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EXPLOSION SUPPRESSION IN AN OCCUPIED COMPARTMENT

by

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INTRODUCTION

Explosion is an exothermic chemical reaction or a spontaneous combustion, generating a high temperature, a large quantity of gases and destructive pressure. Depending on its propagation speed, an explosion can be classified as a detonation in which the combustion wave moves at a rate above the velocity of sound, or can be classified as a deflagration in which the combustion wave moves at a rate below the sound velocity.

Explosion suppression generally means deflagration suppression. This involves detecting and arresting combustion in a confined space while the combustion is still in the incipient stage. This is achieved by rapidly discharging a suppressant to directly terminate the explosion reaction and flame propagation before a destructive pressure rise is reached.

Until recently, Halon 1301 has been used for the protection of an occupied compartment, such as the crew compartment of armoured vehicles. However, the production of halon has been banned by the Montreal protocol due to its environmental impact. In order to pursue environmentally and toxicologically acceptable alternatives to Halon 1301, some new explosion suppression systems have been developed, and initial studies on the capability of these systems with different types of suppressants have been carried out [1-3]. Among these systems, three have been identified for further evaluation. They are: a high pressure/FM-200 extinguishing system, a hybrid gas generator/FM-200 extinguishing system, and a hybrid gas generator/water extinguishing system.

The National Research Council of Canada (NRC) has recently carried out a project to study deflagration-type explosions that could be encountered in the crew

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compartment of military armoured vehicles. The performance of these three extinguishing systems in a real-scale crew compartment was evaluated.

This paper describes the deflagration explosion suppression experiments, provides experimental results, and discusses concerns including toxicity issues associated with the protection systems. The impact of agent discharge direction and using additives on suppression performance is also reported.

EXPERIMENTS

The real-scale explosion suppression experiments were conducted in a compartment constructed to simulate the crew compartment of armoured vehicles. Three explosion suppression systems, with full-system hardware including optical fire sensors and electronic controller, were evaluated.

Test Compartment

A test compartment simulating the back half of an armoured vehicle crew compartment was constructed to carry out explosion suppression experiments. The cross-section area of the test compartment was 2.52 m^2, and it was 1.5 m in length and the total volume of the test compartment was 3.78 m^3. The test compartment had an access door with a dimension of 1.04 m x 1.04 m. This door also acted as a pressure relief vent to protect the compartment integrity.

Explosion Scenario

The explosion scenario used in the experiments simulated a projectile penetrating the hull of the vehicle through a fuel tank, and causing fuel spray and ignition in the crew compartment. The explosion in the test compartment was generated with a fuel spray using a twin-fluid (fuel and air) nozzle and a hot wire igniter. The fuel spray nozzle was located at one corner of the compartment and 0.74 m high from the floor. Gasoline was used as the testing fuel, which made the explosion very challenging for suppression due to its volatility.

During the experiments, the fuel spray was maintained for approximately 2 to 3 seconds. The electric igniter was maintained hot during the experiments to simulate the presence of hot fragments in the crew compartment when a projectile penetrates the wall. The presence of hot ignition wire increased the possibility of fire re-ignition, providing a challenging scenario for explosion suppression.

Explosion Extinguishing Systems

The three fire extinguishing systems with their flame detectors were mounted on the wall of the test compartment, opposite to the fuel spray, respectively.

The high pressure FM-200 extinguisher tested in the experiments used "standard" US Army halon bottles, which had a volume of approximately $0.014 m^3$. FM-200 was stored in the bottle and pressurized up to 40 bar (600 psi) with nitrogen. The initiation of the explosion in the test compartment was detected by a high speed optical UV/IR flame detector. The detection of the explosion activated the discharge of the extinguishing agent. The design concentration of FM-200 in the compartment was 7%, which required 2.26 kg of FM-200 in the extinguisher for the test compartment. In some experiments, the effect of an additive on the explosion suppression, as well as the scavenging effect of the additive on acidic gas products, were studied. The additive used in the experiments was sodium bicarbonate, and the amount used in the experiments was 250 g.

The hybrid gas generator fire extinguisher consists of an initiator, a solid propellant and liquid fire suppression agent [2-4]. Once a fire is detected, the flame detector sends an electrical stimulus to ignite a small pyrotechnic charge in the initiator, which then ignites the solid propellant. The heat and pressure generated by the combustion of the solid propellant are used to heat and expel the liquid suppression agent. Typically, liquid suppression agents used in hybrid gas generator fire extinguishers are water and halocarbon agents.

The hybrid gas generator fire extinguishers used in this project contained either FM-200 (2.26 kg) or water (1.5 kg or 2.25 kg). Both systems were tested with and without additives. The additive used in the hybrid gas generator with FM-200 was sodium bicarbonate, and the additive used in the hybrid gas generator with water was potassium acetate.

Instrumentation

The instrumentation used in the experiments included photodiodes, thermocouples, pressure sensor, simulated skin indicator, gas analyzers and a Fourier Transform Infrared (FTIR) spectrometer. They were used to measure the fire ignition and extinguishment times, compartment temperatures and pressures, and the type and concentration of fire gases in the compartment. Video cameras were also used to monitor the fuel discharge, fire ignition, agent discharge and explosion extinguishment.

RESULTS AND DISCUSSION

Experiments were carried out to study the performance of three explosion suppression systems in extinguishing explosions in the testing compartment with and without additives.

Explosion Suppression without Additive

In the experiments, one extinguisher was installed in the mock-up compartment and the nozzle of the extinguisher was aimed towards the fire source located at one corner of the compartment. A high pressure FM-200 extinguisher, a hybrid/FM-200 or hybrid/water extinguisher was used in each experiment.

Using a high pressure FM-200 extinguisher, the explosion was extinguished in 396 ms. However, the fire quickly re-ignited in 495 ms, after the initial extinguishment. The re-ignited fire lasted for a few seconds until the fuel in the compartment was burnt up.

Since the level of thermal decomposition products generated during suppression was determined by the fire intensity and the duration of the reaction time between the agent and flame, the re-ignition resulted in very high HF and COF_2 concentrations in the compartment. The average HF concentration over a 2 min period in the compartment was approximately 5,000 ppm. At the same time, the oxygen concentration in the compartment dropped to 10%, and CO and CO_2 concentrations exceeded 1.0 and 4.0%.

The hybrid/FM-200 extinguisher extinguished the explosion in 228 ms, however, the fire re-ignited at 2840 ms after the first explosion was extinguished. At the moment of re-ignition, both the agent discharge and fuel spray were completed, but the igniter was still maintained hot. The extinguishing time of the initial explosion was shorter using the hybrid/FM-200 extinguisher than using the high pressure/FM-200 extinguisher.

The hybrid extinguisher with 1.5 kg of water could not extinguish the explosion. When the amount of water was increased to 2.25 kg, the explosion was extinguished in 240 ms, but quickly re-ignited at 300 ms after the first explosion was extinguished.

Experiments showed that all three extinguishers, when the agent discharge was aimed toward the fire source, were able to extinguish the explosion, but could not prevent the fire from re-ignition.

In order to evaluate the impact of agent discharge direction on the explosion suppression, the direction of the extinguisher nozzle was adjusted to aim sideways toward the back of the compartment.

The high pressure extinguisher with 2.26 kg of FM-200 quickly extinguished the explosion in 310 ms and no re-ignition occurred in the compartment. The suppression performance was better than that with the agent discharging toward the fire source. The successful explosion suppression resulted in low fire gases and thermal decomposition products generated in the experiment.

The hybrid extinguisher with 2.26 kg of FM-200 extinguished the explosion in 153 ms, and there was no subsequent re-ignition. The suppression performance of the hybrid/FM-200 extinguisher was significantly improved with discharging sideways, compared to discharging toward the fire source. Its extinguishing performance was also better than the high pressure/FM-200 extinguisher under the same testing conditions.

Experiments showed that with the agent discharging sideways, performance of both the high pressure and hybrid/FM200 extinguishers was improved. However, the performance of the hybrid/water extinguisher was not improved by discharging water sideways. The hybrid extinguisher with 2.25 kg of water reduced the fire size, but could not extinguish the explosion. As observed in the experiment, unlike a gaseous agent, some of the discharged water was lost when discharged sideways, as fine water droplets hit the side and back walls and adhered to them before reaching the fire source. The failure of explosion suppression led to high temperatures (1018^{o}C) and large overpressure (3049 Pa) in the compartment.

Explosion Suppression with Additive

To evaluate the effect of an additive on the explosion suppression and the generation of thermal decomposition products, full-scale experiments were carried out using three extinguishing systems with different types of additives.

Sodium bicarbonate (250 g) was added into 2.26 kg of FM-200 in the high pressure extinguisher. When the nozzle direction of the extinguisher was aimed towards the fire source, the high pressure extinguisher extinguished the explosion in 388 ms, and there was no subsequent re-ignition. The suppression performance was significantly improved in terms of re-ignition protection and HF/COF_2 production, compared to the experiment without the additive under the same testing conditions. It was noted that after the experiment, the whole compartment surface was covered with a light dusting of the additive (sodium bicarbonate).

In the hybrid FM-200 extinguisher test, 25 g of sodium bicarbonate was added into the solid propellant of the gas generator. The nozzle of the hybrid extinguisher was aimed towards the fire source. The explosion was extinguished in 277 ms, and there was no subsequent re-ignition. Compared to the experiment without the additive, the additive helped in preventing re-ignition. Since the explosion was quickly extinguished, the amount of HF and COF_2 generated in the experiment was small.

The additive used in the hybrid/water extinguisher was potassium acetate. When 2.25 kg of water solution with 48% potassium acetate and 4% soap was used in the hybrid water extinguisher, it extinguished the explosion in 264 ms. However, when the water discharge was completed, a blue flame appeared around the igniter. The fuel re-ignited at 415 ms after the first explosion was extinguished and the fire quickly spread to the whole compartment. For the hybrid/water extinguisher, the additive did not improve the fire suppression performance of the extinguisher.

SUMMARY

The experimental results showed that an explosion in a compartment by a fuel spray would be a serious threat to any occupant in the compartment and would cause major damage to equipment. However, the deflagration-type explosion can be controlled or extinguished by appropriate extinguishing systems.

The experiments showed that the high pressure FM-200 extinguisher, the hybrid gas generator with FM-200 or with water, could extinguish an explosion in the compartment. But, they could not prevent re-ignition of the explosion in the compartment in some cases. The explosion suppression performances of the extinguishers were affected by the agent discharge direction and the use of additives.

The test results showed that the nozzle direction of the extinguisher plays a significant role in the extinguishment and re-ignition prevention of explosion in the compartment. For the extinguishers with FM-200, when the nozzle of the extinguisher was aiming towards the fire source, the extinguisher extinguished the explosion, but there was a re-ignition of the explosion in the compartment. When the direction of the extinguisher nozzle was adjusted to aim sideways towards the back of the compartment, the extinguishers extinguished the explosion sooner and prevented the re-ignition of the explosion in the compartment. The experiments showed that discharging the agent sideways, instead of directing it toward the fire source, improved the suppression performance of the extinguishers.

When an additive was used to reduce the amount of thermal decomposition products generated from FM-200, it improved the suppression performance of the extinguishers. Using 250 g of sodium bicarbonate mixed with 2.26 kg of FM-200 made the extinguisher perform better. However, it produced sodium bicarbonate residue on the compartment walls.

A hybrid gas generator extinguisher with 1.5 kg of water failed to extinguish the explosion in the compartment. However, the hybrid water extinguisher containing 2.25 kg of water was able to extinguish the explosion in 240 ms, but the fuel spray quickly re-ignited after the first explosion was extinguished.

Adding potassium acetate to water as an additive did not improve the explosion suppression performance of the hybrid water extinguisher. The hybrid water extinguisher containing 2.25 kg of the water solution with a weight percentage of 48% potassium acetate, extinguished the explosion initially, but there was a subsequent re-ignition.

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