

Experimental Study of the Effect of Water Mist Location On Blast Overpressure Attenuation in A Shock Tube

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Abstract. Explosion protection technologies are based on the formation of a shock wave mitigation barrier between the protection site and the explosion site. Contemporary protective systems use water mist as an extinguishing barrier. To achieve high effectiveness of the protective system, proper selection of water mist characteristics is important. The main factors defining shock wave attenuation in water mist include droplet size distribution, water concentration in the mist, droplet velocity and geometric properties of mist. This paper examines the process of attenuation of shock waves in mist with droplets ranging from 25 to 400 microns under different conditions of water mist location. Experiments were conducted at the Mining Institute with the use of a shock tube to study the processes of explosion suppression by a water mist barrier. The shock tube consists of a blast chamber, a tube, a system for the dosed supply of water, sensors, data recording equipment, and a process control module. Shock wave overpressure reduction coefficient was studied in the shock tube under two different locations of water mist: a) when water mist is created in direct contact with blast chamber and b) the blast chamber and the mist are separated by air space. It is established that in conditions when the air space distance between the blast chamber and the mist is 1 meter, overpressure reduction coefficient is 1.5-1.6 times higher than in conditions when water mist is created in direct contact with blast chamber.

1. Introduction

Blast suppression mechanisms using water mist have been addressed by G. Thomas, Van Winderden, K. Kailasanath, and R. Ananth et al [1-4]. It has been noted that water mist with fine sprays is efficient for the mitigation of explosions. Research has shown that shock energy attenuation in water mist takes place during the process of aerodynamic droplet break-up and vaporization of child droplets. The main purpose of the existing studies is to determine the effect of droplet size distribution and concentration of water on blast overpressure attenuation in water mist. Significant knowledge has been accumulated in this area, however there still are some gaps that need to be addressed in order to improve the design of protective devices. More specifically, the effect of the water barrier location on the suppression impact remains understudied. A. Resnyansky and T. Delaney have compared mitigation curves for an explosion of a charge in direct contact with water and for an explosion of a charge surrounded by air-water [5]. The comparison has shown that the location of mist in relation to the explosion source influenced phase transformation and water breakdown mechanisms and is a factor affecting overall mitigation performance.



This paper presents the results of an experimental study of blast overpressure attenuation in a shock tube when water mist is generated at different distances from the blast chamber

2. Experimental setup

A shock tube was designed to study the effects of water concentration, water drop diameter, and location and length of the water mist on blast attenuation [6]. It enables to study the effects of solid explosive, fuel-air and gas explosions. The shock tube consists of a blast chamber, a tube, a system for the dosed supply of fuel and water, sensors, data recording equipment, and a process control module. It is located in a tunnel Figure 1, while the data recording equipment and the control module are located in the monitoring room at a 6 m distance from the tunnel entry.



Figure 1. Shock tube in the underground experimental base of the Mining Institute

The following are the basic characteristics of the blast chamber and separate tubes: Diameter of the blast chamber and tubes – 50 cm; Blast chamber length – 50 cm; Wall thickness – 8 mm, Number of separate tubes – 10; Total length of the shock tube – 10.5 m. Pressure and flame sensors are fixed in the blast chamber and tubes Figure 2.

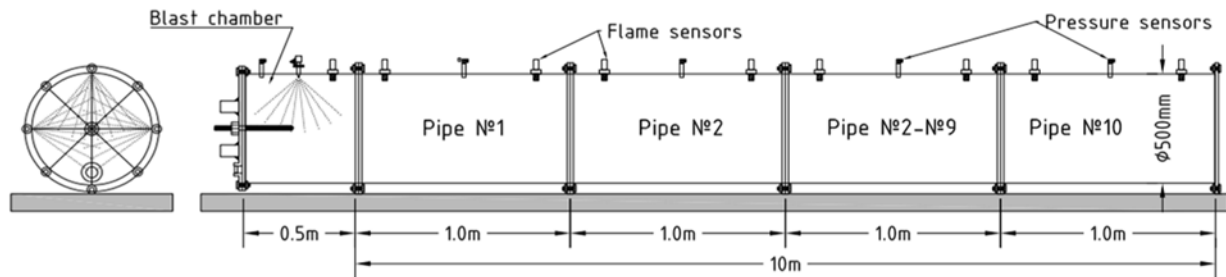


Figure 2. Schematic circuit of the shock tube

The shock tube has a system for the dosed supply of water, which is composed of pumps, pipelines, electric valves and nozzles, and other hydraulic elements needed for water mist creation. Twelve nozzles model BETE P120 are fixed in each of the first and second tube segments (i.e. twenty-four in total) after the blast chamber. Paired nozzles are fixed in the horizontal cross section of the tubes in opposing directions. The distance between the paired nozzles is 25 cm. The blast in the chamber is synchronized with the dispersed water supply system by the process control module. Upon activation, the system creates an almost equally distributed water mist in the shock tube Figure 3-a. Droplet size distribution in mist is shown on Figure 3-b.

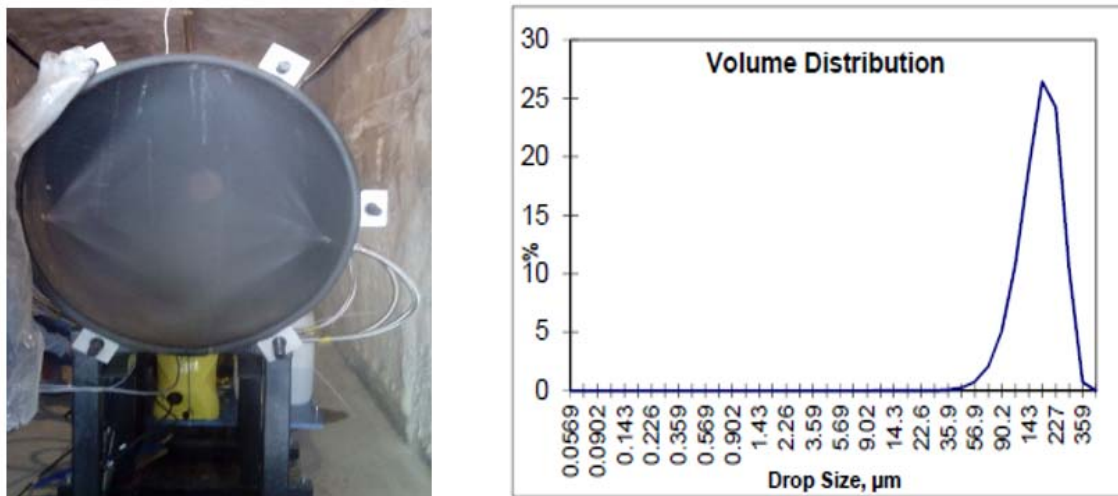


Figure 3. Water mist in the shock tube (a) and droplet sizes distribution in mist (b)

In accordance with the objectives of the experiment, water injection indicators, the duration of injection, and the moment of initiation are entered in the software. After issuing a command, the software ensures the discharge of water in accordance with the predefined sequence and timing, initiates the data registration equipment, generates blast initiation signal, and shuts down the system.

3. Experimental condition

In different cycles of experiments water mist was generated in section #1 (Figure 4, Blast Chamber-Water Mist-Air) and section #2 (Figure 5, Blast Chamber-Air-Water Mist-Air).

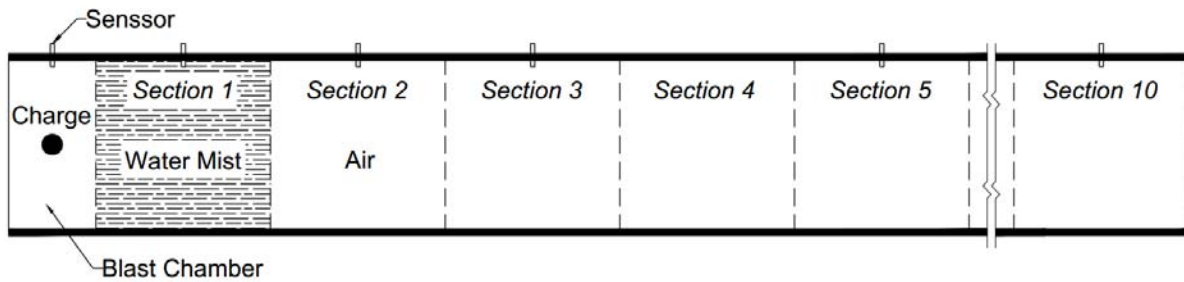


Figure 4. Scheme of the experiments “Blast Chamber-Water Mist-Air”

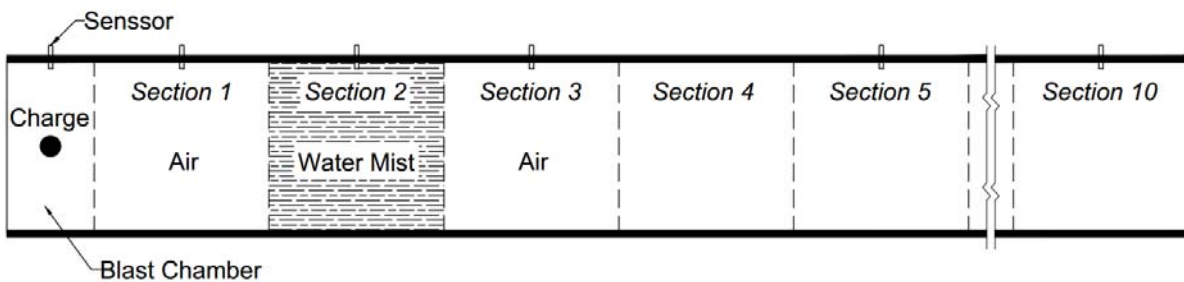


Figure 5. Scheme of the experiments “Blast Chamber-Air-Water Mist-Air”

Series of experiments were conducted to study shock wave attenuation in water mist in the following conditions:

- Explosive charge location - blast chamber of the shock tube;
- Type of explosive and charge weight: hexogen, 5 grams;
- Droplet size distribution in mist: 25-400 μm ;
- Flow rate: 0.9 L/s;
- Length of mist in the shock tube section: 1 m,
- Concentration of water in mist: $4.5 \text{ L} \cdot \text{m}^{-3} \cdot \text{sec}^{-1}$

The blast waves were registered in the blast chamber and shock tube sections in distance 1.5 m, 2.5 m, 4.5 m and 6.5 m from the charge, by using PCB sensors 102B16 and oscilloscope Tektronix 420.

4. Results of the experiments

The overpressure histories measured during the experiments without mist and with mist are given in Figure 6. The results of the experiments show that under other equal conditions water mist location has an effect on the shock wave overpressure attenuation process. At the distance of 2.5-6.5 m, when the blast chamber and the mist are separated by one metre air space, maximum overpressures are lower than in conditions when water mist is created in direct contact with blast chamber Figure 7.

Attenuation of shock waves in mist was estimated using an overpressure reduction coefficient:

$$K = (\Delta P_a - \Delta P_m) / \Delta P_a \quad (1)$$

where ΔP_a and ΔP_m is overpressure without mist and with mist at the same distance from the charge.

The overpressure reduction coefficient K varies according to water mist location when other conditions remain constant Table 1.

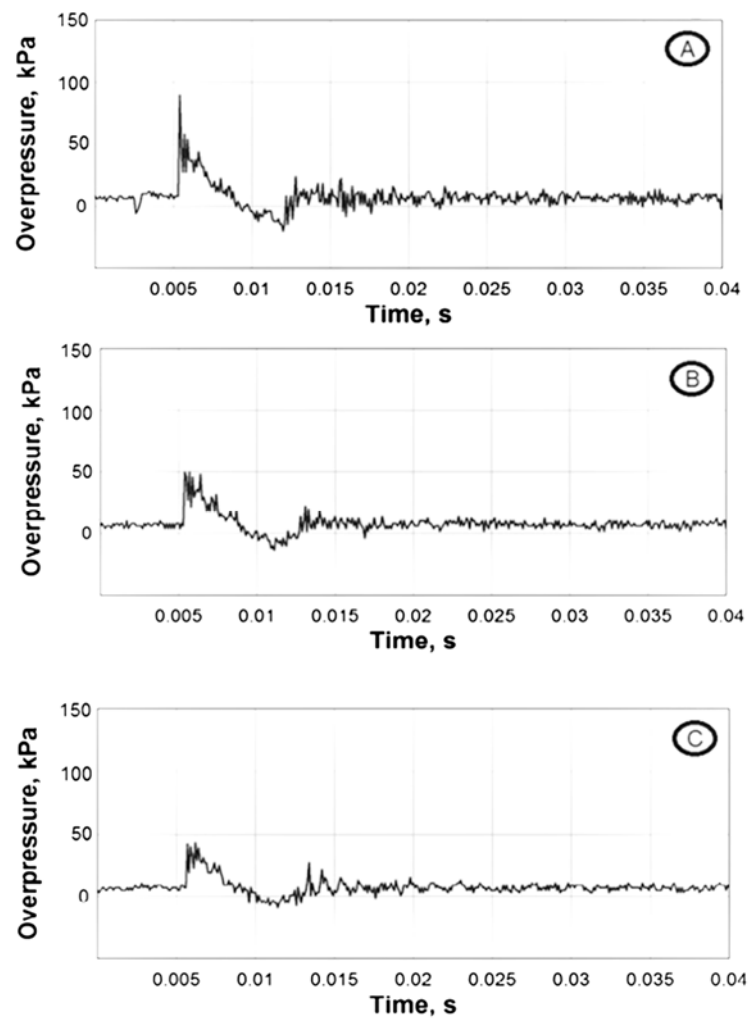


Figure 6. Overpressure histories at the distance of 4.5 m from charge.
A - without mist, B - with mist in section #1, C - with mist in section #2

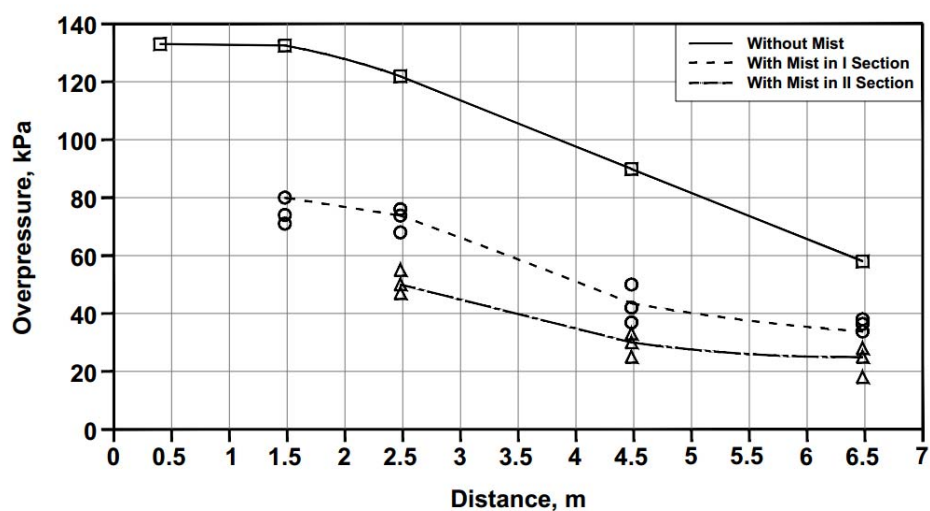


Figure 7. Dependence of maximum overpressures on the water mist location

Table 1. Overpressure reduction coefficient K

Location of mist	Distance from charge, m	Reduction coefficient	Average
In I section	2.5	0.37	0.38
	4.5	0.44	
	6.5	0.33	
In II section	2.5	0.57	0.60
	4.5	0.66	
	6.5	0.58	

5. Conclusions

Shock wave overpressure reduction coefficient was studied in the shock tube under two different locations of water mist: a) when water mist is created in direct contact with blast chamber and b) the blast chamber and the mist are separated by air space. It is established that in conditions when the air space distance between the blast chamber and the mist is one meter, overpressure reduction coefficient is 1.5-1.6 times higher than in conditions when water mist is created in direct contact with blast chamber. This can be explained by different mechanisms of energy suppression near the charge zone where overpressures develop under the effect of gaseous products of explosion and in the zone where shock waves are generated.

Acknowledgment(s)

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