Experimental Study of the Shock Wave Attenuation in the Water Mist with Air Gaps

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Abstract. The paper aims to propose ways for enhancing the effect of attenuating shock waves in the water mist. The fulfillment of this task can significantly contribute to the perfection of technologies for protecting from accidental explosions and the design of protective facilities. A series of experiments were carried out to investigate the influence of air gaps on shock wave attenuation in the water mist. A shock tube with hydraulic equipment capable of producing a 3-meter long dispersed water barrier with droplets ranging from 25 to 400 microns and total flow rate 14.5 l/s within a tube was used during testing. The paper analyzes shock wave attenuation within a tube in the water mist with and without air gaps. It has been established that in conditions when a 3-meter long water mist contains four air gaps, every 20 centimeters in width, overpressure reduction coefficient is 1.10-1.15 times higher than the one in the water mist without air gaps.

1. Introduction
The increasing number of accidents in recent years shows that the design of a new generation of explosion protection facilities with an improved capacity of protection without additional costs remains to be an important task. According to the findings of various studies, water or dispersed water is a simple, effective, and environmentally safe means of suppressing blast energy [1-3]. Water mist is successfully applied as a suppression agent in modern protection systems [4-6]. Water mist based discharge systems are used in modern explosion suppression systems designed to protect people and equipment in various industrial facilities. Their function is to protect equipment from damage during accidental internal explosions in plants producing chemicals, plastics, textiles, pulp and paper, pharmaceuticals, as well as in mills. Systems designed to protect armored vehicles and occupants against anti-vehicular landmine effects also used water mist as a suppressing agent in [7]. It is impossible to fully exclude the possibility of damage following blasts, especially in confined spaces. However, the use of protective systems designed on the basis of cutting-edge knowledge in the field can reduce dynamic pressures, prevent progressive collapse, and limit the extension of detonation to explosive materials located in the vicinity. Protective systems based on the principle of water mist generation allow for the 25-40% reduction of shock wave overpressure and impulse. Protective system efficiency studies must be based on the findings of contemporary studies relating to shock wave attenuation in the water mist, according to which explosion mitigation effect in water mist depends on the droplet size distribution, the concentration of the liquid phase, the speed of the droplet, the geometric and other properties of the mist. The results of these studies are analyzed in the review by O. Igra et al [8]. Our team studied the effect...
of water mist thickness and its influence on blast overpressure attenuation [9,10]. This article presents the results of experiments to study the effect of gaps in the mist on overpressure attenuation.

2. Experimental Setup

A shock tube with hydraulic equipment for water mist generation was used for testing. Hydraulic equipment contains a water tank, a high-pressure pump, a hydraulic accumulator, a water distributor, and water supply pipes that delivered water under high pressure to nozzles fixed on the shock tube wall. Nozzles were located in the 3-meter long section of the tube, at nine cross-sections of the tube with an interval of 40 centimeters. There were 6 nozzles BETE P120 in each cross-section, in all 54 nozzles – in the section. The water distributor allows for water to be delivered both simultaneously to all nozzles at each cross-section or to a limited number of nozzles (Figure 1).

![Figure 1. Photo of the shock tube (A) and water supply pipes with nozzles (B)](image)

The following are the basic characteristics of the shock tube and hydraulic equipment: diameter of the blast chamber and tubes – 50 cm; blast chamber length – 50 cm; wall thickness – 8 mm, total length of the shock tube – 10.5 m (Figure 2).

3. Experimental Conditions

Series of experiments were conducted to study shock wave attenuation in shock tube without mist, with solid mist (Figure 2- A) and with a mist containing 4 air gaps (Figure 2 –B).
Identical blast conditions were provided in each series: charge location – explosion chamber, type of explosive – hexogen, a mass of charge - 5 grams. In scheme A, the total length of the solid mist was 3 meters, while in scheme 2, the 3-meter long mist was divided into 5 segments, every 40 centimeters in length. Four air gaps, each measuring 20 centimeters in length, were left between the segments. The water mist had the following properties: the droplet size distribution under both schemes was 15-345 µm; In scheme A, the mist was generated by 54 nozzles, and in scheme B, with 30 nozzles. In the first case, the flow rate was 15.6 L/s, and in scheme B, it was 8.7 L/s.

Bearing in mind that the volume of the tube segment in which the mist was generated was 0.6 m³, the concentration of water in mist in Scheme A was 26 L· m⁻³ · s⁻¹, while in Scheme B it was 14.5 L·m⁻³ · s⁻¹.

The blast overpressures were recorded in the shock tube at a distance of 4.8 m, 5.8 m and 9.8 m from charge using PCB 102B16 sensors, a PCB 482-C signal conditioner, and a Tektronix 420 oscilloscope (Figure 3).

**Figure 3.** Layout chart of mist and pressure sensors in the shock tube. 1- Explosion chamber, 2 – charge, 3 – water mist, 4,5,6 - pressure sensors

4. **Test Results**

Figures 4 and 5 shows the dependence of the maximum overpressure and impulse on the distance to the charge without mist, with solid mist and mist with air gaps.
Figure 4. The dependence of the maximum overpressure on the distance to the charge without mist (1), with solid mist (2) and mist with air gaps (3)

Figure 5. The dependence of the impulse on the distance to the charge without mist (1), with solid mist (2) and mist with air gaps (3)

Attenuation of shock waves in solid mist and mist with air gaps was estimated using overpressure reduction coefficient $K_p$ and impulse reduction coefficient $K_i$:

$$K_p = (\Delta P_a - \Delta P_m)/\Delta P_a$$
$$K_i = (I_a - I_m)/I_a$$

Where $\Delta P_a$ and $\Delta P_m$ is overpressure without mist and with mist at the same distance from the charge; $I_a$ and $I_m$ - impulse without mist and with mist.

Table 1 presents the average maximum pressures and impulses at different distances from the center of charge and the reduction coefficients at solid mist and mist with air gaps when other conditions remain constant.
Table 1. The reduction coefficients at solid mist and mist with air gaps

| Blast conditions          | R=5.8m |                  | R=9.8m |                  | Reduction coefficient, K (Average) |
|---------------------------|--------|------------------|--------|------------------|-----------------------------------|
|                           | ΔP, kPa| t, ms            | I, kPa·ms| ΔP, kPa| t, ms| I, kPa·ms| Kp | Ki |
| Without mist              | 131    | 13               | 851    | 116  | 14   | 812   | -  | -  |
| Solid mist                | 60     | 11               | 330    | 55   | 11   | 302   | 0.52 | 0.61 |
| Mist with air gaps        | 53     | 11               | 292    | 51   | 10   | 255   | 0.60 | 0.66 |

5. Conclusions
The results of the experiments show that reduction coefficient K varies according to water mist structure when other conditions remain constant. It is established that under the considered conditions, the overpressure reduction coefficient in water mist with air gaps is 1.10-1.15 times higher than that in solid mist. Such an increase of the reduction coefficient appeared possible in conditions when the flow rate in Solid mist is 1.79 higher than in the mist with air gaps.

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