

Methane Explosion Mitigation in Coal Mines by Water Mist

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Abstract. Statistics shows that the majority of accidents with fatal outcome are caused by methane and/or coal dust explosion. This leads to assume that contemporary counter-explosion systems of various designs cannot be considered effective. Considering the growing threat of methane explosion in the coming years along with the development of deeper levels, the improvement of a system for protecting people in underground opening appears urgent.

This paper focuses on technical solutions to be used in designing a protective system for minimizing the consequences of methane explosions in coalmines. The new protective system consists of three main modules: i) a high-speed shock wave suppression section; ii) a suppression section with a long-term action and iii) a system activating device. The shock wave suppressor contains a 200 litre volume water tank with a built-in gas generator and nozzles. It is activated after 12ms from the blast moment, the duration of discharge is 40 s. The suppression section with a long-term action contains a 2000 litre volume water tank, a high-pressure pump, a hydraulic accumulator, solenoid valves, and a system of pipes with built-in nozzles. It is activated after 4 s from the blast moment, the duration of discharge is 8 min. The activation device includes a detection block containing sensors, an emergency signal generation module, a signal transmission module, a signal receiving module and a power supply module. The system operates in a waiting mode and activates immediately upon the receipt of the start signal generated by the detector. The paper also addresses the preliminary results of the system prototype testing in the tunnel.

1. Introduction

At present, mines in different countries use immovable or moveable passive water trough barrier for the protection from methane explosion. The protective water barrier is created in the process of the spill of water from 40-90 litre volume troughs. The protective system activates and water disperses exclusively at the expense of blast pressure. The requirements to the passive water trough barriers are provided in the Standard EN-1459-2 [1]. According to the Standard, the distance between the barriers should not exceed 75m for a concentrated water trough barrier and 30 m for distributed water trough barrier. Water concentration at barrier location should be at least 5 l/m³ and 1 l/m³ respectively. Experiments conducted according to the Standard show that the time for passive water trough barrier activation varies from 0.52 s and 0.78 s [2]. They also reveal that passive barriers protect effectively against the spread of flame, but they are not capable of ensuring blast overpressure attenuation. Apart from that, doing mining work together with the installation of different equipment as required by EN 14591-2 is very difficult or even



unfeasible, especially in small cross-section galleries. Due to its limited effectiveness and a long period of time required for the activation, water trough barriers fail to meet contemporary challenges.

An automatic explosion extinguishing system activated by means of a blast or flame detector has advantages over passive or active water trough barrier. An automatic system allows for the use of dispersed water as an extinguishing agent and enables an immediate formation of a water mist barrier. Studies have shown that water mist is characterized by strong damping properties [3, 4].

The existing automatic blast protection systems used in coalmines and other industrial sites have similar designs. They contain a blast identification module (usually, an optical sensor and electric device generating a trigger signal), and a blast energy absorber that contains a blast suppressing agent dispenser and a device to eject the material into the protected media [5,6,7]. Systems of this kind are developed and have been applied in various mines; e.g., in Ukraine (AVP-1), Germany (BVS), UK ("Graviner"), Russia (ACVP-LV), US, etc. Research has been done to develop a system for protection from dust explosion in industrial sites and plants producing chemicals, plastics, textiles, pulp and paper, pharmaceuticals, and milling operations [8,9].

Analysis has revealed the following major disadvantages of the existing blast suppression automatic systems:

1. Lack of reliability of the effectiveness of a blast identification device in complex underground openings, especially under long-term operation;
2. Low speed of the blast energy absorber activation;
3. Inadequate discharge of a blast absorbing agent required for reducing excess pressure and temperature to an acceptable value, as well as the inability to operate in limited underground facilities.

Paper presents the preliminary results of the testing of a new system for protecting from explosions in tunnels. The tests were conducted in the underground experimental base of the G. Tsulukidze Mining Institute.

2. System Structure

The selection of a protection structure and the design of its separate components was preceded by a series of experiments which included:

- testing of methods of blast identification and absorber activation in tunnels, as well as a comparative analysis of their reliability and speed;
- experimental study of the reduction of blast overpressure by different damping agents and the selection of an efficient damping agent;
- testing of models of key components of an absorber.

The results of the preliminary study [10,11,12] formed the basis for the prototype production and testing. The proposed protective system consists of the following three *sub-systems*: i) A high-speed shock wave suppression section; ii) A suppression section with a long-term action; iii) A system activating device.

The high-speed shock wave suppression section contains a water tank with a built-in gas generator and nozzles. As envisaged by design objectives, it activates creating a water barrier 10-12 ms after the blast moment, while water discharge continues for 25-30 seconds. These characteristics will be further specified based on prototype model testing results.

The suppression section with a long-term action contains a water tank, a high-pressure pump, a hydraulic accumulator, solenoid valves and a system of pipes with built-in nozzles. It ensures the operation of the protective system for 8-10 minutes and formation of a stable barrier after the high-speed section stops its operation. Its main function is to ensure protection from repeated blast and fires caused by deflagration of explosives.

The activation device includes a detection block containing sensors, a signal processing module, an emergency signal transmission module, a signal receiving module and a power supply module. Both sections are activated by a receiver-generated signal. High pressure in high-speed suppression section

tank is generated by a gas-generator, and by a hydro-accumulator in the long-term action pipe system. Under the high pressure a high-speed waterjet is formed in the protection zone of the tunnel by means of nozzles built in both sections figure 1.

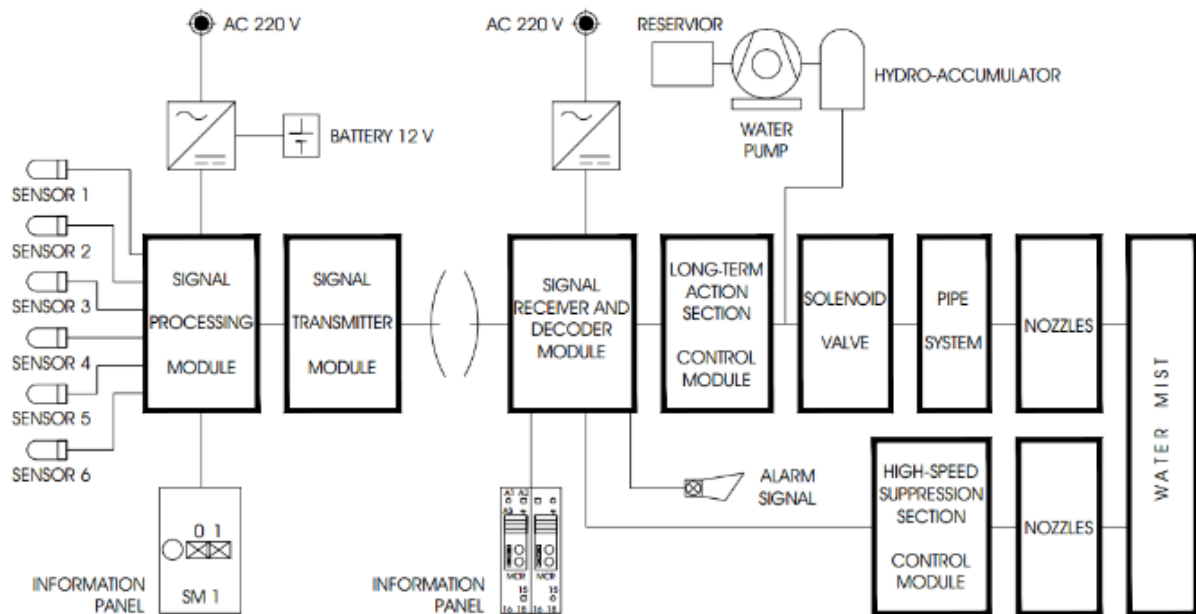


Figure 1. Basic diagram of the protective system structure

Figure 2 shows the layout plan of the system in the tunnel: the sensors and the box in which the signal processing and transmitter modules are built in are fixed on the tunnel ceiling or wall. The sensors are connected to the signal processing device by means of a conduit the maximum length of which is 15m. The number of sensors (minimum 2 and maximum 6) and their locations are selected according to the configuration of the tunnel to be protected and a potential explosion site, on one or both sides of the suppression section. A high-speed suppression section and long-term action section pipes are fixed on the tunnel ceiling so that they do not obstruct the normal functioning of the tunnel. A signal receiver module, a control block and hydro facility are placed in a special niche in a tunnel wall.

The system prototype was manufactured and installed in the tunnel of the underground experimental base of the Tsulukidze Mining Institute. At the initial stage of testing operational characteristics of the high-speed suppression shock wave were determined. An exhaustive testing of the system is planned at the next stage.

3. Suppression section test result

The methodology of testing of the suppression section in the underground opening implied the control of time characteristics of response under blasts and the measurement of overpressures in a tunnel with mist generated by section and without mist under same blast conditions. Testing was conducted in the tunnel of the underground experimental base of the Mining Institute. Tunnel sizes: height – 2.2 m, width – 2.2 m, total length – 150 m, supported by reinforced concrete. The suppression section at the command of the initiation signal produces tailored dispersing water mist along selected sections. The process of water discharge shows in figure 3.

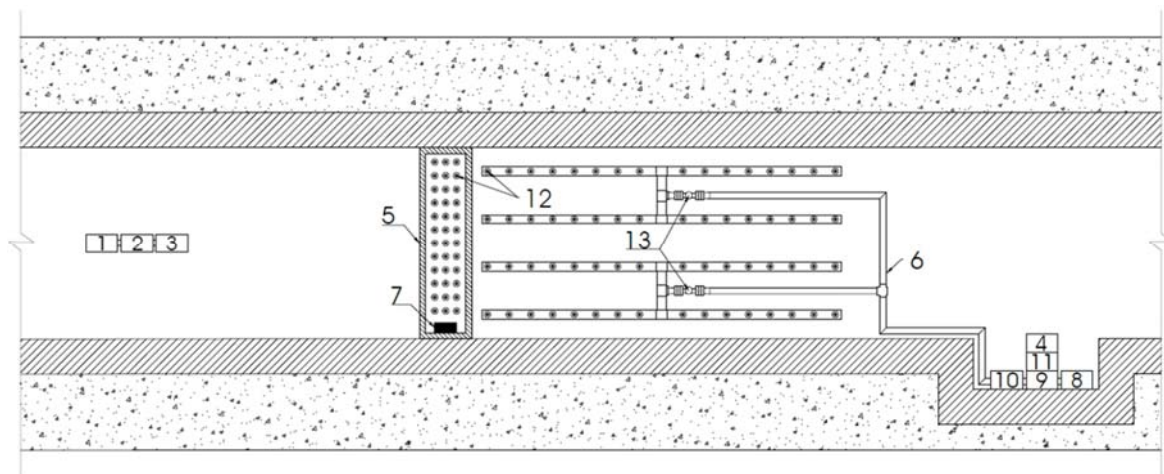


Figure 2. Layout plan of the structural unit in tunnel.

1- sensors, 2 - a signal processing module, 3- an emergency signal transmission module, 4 - an emergency signal receiving module, 5 - shock wave high-speed suppression section, 6 - suppression section with a long-term action, 7- gas-generator, 8 – reservoir, 9 - water pump, 10 – hydro-accumulator, 11- control block, 12- nozzles, 13 – solenoid valve

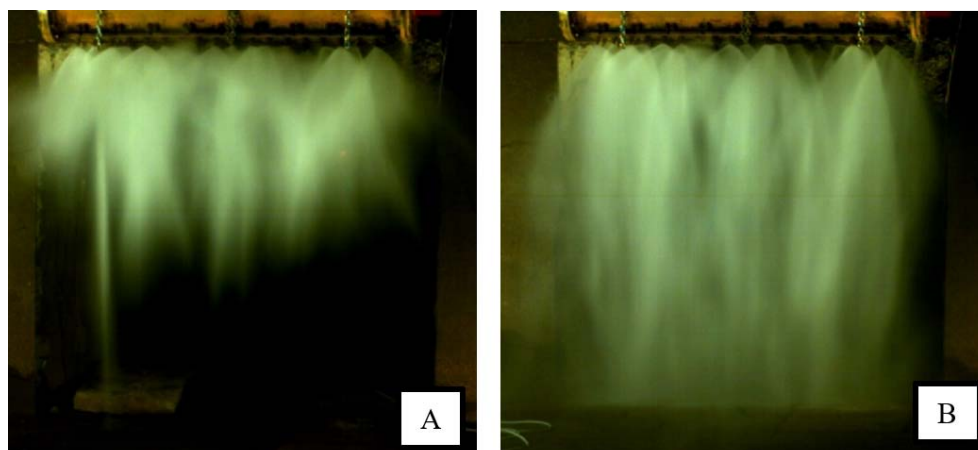


Figure 3. The process of water discharge. A - after 12ms from activation of the suppression section; B - after 25ms

The suppression section was tested under the following conditions:

- charge weight: $W=2$ kg, $W=4$ kg;
- distance from charge to sensors: from charge to mist: 5 m,
- width of mist: 2 m. Overpressures were measured by means of three sensors fixed at 0.6 m and 1.2 m from the tunnel floor respectively.

With the aim of controlling time characteristics, a blast moment, absorber activation moment and shock wave arrival under the explosion were recorded. The time histories of shock wave arrival before and after mist are presented on figure 4.

Test results have shown that the time of the absorber activation from the moment of blast takes 11ms, and the time of shock wave arrival from the moment of absorber activation takes 28ms. This means that under the indicated blast conditions, the shock wave arrives after mist formation and absorber is operable. The speed of a damping agent discharge from an absorber depends on the peak pressures in a water container and the distance from the nozzle. For pressures under 130 bar, the speed of

discharge was 80 m/s at a 1 m distance. Figure 5 shows overpressure histories without mist and with water mist.

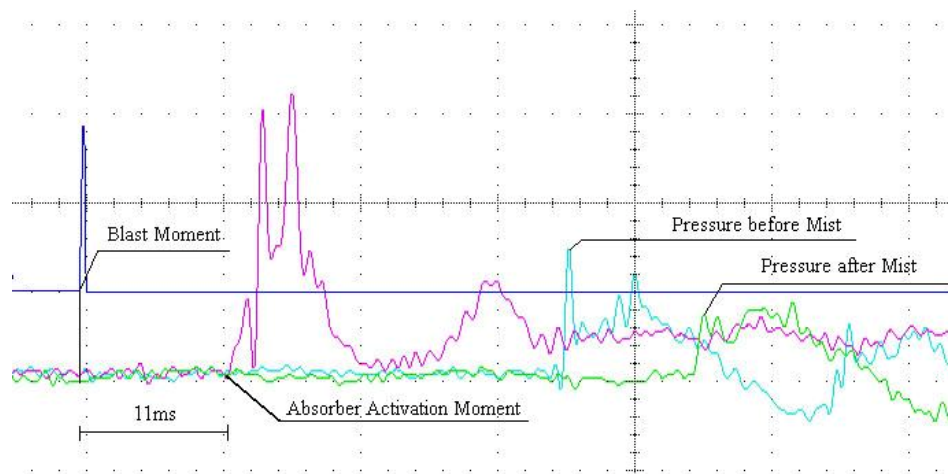


Figure 4. The Time characteristic of the high-speed suppression section

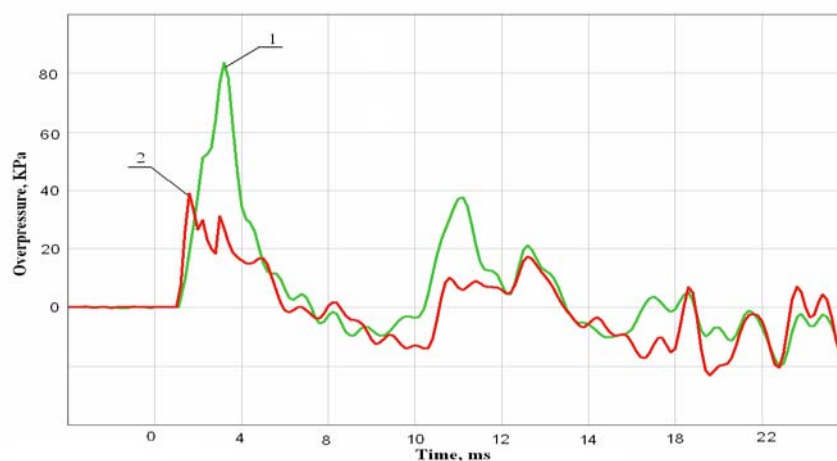


Figure 5. Overpressures histories for high-speed suppression section, W=2 kg;
 1 - without mist, 2 - with water mist

Absorber efficiency is determined by means of a coefficient of the reduction of maximum overpressures $K = \Delta P_b / \Delta P_m$, where ΔP_b is overpressure without mist, while ΔP_m - with water mist (Table 1).

Table 1. Shock wave overpressure without mist and with mist
 Overpressure, ΔP , kPa

sensors	W=2,0 kg			W=4,0 kg		
	Without mist, ΔP_b	With of mist, ΔP_m	$K = \Delta P_b / \Delta P_m$	Without mist, ΔP_b	With of mist, ΔP_m	$K = \Delta P_b / \Delta P_m$
G1	85	36	2,36	221	105	2.10
G2	97	41	2,36	221	89	2.48
Average	91	39	2,36	221	97	2.28

The results of the tests showed that the maximum value of the reduction coefficient is $K=2.98$, while minimum value is $K= 1.80$.

4. Conclusions

A high-speed, long-acting system for explosion mitigation in underground facilities was developed. It is designed for conditions characterised by a threat of repeated explosions and ensuing fire, e.g. for the localization of the consequences of methane/coal dust blasts in coalmines. The suppression system activated at the command of the initiation signal produces tailored dispersing water mist with droplet sizes in the range of 25-400 micron along selected sections of a tunnel.

The high-speed suppression section has the following properties:

- the time of absorber activation from the moment of blast: 11ms;
- speed of a damping agent discharge from an absorber: 60-80 m/s;
- volume of discharge: 200 liters;
- reduction of shock wave overpressures by means of an absorber: 1.80-2.98 times;
- the distance between a transmitter and a receiver in a direct tunnel - at least 150 m; in a tunnel with a 90° bending – 50 m;
- minimum overpressure for activation of protective system: 12 kPa.

The presented protective system can be applied in coal mines under threat of methane explosion, motorway and railway tunnels and long structures with limited cross sections.

Acknowledgments

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