EVALUATION OF SELF-CONTAINED COMMERCIAL HALON SUBSTITUTE SYSTEMS

Alexander Maranghides and Ronald S. Sheinson
Naval Research Laboratory

ABSTRACT

The **US** Navy is transitioning into a new acquisition system where vendors will be proposing to performance specifications rather than design specifications allowing more latitude in system design. To anticipate how shipyards might pursue incorporating fire protection systems, the NRL conducted an open solicitation in the *Commerce Business Daily* for vendors to provide nonhalon system proposals to protect against a shipboard flammable liquid storeroom (FLSR) fire scenario. Four commercial self-contained halon substitute systems were subsequently evaluated: two gaseous-dry powder hybrids and two water mist systems. Baseline HFP (HFC-227ea) tests were conducted to compare the performance of candidate alternative technologies to an established technology. This paper covers the tests conducted and the fire suppression and reignition protection capabilities of the systems evaluated. Rapid reignitions/deflagrations occurred with one of the hybrid systems and with both water mist systems.

The primary objective of the halon alternative program was to evaluate "non-traditional" self-contained halon alternative technologies. The second major objective of the program was to quantify halon alternative suppression system performance in terms of fire suppression and reignition protection for **Class B** fire scenarios. The generation of agent decomposition products and residues from the hybrid systems were closely monitored. Overall suppression system performance was characterized for different agent concentrations and the effects of obstructions. The systems were evaluated in terms of their fire suppression and reignition protection performance as well **as** on their space and weight requirements. The systems were evaluated at the NRL Chesapeake Bay Detachment in the 28-m^3 (1000-ft^3) fire research chamber [1]. The fuels used were methanol, n-heptane, and a mixture of 80% methanol, 20% *n*-heptane. Methanol was selected because of the high HFP concentration required for extinguishment. The methanol was sweetened with n-heptane to enhance flame visibility for increased safety and to facilitate fire extinguishment determination. The test sequence and parameters were modeled after a probable fire scenario in a FLSR aboard the Navy's newest amphibious ship, the LPD-17. **A** simulated fuel spill within loaded shelving was used to **test** the capabilities of the extinguishing system. This fire presented **a** realistic worst-case scenario by creating obstructions that would hinder agent distribution hence, affecting the extinguishing performance of the agent.

HFP BASELINE TESTS

The baseline HFP test series was conducted to compare the performance of candidate alternative technologies to an established technology [1, 2]. Two of the three baseline suppression tests were conducted with an 8.5% agent design concentration. The tests involved a short 20-sec prebum (time from fire initiation to agent discharge) which limited oxygen depletion. Therefore, the low agent concentration coupled with high oxygen levels presented a challenging suppression scenario. The 8.5% HFP concentration corresponded to the maximum weight of HFP, together with the powder, that could be stored in the agent cylinders of the two evaluated hybrid systems. Immediately following agent discharge of each test, the compartment became overpressurized and a rapid flame spread/deflagration occurred. The short preburn time did not deplete as much O_2 as compared to the long preburns; therefore, when the energetic, turbulent agent discharge occurred, it caused increased fuel evaporation and rapid mixing with compartment air, generating a greatly increased flame surface area. This increase in burning resulted in further increased fuel evaporation, as compartment temperatures increased in response to the enhanced burning. The rapid flame spread/deflagration occurred due to localized low agent concentrations resulting from compartment inhomogeneities coupled with enhanced burning induced by agent discharge.

To prevent this incident from occurring on a Navy ship, the Navy's mandated agent design concentration of **10.6–1**1.1% HFP is used to displace more oxygen and decrease localized low agent concentrations. These tests also showed actual agent concentrations in the compartment rising above the design concentration. This increase was attributed to the expansion of the gaseous HFP when discharged into the hot compartment, as actual compartment temperatures during a fire incident exceed the design concentration calculation temperature.

In subsequent tests, the overpressurization was prevented by lengthening the preburn time to 45 sec and changing the ventilation sequence to remain open during fire initiation until 20 sec prior to agent discharge. The modified sequence allowed release of initial pressure buildup from fire initiation. The 11.4% design concentration chosen for this test corresponds closely with the Navy's mandated agent design concentration of 10.6–11.1%.

HYBRID GASEOUS POWDER SUPPRESSION SYSTEMS

The hybrid gaseous powder systems were evaluated with significant input from the manufacturers, as both technologies were still in the developmental stages [1, 2]. Both systems discharged HFP (HFC-227ea) and a dry chemical powder. One of the technologies used manufacturer provided hardware while the other used standard Halon 1301 Navy hardware. The criteria for the design/performance requirements included:

- Compartinent size
- Fuels to include *n*-heptane and methanol
- Fire size can vary and may be located anywhere in the compartment
- Complete and rapid extinguishment (**less** than 10 sec) to limit the amount of hydrofluoric acid (HF) produced
- Require a protection time of 15 min where no reignitions occur during this hold time

CEASE-FIRE™

The first hybrid system evaluated was CEASE-FIRE™, a halon alternative agent containing a blend of dry chemicals and a liquefied hydrofluorocarbon gaseous agent. The dry chemical and gaseous agent chosen for this test program were, respectively, Monoammonium Phosphate (MAP) and HFP. The MAP particles were approximately 11 microns in diameter. The HFP design concentrations ranged from 2.6–8.5%. The basic extinguishing unit was comprised of a nozzle directly mounted underneath a quasi-spherical container. The complete unit was mounted inside the compartment at the overhead. Tests were conducted with one or two units based on the agent/powder requirements. The units were self-contained and did not require agent distribution piping. The CEASE-FIRE™ suppression system was provided by the manufacturer who also prepared, filled. and pressurized the bottles.

ENVIROGEL™

Envirogel™ was the second gaseous-dry powder hybrid system evaluated that contained a blend of a liquefied hydrofluorocarbon gas (HFP). gelling agent. and finely ground powder. The powder for these tests, Ammonium Polyphosphate (APP), consisted of particles of approximately 7 microns in diameter. The basic extinguishing unit comprised of standard Navy cylinders and HFP discharge piping. The Envirogel™ (powder, gelling agent, and part of the required HFP) was provided by the manufacturer. Bottles and standard cylinder valves, flexible hoses, and manifold check valves were obtained from Navy supply. The cylinders were prepared, filled, and pressurized at a local fire suppression bottle filling station.

HYBRID GASEOUS POWDER SUPPRESSION SYSTEMS RESULTS

Both the CEASE-FIRE™ and Envirogel™ testing series were limited explorations of the mixture agents and suppression system hardware [2]. Since full examination of these alternative technologies was not performed, determination of the minimum extinguishment agent concentration or the minimum agent concentration for reignition protection was inconclusive. Neither of these two critical concentrations was determined for either hybrid agent.

The lowest successful extinguishing concentration of CEASE-FIRE™ tested was achieved with 18 Ibs of MAP powder and 31 lbs of HFP (corresponding to a 6.9% HFP design concentration) for a fuel mixture of 80% methanol, 20% n-heptane. The fire out times were 00:05 for the pan and 00:03 for the cascading with reignitions starting at 01:00 for both fires. The data suggest that the addition of the MAP powder in the CEASE-FIRE™ mixture limited the amount of HF initially in the compartment due to quick fire out times and resulted in more desirable decay rates compared to the baseline HFP tests. However, because it was not able to protect the compartment from reignitions during the hold time, the HF levels in the compartment were high at the end of the hold time (peak value of 1600 ppm soon after agent discharge; 400 ppm 15:00 after discharge). Reignition protection was not achieved due to the powder settling leaving only 6.9% HFP concentration, which is well below the 8.3% cup-burner extinguishing concentration for this fuel mixture. These results were not verified for reproducibility due to funding constraints.

The lowest successful extinguishing concentration of Envirogel™ tested was achieved with 22.8 lbs of APP powder and 34.2 lbs of HFP (corresponding to a 7.2% HFP design concentration) for the 80% methanol, 20% n-heptane fuel mixture. The fire out times were 00:01 for the pan and 01:00 for the cascading with reignitions starting at 01:20 for both fires. When the agent mixture was changed to 25.0 lbs of APP powder and 41.0 lbs of HFP (corresponds to a 8.5% HFP design concentration), fire out times were 00:08 for the pan and 00:01 for the cascading while providing reignition protection. This Envirogel™ mixture agent produced lower initial HF peaks relative to the baseline test. However, the HF production did not decay as seen in the baseline test, remaining at slightly higher levels at reclamation (peak value of 800 ppm soon after agent discharge; 600 ppm 15:00 after discharge). As with CEASE-FIRE™, these results were not verified for reproducibility.

The stand-alone CEASE-FIRE™ discharge system weighs significantly less than the manifold system used for baseline testing. During one test, two CEASE-FIRE™ cylinders were completely filled and together weighed 121 Ibs, of which 41.0 lbs was HF" (corresponding to an 8.5% HFP design concentration). In the baseline HFP test, the total system weight was 194 lbs of which 57.1 lbs was HFP (corresponding to an 11.4% HFP design concentration). The HFP discharge system was 73 lbs heavier, but it provided complete suppression and reignition protection of the compartment whereas the full CEASE-FIRE system, as evaluated, did not. The discharge systems are the same for both HFP and Envirogel™. Further testing needs to be conducted to determine if the aerosol powders (MAP and APP) are more efficient (by weight) than HFP.

WATER MIST SUPPRESSION SYSTEMS

Water mist systems differ from clean agent systems in that extensive clean agent intermediate-scale testing has been performed to understand them and develop performance criteria [3]. For this reason, the hybrid systems discussed earlier were required to meet the performance criteria developed from these tests. Such testing has not been conducted with water mist systems, therefore. the systems purchased from and designed by the manufacturers were required to meet a list of performance based criteria developed by NRL, NAVSEA. and NRL contractors. The criteria for the design/performance requirements included:

- Compartment size
- Fuels to include n-heptane and methanol
- Fire size can vary and may be located anywhere in the compartment
- Require a protection time of 15 min defined as follows: within 2.5 min from discharge initiation, require the heat release to be reduced to less than 100 kW and maintained for duration

One system, designed by Marioff®, was a high-pressure, 160+ bar (2400 psi), system that discharged water and nitrogen simultaneously. The other system, designed hy Fike", was a low-pressure system operating at 22 bar (325 psi) and discharged water only. This system was designed to be a pulsed system. cycling on and off during the test. The test variables for this series of tests included oxygen concentration (varied by preburn duration and fire size), effect of heat source on reignition, fuel type, and the effect of a boundary rupture [4,5]. Thirteen (13) suppression tests were conducted. 7 Fike® tests and 6 Marioff® tests [6].

MARIOFF HI-FOG^ DESIGN SPECIFICATIONS

In response to the performance requirements set forth by the NRL, Marioff "provided the following system design and operational guidelines. The Marioff HI-FOG@self-contained water mist system was composed of one spray head located overhead in the center of the 28 m^3 (1000 ft^3) compartment. The HI-FOG@system was electrically or manually actuated. The system was a hybrid, dual-fluid system utilizing nitrogen as the atomizing medium. The self-contained system that was evaluated for NRL testing included one high-pressure 143-bar (2100 psi), 44-L (11.5 gal) nitrogen cylinder (laboratory provided) and one 50-L (13.2 gal) water cylinder. The Marioff® design was to include a 20-L (5.2 gal), 163-bar (2400 psi) nitrogen cylinder, hut a 20-L bottle could not be obtained even after repeated requests to the manufacturer for assistance. Therefore, a larger (44 L) standard laboratory-size nitrogen bottle pressurized to 138 bar (2000 psi) was used. The 44-L bottle was at a lower pressure than the 30-L bottle for the first part of the test, **As** the test progressed, the bottle maintained a higher than that of the 20 L bottle. The 44-L bottle contained more nitrogen than the manufacturer recommended 20-L bottle and, as a result, provided additional suppression capability and reignition protection due to increased oxygen dilution within the compartment after water ran out. According to Marioff®, the droplets had a volumetric diameter less than 100 microns ($Dv_{0.99} < 100$) at the beginning of discharge and did not exceed 50 microns after 8 min of discharge.

FIKE® MICROMIST® DESIGN SPECIFICATIONS

The Fike" Micromist" system was a single fluid system of intermediate pressure (12 to 34 bar (175 to 500 psi)). The Fike" Micromist" system consisted of a nitrogen cylinder and a water container. The nitrogen cylinder had a volume of 67.2 L (17.8 gal) and an initial pressure of 124 bar (1850 psi), used to pressurize the water container. The water storage container has a volume of 265 L (70 gal). The system was composed of four overhead nozzles placed in a square configuration (5 ft apart), each located 2.5 ft from the two adjacent bulkheads. These nozzles discharged a variety of fine water mist droplet sizes at an application rate of 7.9 Lpm (2.1 gpm) per nozzle. The water droplet volumetric diameter ranged from 30–300 microns. The system size, design, and total application duration was based on a defined protection time of 15 min. The system utilized a cycled discharge sequence (40-sec water mist discharge duration, 40-sec off cycle) to effectively suppress the fire and limit water usage. The total application duration of 11 and 40 sec included a 60-sec pause after the first 4 cycles. To provide for the NRL required 15 min protection time, the manufacturer recommended eight application cycles. After the fourth cycle, the system would pause while sensing for heat using a heat detector and the system would resume application of an additional four cycles if the system detector had a positive signal (above the preset temperature). During testing at CBD, the heat detector in the Fike'' system was not used. Regardless if enough heat was present to activate the heat detector during the pause, the Fike® system cycled eight times, with a 60-sec pause after the fourth cycle — theoreticallyproviding its optimum fire suppression capability.

WATER MIST SUPPRESSION SYSTEMS RESULTS

Preburn duration and fire size were modified to create particular oxygen concentrations for each scenario. Preburns throughout both the Marioff and Fike test series were either 45 sec or 2 min in duration. The longer duration preburns were used to consume more oxygen prior to the discharge of water mist. Three fire sizes (200,400, and 800 kW) were also used throughout the test series to affect oxygen concentration.

EFFECTS OF OXYGEN CONCENTRATION

Tests were conducted to evaluate the Marioff HI-FOG@and Fike® Micromist® system's capabilities in scenarios with greater oxygen depletion by employing a 2-min preburn with an 800 kW *n*-heptane fire. During the Marioff® test, the cascading and pan fire outs occurred at 00:10 and 00:20, respectively. There was no fire activity after fire outs until 16:00 when the ventilation system was fully operational and oxygen concentrations began to increase. An energetic reflash/deflagration occurred at 16:02, likely due to the presence of high concentrations of fuel vapors in the compartment resulting from the reignition attempts during the 15-min hold time and the reignition attempt at 16 min. Note that a Fike'' test also exhibited a similar deflagration during venting.

Two energetic reflash/deflagration occurred during the Fike'' Micromist® system tests. One reflash/deflagration occurred during venting in a matter similar to the Marioff® test described above and the second occurred during system cycling. For the test that resulted in a reflash/ deflagration during system cycling, the pan fire was extinguished at 00:48. The cascading fire was extinguished at 01:30 and reignited at 02:20 with deflagration occurring at 02:31. Despite the large number of empirical water mist tests previously conducted, this water mist performance limitation had not been previously identified. This, in part, illustrates the limitations of the current water mist operating envelope.

Tests were conducted to determine the water mist system's capabilities for limited oxygen depletion scenarios resulting from a 200-kW n-heptane fire. The higher oxygen concentrations throughout the compartment led to slower fire extinguishment. For these series of tests, the Marioff HI-FOG'' system was unable to extinguish the cascading fire but suppressed the pan fire. The Fike'' Micromist system was unable to extinguish either fire before fuel was secured or burned off, for the scenarios tested. Marioff® reignitions occurred only after ventilation was initiated at 15:00 whereas the Fike® Micromist® system was unable to provide the 15-min hold time, i.e., both cascading and pan fires burned for extended periods and the cascading fire reignited rapidly at 5 min.

EFFECTS OF HEAT SOURCE ON REIGNITION

The Marioff HI-FOG@test conducted to determine if fire reignition could occur without the aid of heated elements utilized a 2-min preburn in conjunction with a 400-kW n-heptane fire. The hotrods were secured following fire ignition resulting in faster fire outs than in the baseline test. There were no reignitions throughout the remainder of the test.

The Fike® Micromist® test conducted to determine the effect of no heat source on fire reignition utilized a 2-min preburn and an 800-kW n-heptane fire. An 800-kW fire was employed because neither the pan nor the cascading fire in the analogous Marioff® test reignited after the initial fire suppression. It was assumed. therefore, that a larger fire for the Fike® test would increase the chances of reignition due to increased compartment temperatures and potentially greater fuel vapor concentrations. During the test, the pan and cascading fires were extinguished by 00:20, and there were no reignitions.

EFFECTS OF VARIOUS FUELS

Two Marioff HI-FOG' tests and one Fike® Micromist® test were performed to determine the systems ability to suppress fires with other flammable liquids, namely an 80/20 mixture of methanol/heptane. The Marioff HI-FOG" system extinguished the pan fire at 01:26 and the cascading 02:50. The Marioff® system provided the 15-min hold time protection for the cascading fire only while the pan reignited ut 11:07. The Fike® Micromist® system suppressed the pan fire at 01:30 and the cascading at 02:50. The Fike® system provided protection for the pan fire during the 15-min hold time, however, the cascading fire reignited after a 5-min hold time.

EFFECT OF BOUNDARY RUPTURE

The capabilities of the Marioff HI-FOG" and Fike® Micromist® systems' performance during a simulated boundary rupture scenario were assessed by leaving the watertight door open through the duration of the test. During the Marioff® test, the pan fire was extinguished at 09:30. The cascading fire was extinguished at 02:15 after agent discharge, when fuel was secured. Cascading reignition occurred at 05:11, during hold time. This meant that the fire was extinguished soon after the fuel supply was shut off and reignited as soon as the fuel supply was reactivated. There was no reignition at the pan location due to the lack of fuel.

During the Fike® test, the pan fire was extinguished 6:05 after agent discharge. The cascading fire was extinguished 2:08 after agent discharge, when the fuel was secured. Reignition occurred at the cascading location at the 5-min reignition attempt. The same sequence of events occurred during the Marioff® test where the fire was extinguished soon after the fuel supply was shut off and reignited as soon as the fuel supply was reactivated.

SUMMARY OF RESULTS

HYBRID GASEOUS POWDER SUPPRESSION SYSTEMS

In order for the additional cleanup procedures of an unclean agent (gaseous agent plus powder) suppression to be justified, that technology would have to at least perform as well as the clean agent suppression and most likely better. At this time, the Envirogel™ mixture used with standard Navy discharge system hardware is not recommended as a viable alternative to the clean agent HFP aboard Navy ships. A key issue is the system weight. Using a different discharge system may ameliorate this disadvantage. The data collected for the CEASE-FIRE™ mixture suggest that the addition of MAP powder results in lower peak HF values and more desirable decay rates compared to the baseline HFF tests. It is possible that the CEASE-FIRE™ system, tested at a concentration above that chosen for the current study, will perform better than the clean agent, outweighing the drawbacks associated with additional cleanup procedures.

For a true agent comparison (instead of a system comparison) of Envirogel™ to CEASE-FIRE™, the same hardware should be used. This would allow for the same agent concentrations to be tested at the same discharge pressures. Agent distribution, extinguishing capabilities, and reignition protection could all be compared. If a gaseous agent dry chemical blend is found to perform better than the clean agent, agent distribution issues associated with the protection of compartments will still need to be explicitly addressed. Powder (and water mist) dissemination and distribution are much more affected by obstacles than gaseous dissemination and distribution.

WATER MIST SUPPRESSION SYSTEMS

Continuously applied water mist (without N_2) most likely can be made to provide control, if not complete extinguishment, with some degree of reignition protection. In the 28 m^3 (1000 ft^3) compartment with fire sizes ranging from 200–800 kW and preburns from 4.5 sec–2 min, 1.3 gpm (5 lpm, 590 g/m^2, 180 g/m^3) flow with $Dv_{0.99}$ <50 microns put out all fires. The cycling water mist system evaluated (intermediate/low pressure 200–300 psi) did not provide protection per design criteria.

The presence of ignition sources (heated elements) significantly affects water mist performance for suppression and reignition protection. For both systems evaluated, fire suppressions occurred sooner without the presence of heated elements and no reignitions were detected after the initial suppressions. Reignitions occurred with the cycling (low/intermediate pressure) system in all tests except when no reignition sources were used. The 80/20 methanol/heptane fuel mixture reignited during the hold time with the Marioff® system.

Water mist systems are not true total-flooding systems in the sense that obstructions severely affect distribution. In some scenarios, water mist systems might not be able to extinguish all fires. If the fire is not extinguished, the compartment temperature remains sufficiently high to evaporate highly volatile fuels. Fuel vapors reaching the fire (ignition source) can then provide the potential for an energetic reflash/deflagration to occur. For this reason, water mist systems alone should not be the sole suppression system used to protect Navy shipboard FLSRs containing highly volatile fuels.

The tests described in this paper were explanatory and not meant to establish definitive design criteria. Due to the nature of the ship missions and the high emphasis on platform survivability, the Navy success criteria are very stringent. System implementation is very scenario specific. Failure to meet Navy requirements does not imply inadequate performance in certain commercial sector applications.

ACKNOWLEDGMENT

Sincere thanks and appreciation to Philip M. Gunning for assisting in the preparation of this document.

REFERENCES

1. Maranghides, A., and Sheinson, R.S., *Test Plan for Self-Contained Total Flooding Halon 1301 Alternative Technologies Evaluation—Test Bed and Test Scenario Particulars*, NRL Ltr Rpt 6180/0331, Naval Research Laboratory, Washington, DC, July 6, 1998.

2. Sheinson, R.S., Wellens, J.C., Leonard. **K.**, and Maranghides. **A.**, *Self-Contained Total Flooding Halon 1301 Alternatives Technologies – Test Results*, NRL Ltr Rpt 6180/0403, Naval Research Laboratory, Washington, DC, June 30, 1999.

3. Sheinson, R.S.. Eaton. H.G., Black. B.H., Burchell, H., Maranghides, A., Mitchell, C., Salmon, G., and Smith, W.D., "Halon 1301 Replacement Total Flooding Fire Testing, Intermediate Scale," *Proceedings*, Halon Options Technical Working Conference. Albuquerque, NM, pp. 43-54, 1994.

4. Binette, C., Sheinson. R.S., and Maranghides, A., *Test Plan for Self-Contained Total Flooding Halon 1301 Alternatives Technologies Evaluation – Phase 1, Marioff HI-FOG® Water Mist System*, NRL Ltr Rpt 6180/0108, Naval Research Laboratory, Washington. DC, March 11, 1999.

5. Austin, E., Binette, C., Sheinson, R.S., and Maranghides, **A.**, *Test Plan for Self-Contained Total Flooding Hulon 1301 Alternatives Technologies Evaluation – Phase 2, Fike® Micromist® Water Mist System*, NRL Ltr Rpt 6180/0439, Naval Research Laboratory. Washington, DC, June 30, 1999.

6. Maranghides, **A.**. Sheinson, R.S., Gunning, P., and Anleitner, R., *Results for Self-Contained Total Flooding Halon 1301 Alternative Technologies Evaluation*, Naval Research Laboratory, Washington, DC, NRL Ltr Rpt in progress, 2000. (Draft on file with the author.)