FULL-SCALE FIRE TESTING OF ARGON AS AN INERT GAS AGENT

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INTRODUCTION

Halon is an effective fire suppressant: however, because of its ozone-depleting potential, its use is regulated by international consensus. the Montreal Protocol. There is a major thrust. therefore, to find an appropriate fire suppression agent to replace halon. At present, two types of halon substitutes are available for consideration: halon replacement and halon alternative. For instance. halocarbons with modified molecular structures are considered to be "replacements," whereas not-in-kind substitutes such as water mist, inert gases and solid aerosols are considered to be "alternatives."

Since there is no ideal halon replacement agent available in terms of its fire suppression performance and the toxicity of its thermal decomposition products. it is worthwhile to consider evaluating some of the potential halon alternatives. In a previous study, National Research Council (NRC) investigated the performance of water-mist systems, and determined that water mist is an effective system for some applications, but not for all situations. Water mist extinguishes fire by physical means but does not act as a total-flooding agent, like Halon 1301.

Another option is inert gases, which extinguish fire by oxygen depletion, but behave like total Hooding agents and may be long-term alternatives to Halon 1301. These inert agents, such as nitrogen (N_2), argon (Ar) and helium (He), are clean and naturally occurring ingredients in the atmosphere, and produce no decomposition products when used in extinguishing fires.

In this study. the performance of argon as an inert gas agent was evaluated. The objectives of these tests were to evaluate the fire suppression effectiveness **of** argon in full-scale fire testing and to identify any potential problems such as toxicity. compartment over-pressurization, and discharge time delay. Argon was evaluated using fire scenarios similar to those used in other halocarbon tests previously conducted by NRC. In addition to the heptane that was used as a liquid fuel in previous tests, toluene was used to evaluate the effectiveness of argon in suppressing different fuels.

TEST FACILITY

Test Room

The test compartment was the same one used in the previous tests [1] of the Halon Alternatives Performance Evaluation **(HAPE)** program. A mock-up of Radar Room No. 2 on the DND Halifax Class Frigates, it was an irregular-shaped. rectangular room with dimensions of 9.7 by 4.9 by 2.9 m high, with ***a*** corner (2.9 by 2.2 m) removed.

The test compartment had one 2.0 by 0.9 m door and one 0.5 by 0.5 m pressure relief vent in the south wall near the floor. The pressure relief vent was used to relieve over-pressure in the room during agent discharge. This vent was purposely located near the floor, rather than at the ceiling, to better simulate fire conditions in the compartment during the preburn period of the tests.

Piping System

The pipe layout in the compartment was similar to the existing Halon 1301 piping in Radar Room No. 2 of the Halifax Class Frigates [1] except that four nozzles instead of two were installed on the ceiling of the compartment at the two discharge locations. Each nozzle was cylindrical in shape and contained an outlet orifice that discharged onto a deflector located 25 mm away. All nozzles had 10.3 to 11.0 mm outlet orifices.

Five to seven pressurized cylinders, each with a pressure of 15.85 MPa (2300 psi) and with dimensions of 0.23 m (diameter) x 1.48 m (height to the collar). were placed outside of the test compartment. The cylinders were placed in a metal rack; each cylinder was hanging from its bracket by two metal rods. The manufacturer claims that this hanging arrangement, instead of the more conventional method of cylinders sitting on the floor, provides an inexpensive way to monitor potential argon leaks from the cylinders without actually weighing the cylinders. Should a leak occur, a bright red arm is lowered which provides a visual indication of the problem.

All cylinder outlets were connected to a manifold by flexible rubber hoses. The manifold was connected to the distribution pipe through a 38 mm pipe union and contained a 10.5 mm orifice plate that acted as a pressure reducer during the discharge. During the tests the cylinders were activated manually by pulling a lever; this action initiated a timer mechanism, which delayed the discharge activation for 30 sec.

Fire Scenarios

Fire scenarios included small telltale and square pan fires and large pool and spray fires using both heptane and toluene as fuels. Also used were a wood crib fire and small heptane and toluene fires inside cabinets. The fires were placed at various locations in the test compartment and represented serious challenges for fire suppression.

Eight telltale (TT) fires, each in a 75 mm diameter can, were placed strategically throughout the room at different elevations. The total heat output from these 8 (heptane fuel) telltale fires was approximately 50 kW. To simulate small fires in the cabinets, 4 additional TT fires were placed in the cabinets. These cabinets, each with dimensions of 0.81 by 0.81 by 1 m high, had two small grill openings at the lower and upper portions of the side walls. Two cabinets had ventilation opening ratios of 5% and were placed near the southeast corner, one on top of the other. The third mock-up cabinet had a ventilation opening ratio of 2% and was placed near the middle of the north wall, approximately 1.45 m from the west wall and 0.67 m from the north wall.

Three square-pan (SP) fires with dimensions of 0.3 by 0.3 m were placed at three corners of the room. The total heat output from these SP heptane fires was approximately 150 kW.

To evaluate the extinguishing performance of Argon against Class A fires, one wood crib was placed at the southwest comer of the room. The wood crib was made of 0.04 m pine sticks in 6 layers and was approximately 0.6 by 0.6 by 0.25 m high. The heat release rate of the wood crib was approximately 450 kW.

A 0.7 m diameter round pan (RP) was used in the tests. The pan contained 8 L of heptane or toluene fuel on a water base. and the lip height of the pan above the fuel level was approximately 20 mm. The heat release rate of the RP with heptane fuel was approximately 500 kW. During the tests, the round pan was unshielded or partially shielded from the direct spray of the agent discharge: In the partially shielded case, the pan was covered with a metal box measuring 0.80 by 0.84 by 1.0 m high with side metal mesh; the top of the box was covered by a layer of sheet metal with holes that constituted a 6% opening ratio of the surface area.

One spray nozzle was placed under a metal table (1 m wide by 1.36 m long by 0.64 m high), approximately 1.0 m from the east wall and 1.77 m from the south wall of the compartment. The operating pressure of the spray fuel was 8.3 bar, and the total heat release rate of the spray fire with heptane fuel was approximately 520 kW.

Instrumentation

Test data from a wide array of instrumentation were collected by a data acquisition system. The room temperature distributions and the extinguishment times of the fires were measured by thermocouples. The pressure changes in the compartment were monitored by pressure taps. The concentrations of O_2, CO_2, and CO in the compartment were determined using gas analyzers. Also, to monitor the agent discharge. four pressure transducers/thermocouples were installed in the pipe and one pressure transducer/thermocouple was placed near each of the two discharge locations. To monitor the sound level during agent discharge. a broad-band sound level meter was installed in the test room, located near the door approximately 1.7 m above the floor. And. two video cameras were set up at the south and north windows to obtain visual records of the agent discharge and fire behaviour during suppression.

TEST RESULTS

Ten full-scale tests were conducted in the test program. Test results showed that the design concentration of 40% in the compartment (120 m^3) was achieved using six pressurized cylinders, each containing approximately 17 kg of argon. Agent discharge time depended on the orifice size used in the discharge pipe. The original orifice sizes recommended by the manufacturer were too small, and the discharge time unacceptably long (83 sec for 90% discharge). With proper orifice size, the discharge period for 90% of the agent was approximately 45 sec using six cylinders. which resulted in 40% agent concentration in the compartment.

The maximum discharge sound level measured during the tests was approximately 128 dB. It was slightly higher than the level measured during the tests of halocarbon agents, and also the discharge period of argon with high sound intensity was longer than that of halocarbon agents.

With the discharge of argon, there was no significant clouding or obscuration. and the compartment remained visible. There was a rapid pressure increase in the test compartment caused by the agent discharge, as observed in tests with other gaseous fire suppression agents. With proper ventilation openings, the room pressure rise was not significant, and the pressure increase in the compartment was limited a maximum of 580 Pa.

Argon extinguishes fire by oxygen depletion. During the tests. argon, with at least 40% concentration, extinguished all fires in the compartment, regardless of their positions in the room and fire scenarios. The extinguishing times varied with fire size and location in the compartment; however, the extinguishing times of argon were generally longer than those using halocarbon agents due to its longer discharge period, but were similar to the extinguishing times of other inert gases such as IG-541 (Inergen).

The test results showed that toluene fires were much easier to extinguish than heptane fires. Agent concentration as low as 30% extinguished TT and square-pan toluene fires, whereas the same agent concentration failed to extinguish the same fire scenario using heptane fuel. This confirmed the results of laboratory-scale cup-burner tests where it was noted that toluene fires require lower concentration of argon compared to heptane fires.

The test results also showed that it was easier for argon to extinguish larger fires than smaller fires. In the case of small fires, only a small amount of oxygen was consumed by the fires, whereas more oxygen was consumed during the prebum period of larger fires. A large quantity of combustion products was also generated, which enhanced the extinguishing performance of the agent (argon).

When there was no ventilation in the compartment, the agent concentration in the room remained steady and argon was effective in preventing the reignition of the fuel. If the door was kept open after fire extinguishment however, the air flow between the hot compartment and its cold surroundings resulted in a reduction of the agent concentration in the compartment. As a result, argon, as with any other gaseous agents, could not effectively prevent the reignition of the fuel under ventilation conditions.

Argon is heavier than air and the test results demonstrated the non-uniformity of argon distribution in the compartment. After fire extinguishment, argon distribution in the compartment stratified with time, resulting in a higher concentration of argon in the lower portion of the compartment. If all potential fire sources are in the lower portion of the compartment, this would be beneficial for preventing reignition; however. if the location of the fire source is not known, it may require higher agent concentration to compensate for the agent stratification in the upper portion of the compartment.

CONCLUSION

The following conclusions were obtained from the full-scale fire tests of argon.

1. In the test program, the design concentration of 40% in the compartment (120 m^3) was achieved using six pressurized cylinders. each at a pressure of 15.85 Mpa (2300 psi) and with dimensions of 0.23 m in diameter and 1.48 m in height.
2. At the beginning of the argon discharge, there was a rapid pressure increase in the test compartment, as observed in the case with other gaseous fire suppression agents. With proper ventilation openings, however, the initial pressure rise was manageable, and no damage to the integrity of the compartment was observed in the test program.
3. The maximum discharge sound level for argon was approximately 128 dB. It was slightly higher than that measured in the tests with halocarbon agents (such as HCFC Blend A and FM-200), and the period with high sound intensities was longer than that for the other halocarbon agents.

4. In the tests, argon, with 40% concentration, extinguished all fires in the compartment by oxygen depletion, regardless of their size, type and position in the room. The extinguishing times of argon were generally longer than those of halocarbon agents.
5. Argon operated in a total-flooding mode to extinguish fires and was able to penetrate into the cabinets and extinguish the small fires.
6. **As** the target concentration of argon was reduced, the fire extinguishment times were delayed. **At** below 30%. argon failed to extinguish all heptane test fires, yet, the same concentration of argon extinguished all test fires with toluene fuel.
7. It was easier for argon to extinguish larger fires than smaller fires.
8. Argon is heavier than air; a non-uniformity of argon distribution in the compartment resulted in a higher concentration of argon in the lower portion of the compartment. If all potential fire sources were in the lower portion of the compartment. this would be beneficial for preventing reignition; however, if the location of the fire source is not known, a higher agent concentration may be required to compensate for the agent stratification in the upper portion of the compartment.

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REFERENCES

1. Kim, **A.** K., Su. J.Z.. Mawhinney. J. R. and Kanabus-Kaminska. M.. "Full-Scale Fire Testing of HFC-227ea and HCFC Blend A," *Proceedings*, Halon Options Technical Working Conference, Albuquerque, NM. pp. 413-422, 1996.