокого давления, как способа локализации импульса взрыва в замкнутом пространстве тоннелей и шахт. Изучен импульс взрыва и процесс его затухания при взаимодействии с водным туманом. В ходе полигоных исследований в ударной установке имитировался взрыв, и был разработан метод его локализации с применением четырех водяных экранов (барьеров). Водный экран создавался с помощью системы кольцеобразных водораспределительных коллекторов с установленными по кругу форсунками высокого давления. В качестве взрывчатого вещества использовался гексоген. Эксперименты по локализации взрывов были проведены на базе «Горного института им. Г. Цулукидзе» г. Тбилиси, Грузия совместно с исследовательской группой факультета химии и химической технологии Казахского национального университета им. аль-Фараби и Института проблем горения. Установлено влияние водного барьера на процесс затухания ударной волны в 3 точках перенапряжения секции. Результаты испытаний показали, что средние значения избыточного давления в трех секциях снижены на 38,8%, 26,67% и на 19,2% соответственно. Действие ударной волны происходит по экспоненциальной функции, а все другие волновые изменения вдоль любой другой траектории на плоскости изменения h–t описываются единой зависимостью от времени.

Ключевые слова: локализация взрыва, ударная волна, водная завеса (преграда, завеса), водяной туман.

Көмір өндіру жөніндегі шахталардағы тұйық кеңістіктегі жарылыс импульстарын оқшаулау

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Аңдатпа

Тоннельдер мен шахталардың тұйық кеңістігінде жарылыстың импульсін оқшаулау тәсілі ретінде жоғары қысымды жасанды су тосқауылын пайдалану перспективасы бойынша деректер ұсынылған. Су тұманымен өзара әрекеттесу кезінде жарылыс импульсі мен оның ыдырау процесі зерттелді. Полигондық зерттеулер барысында соққы қондырғысында жарылыс имитацияланды және төрт су экрандарын (тосқауылдарды) қолдана отырып, оны оқшаулау әдісі әзірленді. Су экраны шеңберге орнатылған жоғары қысымды саптамалары бар сақиналы су тарату коллекторлары жүйесінің көмегімен жасалды. Жарылғыш зат ретінде гексоген қолданылды. Жарылыстарды локализациялау бойынша эксперименттер Грузияның Тбилиси қаласындағы «Цулукидзе атындағы тау-кен институты» базасында Қазақ ұлттық университетінің химия және химиялық технология факультеті мен Жану проблемалары институты зерттеу тобымен бірлесіп жүргізілді. Су тосқауылының секцияның шамадан тыс кернеуінің 3 нүктесінде соққы толқынының сөну процесіне әсері анықталды. Сынақ нәтижелері үш секциядағы артық қысымның орташа мәндері тиісінше 38,8% – ға, 26,67% – ға және 19,2% – ға төмендегенін көрсетті. Соққы толқынының әрекеті экспоненциалды функция арқылы жүреді, ал h-t өзгеру жазықтығындағы кез-келген басқа траектория бойындағы барлық басқа толқындық өзгерістер уақытқа байланысты сипатталады.

Кілт сөздер: жарылыстың локализациясы, соққы толқыны, судың экраны (тосқауыл, экран), су тұманы.