PROTECTING SHIPBOARD FLAMMABLE LIQUID ROOMS WITH HFP (HFC-227ea)

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The US Navy is investigating fixed fire extinguishing systems for future use in Flammable Liquid Storerooms (FLSR) where Halon 1301 total-flooding systems have been used. Previous fire suppression evaluations led to HFP (HFC-227ea) being selected as the gaseous agent for shipboard use. The key to successful application is getting the required concentration of agent to the fire quickly. This achieves rapid extinguishment and thereby minimizes formation of toxic and corrosive agent byproducts, especially hydrogen fluoride (HF). FLSRs contain many obstructions, leading to pronounced agent concentration inhomogeneities. Thoughtful consideration of nozzle placement and agent design concentration selection is required.

This three-phase program conducted at NRL's Chesapeake Bay Facility (CBD) is exploring the implementation parameters for providing fire protection for FLSR applications. Phase 1 tests were conducted in a 28 m^3 (1000 ft^3) test compartment. This test bed is applicable to many smaller shipboard compartments. Phase 1 testing results served as a learning process for designing and executing Phase 2 and **3** of the program. Phase 2 testing is currently underway in a 126 m^3 (4460 ft^3) compartment. which acts as an intermediate step to the large 300 m^3 test chamber. This step process is necessary since agent performance does not scale linearly with compartment size due the complexity of fire dynamics and agent distribution. The testing will quantify nozzle throw distance and coverage area as well as HFP performance with fire sizes ranging from 400 kW to 800 kW. Phase **3** testing will be conducted in 2001 in a 300 m^3 (10,500 ft') compartment, which is a representative size for large shipboard FLSRs. These tests will address the same issues as Phase 2 but for larger spaces.

PHASE 1

Phase 1 objectives were to quantify the performance of HFP in terms of fire suppression. reignition protection. and quantities of agent decomposition products generated. Overall suppression system performance was characterized as a function of agent concentration, effects of obstructions, and fuel and fire type. The effects of compartment leakage area and hold time (time period from agent discharge to compartment ventilation initiation) in terms of compartment reclamation were also examined. Over 100 tests were conducted including over 20 suppressions. Limited baseline tests were conducted with Halon 1301. Some preliminary results from Phase 1 testing were reported at *HOTWC-98* [11.

Suppression agent design concentration selection must be directly linked to fuel suppression requirements. Methanol, present in US Navy shipboard FLSRs, was the primary fuel evaluated due to its high HFP extinction concentration requirements. Comparable rapid fire extinguishment times (**less** than 7 sec) were observed for each of the four HFP design concentrations evaluated, ranging from 9.0 to 11.5%. However, these fire-out times are not a sufficient characterization of the extinguishment capabilities of HFP. Although an HFP concentration of 9.0% extinguished the fire. 8400 ppm of HF was produced, where only 2450 ppm of' HF was produced when an HFP concentration of 11.5% was discharged [2]. As identified through earlier intermediate-scale HFC and PFC testing [3], HF generation decreases significantly until agent at the flame sheet reaches 30% above cup-burner extinguishing concentration. However, for large fires, the amount of HF produced initially most likely will still be hazardous to life even at high agent concentrations. This emphasizes that test parameters and results form a complex evaluation matrix, well beyond simply answering the question—will the fire will go out?

Oxygen depletion is a critical factor in fire suppression for small, tight compartments such as FLSR 1. Oxygen available to support combustion, initially limited by the size of the small compartment, is further depleted during the time elapsed (preburn time for tests, response time for applications) from fire initiation to agent discharge. In a larger compartment, such as in FLSR 2, the effects of oxygen depletion would be less pronounced.

The use of low agent design concentrations (less than 20% above cup-burner extinguishing Concentration) with unconfined highly volatile fuels can yield hazardous conditions. An energetic flame spread/deflagration was observed when 8.5% HFP was discharged after a very short preburn (very little oxygen depletion) to extinguish an 80% methanol, 20% heptane, 3-dimensional cascading fire. It was determined that induced turbulence caused by agent discharge enhances the burning rate of the fire by spreading the fuel of the evaluated cascading fire and hence increasing the effective fuel surface area as well as increasing fuel evaporation and mixing with air. This increase in burning rate can also create a rapid pressure rise in a sealed compartment. If rapid extinguishment is not achieved, the pressures reached can be damaging. It is therefore clear that ventilation specifics and the time before system activation can make a large difference in the effectiveness of a suppression system.

The presence of mockups (e.g., flammable liquid containers) influence compartment conditions in several ways. The containers reduce the floodable volume of the compartment, thus increasing the effective agent design concentration, aiding extinguishment. The presence of containers and obstructions (i.e., shelving and cabinets) also restricts suppression agent distribution, inducing agent inhomogeneities, and hindering extinguishment at low agent concentration locations. In highly obstructed compartments, these inhomogeneities make the agent concentration very location specific, significantly affecting agent fire suppression performance.

HFP fire suppressions generated significantly more halide acid gas than would a comparable Halon 1301 fire suppression. The increased hydrogen fluoride gas production from hydrofluorocarbon agents compared with bromine containing Halon 1301 has already been reported from earlier NRL intermediate-scale *[3]* and real-scale [4] testing.

FLSR 1 testing has shown that small Navy shipboard FLSRs, in the order of 30 m^3 (1100 ft^3), can be protected by HFP with a design concentration of 11.5%. This elevated concentration requirement is directly linked to the higher suppression requirements of methanol present in FLSRs. Agent performance does not scale linearly with compartment size due the complexity of fire dynamics and agent distribution. **As** FLSRs get larger (including height) a small fire will generate only limited oxygen depletion and will not significantly enhance agent performance. As the complexity of compartment layout increases, agent inhomogeneities further hinder agent performance. Phases 2 and 3 are designed to provide answers for larger shipboard FLSRs.

PHASE 2

Phase 2 testing includes cold discharges (agent discharges without fires, completed in 1999) and on-going fire suppressions to be completed in 2000. The primary goals of Phase 2 cold discharge tests were to quantify the throw distance and coverage area for agent discharge nozzle(s) in a highly obstructed FLSR. Cold discharges were conducted in two compartments: Subcompartments 1 and 2. The dimensions of Sub-compartment 1 comprise the maximum allowable volume that can be protected by a single nozzle system as per US Naval Sea Systems Command **(NAVSEA)** specifications, while the volume of Sub-compartment 2 matches the maximum allowable protected volume for a two-nozzle system. The cold discharges allowed for the full characterization of the nozzle coverage area for both compartments. The various shelving layouts and number of obstructions challenged the current design limits and permitted analysis of the interactions of a two-nozzle discharge system.

Three agent distribution systems were evaluated in Sub-compartment 1: a single overhead nozzle with a 4-hole at right angles (360 deg) discharge pattern, positioned just below the ceiling level in the center of the compartment; a bulkhead (sidewall) nozzle system discharged simultaneously with the single overhead nozzlc; and two overhead nozzles each with a4-hole (360 deg) discharge pattern. Sub-compartment 2 testing was conducted using two independent agent discharge systems discharging through single overhead nozzles. each with a 4-hole (360 deg) discharge pattern. Four overhead and bulkhead nozzle discharge systems were not evaluated during Sub-compartment 2 testing because Sub-compartment 1 testing demonstrated that the two overhead nozzle configuration should provide the necessary protection. Various shelving and mockup configurations were employed during Sub-compartment 1 and 2 testing to challenge the agent distribution capacity of the discharge systems. Twelve (12) cold discharge tests were conducted in Sub-compartment 1 and six were conducted in Sub-compartment 2.

Pronounced agent inhomogeneities exist during and soon after discharge. They arc greatly reduced by 25 sec after discharge initiation by which point suppression should have occurred. The effectiveness of a bulkhead nozzle is very scenario dependent, including shelving location and loading. Specific configuration validation is required. While a bulkhead nozzle design is feasible, an overhead nozzle design provides a less risky/costly option due to easily implementable overhead nozzle spacing guidance generated from a limited number of validation tests.

It was determined that for compartment volumes up to 126 m^3 (4470 ft^3), while agent inhomogeneities where observed, the two overhead nozzle configuration can provide acceptable agent distribution (during cold discharges) for the various evaluated shelving and obstruction layouts. The inclusion of fire suppression testing in Sub-compartment 2 will permit the characterization of fire dynamics effects on agent distribution and nozzle coverage area.

FUTURE DIRECTION

Ongoing Phase 2 fire suppressions will provide critical input for the development for the Phase 3 test matrix and the internal configurations of the test compartment. **All** tests to date have been conducted in compartments with a ceiling 10 feet in height. The Phase 3 test compartment. with a ceiling 15 feet in height and representative of the larger FLSRs in the Fleet, will significantly challenge agent distribution and suppression performance. Previous tests have dramatically illustrated the importance of full-scale evaluation and the need for realistic test platforms. Non-uniform agent distribution and fire dynamics interactions are more strongly encountered in larger, more obstructed spaces. Due to the complex nature of the fire environment, real-scale testing must be conducted to develop the engineering tools to allow safe system implementation.

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