Foam Fire Suppression for High Challenge Shipboard Spaces

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BACKGROUND

Large volume storage spaces on Navy ships, such as vehicle well decks, can include multiple Class A and Class B fire threats. Prior testing had identified the limitations in protecting these spaces using AFFF sprinklers designed only to combat Class B two-dimensional pool fires. Manual fire attack is also problematic. Testing was performed in a large volume, high overhead space to evaluate manually activated, high flow rate AFFF overhead deluge sprinklers and two high expansion foam systems against a high challenge fire. This challenge included simultaneous Class B pool, Class B three-dimensional spill, Class A storage, and obstructed Class A/B fire threats. The high expansion (hi ex) foam systems included a fan-type system using outside air to generate expanded foam, and an inside-air system using ceiling-mounted generators within the protected space. Currently, inside air systems are recognized in NFPA 11 only where there is specific fire test data for the intended hazard.

SETUP

The US Navy fire test vessel, ex-USS *Shadwell*, located in Mobile, AL, was used for these tests. The well deck area was located between FR67 and FR84.5 (Fig.1). The dimensions of this area were 21.3 m (70 ft) long, by 13.4 m (44 ft) wide, with an 8.5 m (28 ft) high overhead. The total deck area was 285 sq m (3080 sq ft). The volume of the well deck fire test area to the LVSA overhead (3.8 m (12.5 ft) above the deck), the space of primary interest, was 1,014 cu m (38,500 cu ft).

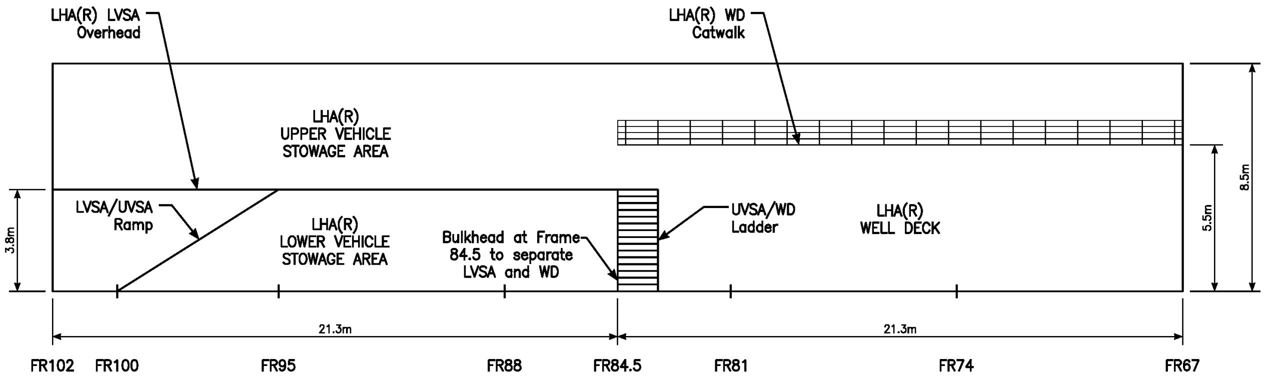

Fig. 1—ex-USS *SHADWELL* test area, section view

Class A and B test materials were used to simulate an actual fire casualty involving stowed, fueled, and loaded combat vehicles, boats, or other equipment. A quadruple fire treat, involving four surrogate fuel packages, were used. Fires were centered in the well deck, FR74 and FR81.

The Class A fuel package, a repeatable surrogate for Class A vehicle fires, consisted of six, 1.8 m (6 ft) high stacks consisting of 15 standard size oak pallets. This is roughly a 30 MW fire when all were fully involved. The Class A fuel packages were enclosed in a test pan area measuring 4.6 m x 6.1 m (15 x 20 ft). A Class B (marine diesel) spill fire was created in this area. This would be roughly 60 MW if it was an open pool, but the wood pallets created an obstructed pool, so the pool fire heat release rate was less than 60MW.

A three-dimensional (3D), running spill fire was created using a cascade apparatus located adjacent to the pan area. It was a 0.9 m (3.0 ft) by 0.6 m (2.0 ft) by 1.8 m (6.0 ft) high steel frame constructed angle iron. A diesel fuel flow rate of 13.6 Lpm (3.6 gpm) created an 8 MW fire

An additional, shielded/obstructed Class B-initiated small wood crib fire was located in an adjacent compartment which opened into the well deck at FR 80. This setup simulated a vehicle in the well deck which had an obstructed area, e.g., vehicle cargo deck with part of the tailgate area open.

High expansion foam design discharge rates were calculated using NFPA 11 parameters (i.e., shrinkage and leakage factors) as a minimum design basis. Measures of control and extinguishment were derived by visual observation and by thermocouple data.

TEST OBJECTIVES AND VARIABLES

The objectives were to: determine if a high flow rate AFFF system could suppress the multiple threat fire scenario; verify that outside air hi ex foam system parameters previously tested without a roof enclosure were acceptable; and to determine the viability of the inside air hi ex foam concept. Test variables included flow rate and time of system activation.

AFFF TESTS

A 3 x 3 m (10ft x10ft) sprinkler grid was installed at the overhead to provide 12.2 Lpm/sq m (0.30 gpm/sq ft), 16.3 Lpm/ sq m (0.40 gpm/sq ft), or 24.5 Lpm/sq m (0.60 gpm/sq ft) AFFF application rates to the fuel package below. Non-air aspirating sprinklers Listed by Underwriters Laboratories for use with AFFF were used.

The results of the tests are shown in Table 1. A 3D Class B fire presented a severe challenge to the overhead AFFF deluge sprinkler systems. When the 3D fire was combined with a Class A pallet and Class B pool fire threat, AFFF sprinklers discharging at 0.30 or 0.40 gpm/sq ft could not extinguish any part of the combined fire. With the 3D Class B fire removed from the fire scenario, either application rate could extinguish the Class B pool fire. The lower 12.2 Lpm/ sq m (0.30 gpm/sq ft) rate could not extinguish the Class A threat. The performance of the 46.3 Lpm/sq m (0.40 gpm/sq ft) application rate was marginal against the Class A threat, dependent on the degree of involvement of the Class A fuel package. An application rate of 24.5 Lpm/sq m (0.60 gpm/sq ft) easily extinguished the combined Class A/Class B pool fire. Even at this high application rate, a stand-alone 3D Class B fire could not be extinguished.

Table 1. AFFF Overhead Sprinkler Results

Test	Application Rate (gpm/sq ft)	Cascade Fire Included?	Activation Time (min:sec)	Pool Fire Exting. (min:sec)[1]	Class A Fire Exting. (min:sec)[1]	Cascade Fire Exting.
1a	0.40	Yes	3:00 (delayed act.)	Only after cascade was secured at 6:53	No	No
1	0.40	No	1:52	0:53	3:25 (Pallets not fully involved)	NA
2	0.30	Yes: Secured at 3:30	2:07	2:06 (0.43 after cascade secured)	No	No
3	0.30	No	1:30	0:37	No	NA
4	0.40	No	1:49	0:24	No (after 5:50)	No
5	0.60	No	1:55	0:30–0:35	0:40	NA

[1] After system activation

OUTSIDE AIR HIGH EXPANSION FOAM TESTS

A manually activated, total flooding, high expansion foam system was used in these tests. Components of the system were UL Listed. The system consisted of four 28,000 cfm (793 cmm) high expansion foam generators drawing outside air to generate foam. Each had a *k*-factor of 465 Lpm/bar^{½} (32.3 gpm/psi^{½}). The system was operated at a pressure of 2.7 bar (40 psi) at the generator, producing a solution flow rate of about 3214 Lpm (820 gpm) when all four generators are used. The fill time to the LVSA overhead was 47 seconds. The corresponding average fill rate was 16 ft/min. The calculated expansion ratio was 464:1.

The results are shown in Table 2. The quadruple fire threat was extinguished by the high expansion foam system. All fires and fire combinations were extinguished, and there were no reflashes of fuel packages for up to sixty minutes after the system was secured. Most fires were extinguished within one-minute. The adjacent space fires, simulating obstructed fire sources, were readily extinguished by the hi ex system.

Table 2. High Expansion Foam Test Results

Test	3D Cascade Included in Scenario?	Class A/ Class B Well Deck Preburn (min:sec)	Extinguishment Time (min:sec)						Submerg Time (min:sec) To UVSA Deck (12.5 ft)	Total Discharge Time (min:sec)
			Pool (data)	Pallet		Cascade		Adj Comp (data)		
				Visual	Data	Visual	Data			
Hi Ex_03	No	1:07	0:35	0:35	0:56	NA		1:34	1:04 (est)	1:48
Hi Ex_04	Yes, but not fully involved	1:54	0:26	1:20	0:43	Approx. the same as pallets (1:20)	0:50	1:40	1:34	2:32
Hi Ex_05	Yes	2:20	0:28	< 1:14	0:46	1:14	1:21	1:43	2:45	3:37

HOTFOAM TESTS

A manually activated, total flooding, inside air hi ex foam system, called HotFoam, was used in these tests. The system consisted of a uniformly spaced overhead grid of generators. Air was entrained by a spray nozzle within the generator to make the foam, rather than by a fan drawing outside air. It is an “inside air” system since it uses air within the protected volume to generate foam. The HotFoam system is approved by international agencies such as DNV for protecting machinery spaces and pump rooms, but is not currently recognized by UL of FM. The HotFoam generators were installed in the test space sprinkler grid.

The following generators were used:

HG-25 – 51 cmm (1800 cfm) at 5 bar (74 psi), *k* factor of 36.7 Lpm/bar$^{1/2}$ (2.55 gpm/psi$^{1/2}$) – used in the overhead

HG-15 – 16 cmm (570 cfm) at 5 bar (74 psi), *k* factor of 12.3 Lpm/ bar$^{1/2}$ (0.85 gpm/psi$^{1/2}$) – used in combination with HG-25 generators in a low level installation

A cold discharge test conducted with 23 overhead HG-25 generators was used to establish and verify the system pressure, flow, and concentration characteristics. The foam filled the volume to the LVAS overhead in 1 min 44 seconds. The calculated average fill rate was 7.2 ft/minute. This was a slower fill rate than in the outside air high ex tests. The calculated expansion ratio was 352–373:1, lower than the vendor estimated 440:1 At a pressure of 5 bar (75 psi) and lower, foam was noticeably fluid; the fire tests were conducted with generator pressures of 5.5–5.9 bar (80–85 psi). Volumetric flow was increased for some tests by adding generators to the original design of 23 overhead generators. This is shown in the summary data as an increase in the solution flow rate (Tests HF_03 and 04). This increased the corresponding theoretical volumetric fill rate, decreasing the fill time.

An experimental low level system was installed for Test HF_03. The concept was to lower some of the generators so they were out of the hot layer. A combination of HF-25 and 15 generators were used, combined with 23 HF-25 overhead generators.

Table 3 shows the results of the HotFoam tests. The system tested was effective on all fire scenarios, including the quadruple fire threat and delayed activation scenarios. Placing HotFoam generators at a lower level appeared to improve suppression performance (HF_03), but adequate system performance does not appear to be dependent on this design attribute. The foam fill times, as observed during the tests, were greater in the HotFoam tests compared to the hi ex tests. This was attributed to the need for initial cooling of the HotFoam generators to create expanded foam. Test HF_04 totally extinguished all fires, prior to the rupture of foam supply pipe 2-minutes into the test. Essentially no high expansion foam was created during this period.

DISCUSSSION

Table 4 is a comparison of the hi ex and HotFoam results, for tests with similar variables. The HotFoam system, at a lower comparable fill rate, was as effective as or more effective than the outside air high expansion foam system. The exception was for the adjacent space fire threat. At a greater fill rate (HF_04), the HotFoam system was essentially equivalent to the outside air system for the adjacent space fire also. However, the lower amount of foam generated by the HotFoam allowed for reflash potential in the adjacent space. This was not a problem with the Class A materials directly exposed to agent application in the hi ex tests.

Table 3. HotFoam Fire Suppression Results

Test	3D Casc. Incl. in Scen.?	Solution Flow (gpm)	Class A/ Class B Well Deck Preburn (min: sec)	Extinguishment Time (min:sec)					Sub. Time (min:sec) To UVSA Deck (12.5 ft)	Total Discharge Time (min:sec)
				Pool (data)	Pallet		Cascade	Adj Comp (Class A data)		
					Knock-down	Data	Data			
HF_01	No	538	1:36	0:36	0:48	1:16	NA	2:12	4:38	5:00
HF_02	Yes	534	2:43	0:43	0:48	1:30	1:36	10:16, reflash at 31:00	10:12 (11 ft)	10:16
HF_03	Yes, but not fully involv.	648 (sidewall included)	2:42	0:12	0:06	0:36	0:36	4:42 (knock-down at 1:06)	5:45	6:36
HF_04*	Yes	684	2:48	0:36	0:18	0:48	1:06	2:06	N/A	2:00

*Ruptured pipe at 1:30 after system activation.

The mechanisms of extinguishment, particularly for the adjacent space fire and high challenge threats, were different for the two systems. The outside air hi ex foam appears to have relied more on cooling and fuel surface oxygen displacement. The HotFoam system, particularly for the high threat, delayed activation scenario, relied more on steam conversion and associated steam smothering. It generally took longer for the HotFoam system to generate good quality foam and fill the hazard area. The exact mechanics of suppression over the range of conditions requires more investigation, particularly from a first principles basis.

Table 4. Comparison of Hi Ex and HotFoam

Test	3D Cascade In Scenario?	Solution Flow (gpm)	Class A/B Preburn	Pool Data (50^0C)	Extinguishment				Fill Time to UVSA (min:sec)
					Pallet		Cascade	Adj Compart Class A Data (230^0C)	
					Knock down (Rapid Cooling)	Data (230^0C)			
Well Deck Fire – No Cascade, Short Preburn									
HotFoam_01	No	538	1:36	0:36	0:48	1:16	NA	2:12	4:38
Hi Ex_03	No	820	1:07	0:35	—	0:56	NA	1:34	1:04
Well Deck Fire -- Long Preburn									
HotFoam_03 (sidewall test)	Yes, but not fully involv. at syst act.	648	2:42	0:12	0:06 (Immed. on system act.)	0:36	0:36	4:42 (knock-down at 1:06)	5:45
Hi Ex_04	Yes, but not fully involv. at syst act.	820	1:54	0:26	—	0:43	0:50	1:40	1:38
Quadruple Fire Threat									
HotFoam_02	Yes	534	2:43	0:43	0:48	1:30	1:36	10:16 reflash at 31:00	10:12 (11 ft)
HotFoam_04	Yes	684	2:48	0:36	—	0:48	1:06	2:06	Rupt. pipe
Hi Ex_05	Yes	820	2:20	0:28	—	0:46	1:21	1:43	2:45

SUMMARY AND CONCLUSIONS

An overhead AFFF deluge sprinkler system, even at very high flow rates, was not able to control and extinguish the combined, multiple fire threats possible in a Navy well deck/vehicle storage area. High expansion foam was verified to be the system of choice for those areas where there is a potential for multiple obstructed fire threats. Outside air-generated foam, designed in accordance with NFPA 11 and having a maximum cold fill time appropriate for the hazard, was shown to be effective.

There was concern that the HotFoam system would be ineffective on large fires due to ingestion of heat and smoke into the generators. Provided the HotFoam system follows the manufacturer's recommendations, NFPA 11 requirements, and specific criteria for the Navy ship hazard, it can be considered as an acceptable alternative to outside air high expansion foam. An increase in concentrate supply may be appropriate to compensate for the slower observed fill times during the actual fire test (note that NFPA 11 only characterizes fill time based on cold discharge tests). A minimum discharge pressure of 80 psi from the hydraulically most remote generator is recommended.

Understanding of high expansion foam extinguishing mechanisms should be pursued; some modeling efforts in this regard have been initiated. Longer term goals might include establishing compatibility between different manufacturers' agents and common proportioning system attributes. Development of dual AFFF/hi ex agents and multi-use proportioning systems would significantly increase installation flexibility for shipboard applications.

Historically, the use of inside air, i.e., hot air contaminated with combustion products, has presented a challenge. NFPA only permits inside air for high expansion foam systems if data is provided to show that air from inside the hazard can be successfully employed. NFPA 409 on hangar fire protection currently prohibits the use of inside air for high expansion foam systems. Successful use of an inside air foam system was shown in these tests.