New Design of Shock Tube for the Study of Vapour Cloud Explosion

Edgar Mataradze[1], Nikoloz Chikhradze[1,2], Irakli Akhvlediani[1], Nika Bochorishvili[1], Ted Krauthammer[3]

[1] G. Tsulukidze Mining Institute, 7, E. Mindeli str., Tbilisi, 0186, Georgia
[2] Georgian Technical University, 0175, Tbilisi, Georgia
[3] Center for Infrastructure Protection and Physical Security (CIPPS), University of Florida, 3127 Research Drive, State College, PA16801, USA

E-mail: mataradze@mining.org.ge

Abstract. Determination of blast energy suppression characteristics is key to developing new protective techniques ensuring effective blast-suppression capacity, and enabling the formation of a blast-suppression barrier. The Mining Institute of Georgia and CIPPS of the University of Florida have designed a new type of a shock tube for investigating the processes of explosion suppression by a water mist barrier. The shock tube consists of a blast chamber, a tube, a system for dosed supply of fuel and water, sensors, registering equipment, and a process control module. The paper describes the structural and flow characteristics of the shock tube, and the possibilities it may offer for the study of the processes of blast mitigation with water mist.

1. Introduction

Blast experimentation with shock tube testing is an effective approach for studying various fundamental and applied aspects relating to blast wave dynamics and related effects. The overpressure is initiated in a shock tube as a result of the rupture of a diaphragm separating high-pressure and low-pressure chambers, and the dynamic process parameters in shock tubes depend on the design of both chambers. According to Bazhenova [1], shock tubes can be divided into four groups: i) shock tubes with inert gas in the high-pressure chamber; ii) shock tubes with an explosive in the high-pressure chamber; iii) electrically driven shock tubes, iv) shock tubes with shock wave enhancement.

The present shock tube was designed for the study of vapor cloud or solid explosive charge explosions in tunnels, and shock wave attenuation by water mist. The objective is very important since designing a high suppression capacity blast energy absorber requires the proper characterization of the water mist protective barriers. The suppression mechanisms of blast with water mist are addressed in works by Thomas [2], Van Winderden [3], Kailasanath [4], and Ananth et al [5]. It has been noted that water mist with fine sprays is efficient for the mitigation of explosions. Research has shown that shock energy extraction by water mist takes place during the processes of aerodynamic droplet break-up and vaporization of the child droplets. The main factors defining shock wave attenuation in mist include: the type of the damping agent, droplet size distribution, water concentration in the mist, and the geometric properties of the 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 devices for the protection of tunnels from explosions.

The shock tube developed for this research allows one to study the effects of water phase concentration, water drop diameter, inert admixtures in dispersed water, and length of the water mist on the blast attenuation, which has not been adequately addressed in previous studies. The results of such blast test scan be used for the selection of the design parameters for the protecting system.

2. Shock Tube Structure

The shock tube consists of a blast chamber, tube, system for the dosed supply of fuel and water, sensors, data recording equipment, and a process control module. The shock tube is located in a tunnel (Figure 1), while the data recording equipment and the control module are located in the monitoring room placed at a 6m distance from the tunnel entry.

Below are given the key characteristics of the blast chamber and separate tubes (Figure 2): diameter of blast chamber and tubes – 50 cm; length of blast chamber – 50 cm; length of separate tubes – 1 m; wall thickness – 8mm; number of separate tubes– 10, total length of shock tube – 10.5 m.

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

Pressure and flame sensors are fixed in the blast chamber and tubes. A high speed video camera records the blast in the chamber.

3. System for Dosed Supply of Water

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 for creating water mist.

Twelve nozzles 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 (Figure 3).

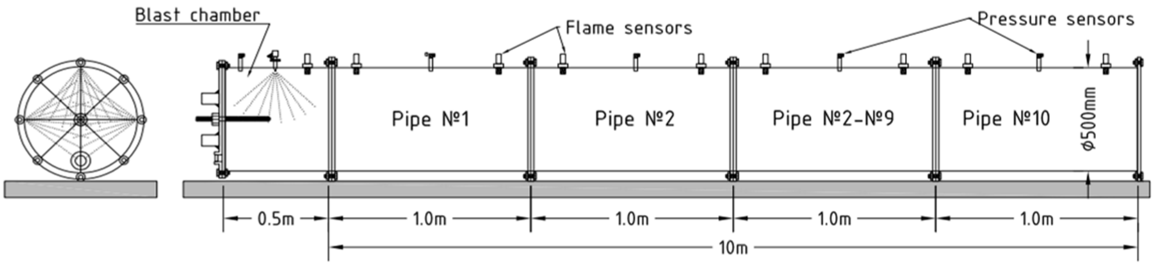

Figure 2. Schematic circuit of the shock tube

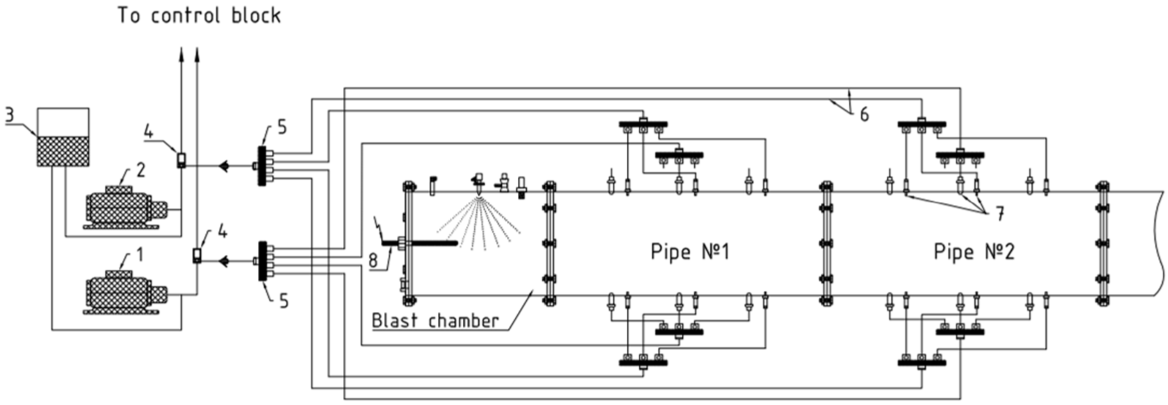

Figure 3. System for dosed supply of water. 1-low-pressure pump, 2- high pressure pump, 3- water tank, 4- electric valves, 5- water distribution manifolds, 6- pipes, 7- nozzles, 8- initiator

Upon activation, the system creates an almost equally distributed water mist in the shock tube (Figure 4).

Figure 4. Water mist in shock tube

The pipes can be fitted with spray nozzles of different models, which allows one to vary the droplet size in the mist at different stages of the experiments (i.e. the initial drop size distribution, spray mass flow rate, spray angle and spray projection). The use of modern nozzles allows the formation of mists in which the droplet size varies largely (Table 1). The use of nozzles in the shock tube at separate stages of the experiments enables the study of the blast energy mitigation processes with mists of different characteristics.

Table 1. Droplet size classifications, based on ASAE S-572

Category	Symbol	The Volume Median Diameter (VMD) Range (microns)
Extremely Fine	XF	~50
Very Fine	VF	<136
Fine	F	136-177
Medium	M	177-218
Coarse	C	218-349
Very Coarse	VC	349-428
Extremely Coarse	EC	428-622
Ultra Coarse	UC	>622

4. Process Control Module

The blast in the chamber is synchronized with the dispersed water supply system by the process control module (Figure 5).

The process control module has the following functions:

- provide information regarding the current state of the experiment;
- in accordance with the pre-defined objective of the experiment, give commands regarding the amount of water to be supplied to the chamber and tubes, as well as time intervals for the water supply;
- give commands regarding the initiation of water spray in the tube and blast initiation in the chamber;
- memory management information.

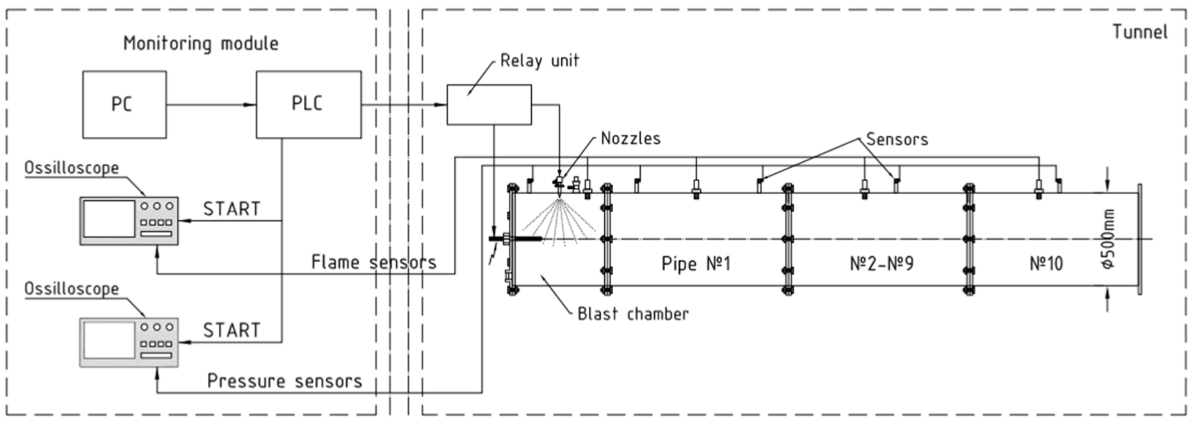

Figure 5. Control and measurement circuit

The control module operates it two modes: testing and experimental. The testing mode enables to check the performance of the system before the start of the experiment.

In accordance with the objectives of the experiment, indicators of the amount of the fuel injected, amount of the water injected, the time of injection, and the moment of initiation are entered in the program (Figures 6, 7).

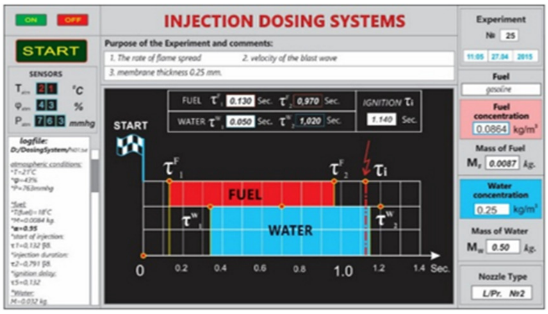

Figure 6. Interface of Control Block

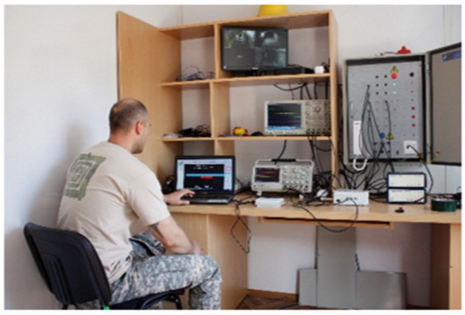

Figure 7. Monitoring module

After issuing a command, the software ensures the discharge of fuel and water in accordance with the predefined sequence and timing, initiates the data registration equipment, generates blast initiation signal, and shuts down the system.

5. Conclusions

The presented shock tube is designed to ensure the selection of design parameters of the blast suppression system. The results of blast experimentation using the shock tube with the various mist characteristics will contribute to the determination of blast wave absorber design parameters.

Acknowledgements

These tasks were performed with the financial support of the NATO SPS Programme and ISTC.

References

[1] Bazhenova, T. V. Shock tubes. DOI:10.16.15/AtoZ.s.shock_tubes, www.thermopedia.com/ru/content/1124. 2011, online: 05/2016
[2] Thomas G.O. On the Conditions Required for Explosion Mitigation by Water Sprays. Trans I Chem E: Part B - Process Safety and Environmental Protection Vol. 78 pp. 339-354, 2000.
[3] Van Wingerden, K., Mitigation of Gas Explosions Using Water Deluge, Process Safety Progress, v. 19, pp. 173-178, 2000.
[4] Kailasanath K. and Schwer D. Shock Attenuation Using Water Mists. Naval Research Laboratory, Code 6410. Washington, DC 20375, 2007.
[5] Ananth R., Ladouceur H., Willauer H., Farley J. and Williams F. Effect of Water Mist on a Confined Blast. www.nfpa.org/assets/files//PDF/Foundation%20proceedings/Ananth.pdf. 2009