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From: Commanding Officer, Naval Research Laboratory
To: Commanding Officer, Naval Facilities Engineering Service Center, Port Hueneme, CA (Code ESC421 R. Lee)

Subj: AQUEOUS FILM FORMING FOAM (AFFF) ALTERNATIVES

Encl: (1) Two copies of subject report

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AQUEOUS FILM FORMING FOAM (AFFF) ALTERNATIVES

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References

(a) Qualified Products List for Military Specification Aqueous Film-Forming Foam

(b) Military Specification MIL-F-0024385F, 7 January 1992, Fire Extinguishing Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water

Introduction

Military Specification Aqueous Film Forming Foam (AFFF) is used worldwide to combat liquid fuel fires. It is the best available agent for rapid fire extinguishing and burn back resistance of aviation, shipboard, chemical process and petrochemical hydrocarbon fuel fires. The very chemical structures of the agent that makes it effective for fire fighting also results in potentially undesirable environmental characteristics including: persistence in the environment, potential bioaccumulation in human tissues and toxicity at certain concentrations. Additionally, discharge of foam solution may interfere with waste-water treatment plants. The trend is clearly toward stricter regulation of the chemicals in AFFF and of the discharge of AFFF into the environment.

There are several potential options to address issues related to AFFF impact on the environment. In the short term, there is current technology that appears to be able to reduce the quantities of these environmentally unacceptable chemicals. Additionally, there are other existing agents with potentially less environmental impacts than AFFF that may meet some of the current fire protection requirements. An investigation of the currently available agents is needed to determine that these agents can meet current requirements.

The Naval Research Laboratory, in conjunction with Naval Facilities Engineering Service Center, has conducted a test program to evaluate environmentally friendly fire fighting foam candidates as AFFF alternatives. The objective of this program was to determine the extent to which commercially available or newly developed agents with potentially less environmental impact can meet the current fire protection requirements of the AFFF military specification. The fire fighting performance, sealability and foamability were evaluated to assess the suitability of submitted products as alternatives. Product information provided by manufacturers disclosed explicitly and quantitatively the presence of fluoro-surfactants. No effort has been made to date in this project to substantiate the stated "environmental friendliness" of the submitted agents. A screening test procedure for fire fighting performance only was conducted at the NRL Chesapeake Bay Detachment with no on-site vendor participation. A representative AFFF agent from the Qualified Products List (QPL) (reference (a)) was tested for comparison with the alternative products.

Selective information for the agents that were tested is listed in Table 1. Information includes the recommended working solution concentration, advertised use, and whether the agent is fluorinated or not. The listing is coded so as not to specifically identify products but to provide a means for comparing their relative fire fighting performance to the QPL agent in the Table.

TABLE 1. Agents tested

Agent #	Concentration	Fluorinated
1	3 % / 6 %	Yes
2	3 %	Yes
3	3 %	Yes
4	3 %	Yes
5	3 %	Yes
6	3 %	Yes
7	6 %	No
8	6 %	No
9	0.3 % / 1 %	No
10	1 % / 3 %	Yes
11	3 %	No
12	6 %	No
13	6 %	No
14	3 %	Yes
15 (QPL)	6 %	Yes

Test Procedure

The tests used for screening to evaluate fire extinguishing performance were based on the Military Specification MIL-F-24385F(SH) dated 7 January 1992, "Fire Extinguishing Agent, Aqueous Film Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water" (reference (b)). The 28-ft^2 fire extinguishment test described in the MIL-SPEC was used to evaluate extinguishment capability. All agents were mixed full strength in fresh water using the vendor suggested mixing ratio. Ten gallons of unleaded gasoline fuel were used that conformed to ASTM D439. The fuel was poured within a 30-sec period, ignited within 30 sec of fueling and allowed to burn freely for 10 sec. After the preburn period, the fire was attacked and extinguished as expeditiously as possible, continuing foam application for a total of 90 sec even if the fire had been extinguished. All fire tests were continued until extinguishment occurred if extinguishment could be accomplished safely. The actual fire extinguishing time was recorded. If the agent extinguished the fire, the MIL-SPEC burnback test procedure was performed to evaluate foam blanket resistance to degradation, followed by the expansion and drainage test (foamability) to evaluate the quality of the foam, and the film and seal test to evaluate the effective sealing of the surface of the fuel to prevent re-ignition. The following burnback procedure was done according to the MIL-SPEC: A burning pan (1-foot in diameter with 2-in. sides) containing 1 gal of unleaded gasoline was placed in the center of the 28 sq ft pan and a time started. When it appeared that the fire had spread outside the pan so that burning would continue after the pan was removed, the pan was removed. The burnback time is that time at which it is estimated that 7 sq ft (25 percent) of the total area is involved in flames. The burnback time was also recorded. The purpose of each of these tests was to provide data for comparison of the agents being tested, and not to determine if they would pass or fail the MIL-SPEC criteria.

Test Results

The MIL-SPEC criteria given in reference (b) are listed to give perspective when comparing the test results.

- Fire extinguishment time: 30 seconds maximum
- Burnback time: 360 seconds (6 minutes) minimum
- Expansion: 5.0 minimum
- Drainage time: 150 seconds (2 minutes 30 seconds) minimum
- Film & seal: Pass / Fail (no sustained ignition)

The extinguishment tests were done in at least duplicate; the best times or performance figures are listed in Table 2. If the agent failed to extinguish the fire, then the burnback, expansion and drainage, and film and seal tests were not performed. A "+" sign following the "Fire Out" time indicates the foam being tested did not extinguish the fire and alternative methods (portable QPL AFFF extinguishers and/or fixed water spray nozzles on the perimeter of the 28 sq ft fuel pan) were necessary for extinguishment. In those tests, the 10 gallons of agent mixed for each test provided foam application of 4:30 to 4:45 ((min:sec) before being exhausted. Agent #15 is from the Qualified Products List and had previously passed all the MIL-SPEC criteria.

Table 2. Test Results.

Agent #	Tested Conc. %	Fire Out (seconds)	Burn Back Time (seconds)	Expansion	Drain Time (min:sec)	Film & Seal	Suggested Use
1	6%	90 +					
1	3 %	220 +					
2	3 %	31	455	8.7	8:50	Pass	
3	3 %	79	420	3.6	2:50	Fail	
4	3 %	42	353	8.9	3:35	Pass	
5	3 %	36	424	7.7	5:30	Pass	
6	3 %	32	505	8.5	8:10	Pass	
7	6 %	210 +					
8	6 %	289 +					
9	1 %	136	30				
9	3 %	290 +					
10	3 %	30	680	9.1	34:00	Pass	
11	3 %	287 +					
12	6 %	160 +					
13	6 %	50	475	10.3	No drainage observed	Fail	
14	3 %	29	485	8.6	6:20	Pass	
15	6 %	32	555				QPL

DISCUSSION

Comments/observations are given below for each of the agents:

Agent #1

- This agent was designed for application at 3% and 6%, suggesting 3% usage with aspirated nozzles.
- Early application of the foam to a directed area of the burning fuel surface provided a thick layer of foam that appeared to diminish the fire in that limited area. Redirection of the foam in an attempt to control the fire allowed it to increase to its full intensity again. Both the 6% and 3% solutions were tested with no discernible difference in performance. The 6% test was conducted for only a short period of time (90+ sec) because of the intensity of the fire and hazardous conditions created for the fire fighter.
- The foam quality prior to application to the fire appeared to be "good".

Agent #2

- "Good" quality foam blanket was produced.

Agent #3

- The foam quality was "soupy".
- Very little foam blanket build-up.
- There did not appear to be a seal forming on the surface and the splashing of the new foam being applied broke the surface coating and caused substantial flare up of the fire.

Agent #4

- The foam appeared "wet" compared to other foams generated.
- The extinguishment time was marginal with fire flaring again when the fire was almost extinguished.
- The fire was more difficult to extinguish following the burnback. This could be due to the fuel being heated by the burnback process.

Agent #5

- When the fire was nearly out, small flickering flames were difficult to extinguish and added approximately 5 seconds to the "Fire Out" time.
- During the burnback, the surface resealed without extinguishing the fire completely and the burnback time was extended significantly.

Agent #6

- The foam blanket and effectiveness were "good".
- Small flames at the pan edge persisted, adding a few seconds to the "Fire Out" time.

Agent #7

- Foam was applied with no noticeable suppression of the fire.
- At 90 seconds the heat was so intense the fire fighter backed away and the water nozzles on the edge of the pan were briefly turned on. The water was secured and foam application was continued after a few seconds. This happened again briefly at approximately 60 seconds later. The foam application was initiated again until 3:50 (min:sec) had elapsed with no noticeable suppression of the fire. Portable extinguishers with an AFFF from the QPL were used to extinguish the fire.

Agent #8

- The foam did not extinguish the fire.
- The overall intensity and heat release rate of the fire were diminished but a seal on the surface did not seem to form to extinguish the fire.
- Where the foam blanket was "piled" up at the edges, some suppression occurred, but when the foam was redirected to other areas on the flaming fuel surface, the initially suppressed flames quickly returned to full intensity.
- At 4:49 (min:sec) the foam in the system reservoir (10 gallons) was exhausted and the fire was not extinguished.
- At 5:07 (min:sec) portable extinguishers were used to extinguish the fire.
- The effect of the QPL AFFF was diminished, perhaps because of mixing with the agent being tested or the temperature of the fuel from the long burning time of the fire.

Agent #9

- At 60 seconds the fire was out over 6% of the surface.
- At 90 seconds the fire was out over 75% of the surface.
- At 2:16 (min:sec) the fire was extinguished. The foam blanket looked good
- The foam seemed to form a seal on the surface, but its resistance to burnback wasn't effective. When the burnback pan was inserted the fire reached 5% to 10 % of the surface immediately and the pan was removed at 26 seconds.
- In 30 seconds 50% of the surface was burning.
- In 60 seconds 100% of the surface was burning.
- Agent #9 was reapplied.
  - At 2:15 (min:sec) after starting the burnback, fire covered 50% of the surface at a low intensity.
  - At 3:19 (min:sec) the foam in the reservoir was exhausted and fire still covered over 30% of the surface.
  - At 3:40 (min:sec) the portable extinguishers were used to extinguish the fire.
  - At 4:30 (min:sec) the fire was extinguished with the portables.
  - In a separate test, in which Agent #9 was mixed at 3% (note this was higher than the manufacturer's recommendation), it failed to extinguish the fire by 290 seconds, at which time the system reservoir was exhausted and portable extinguishers were used to extinguish the fire.

Agent #10

- The foam looked "good" (similar to MIL-SPEC AFFF) and performed well.
- The surface resealed when the burnback fire pan was removed at 6:00 (min:sec) and the fire re-extinguished.

Agent #11

- After 60 seconds of foam application, about 50% of the surface was out.
- After 96 seconds of foam application, about 60% was out.
- The flame intensity and heat release rate were diminished by this foam, but when the foam application was redirected to other areas on the fuel surface, control of the fire was lost.
- The foam blanket seemed to control the fire but did not seal the surface to extinguish the fire.
- At 4:47 (min:sec), the foam in the reservoir was exhausted and the fire intensity grew quickly.
- At 5:00 (min:sec), the portable extinguishers were used. The performance of the QPL AFFF seemed diminished, due perhaps to mixing with this non-fluorinated AFFF or the temperature of the fuel.

Agent #12

- At 160 seconds there was no discernable suppression of the fire, and the portable extinguishers were used to extinguish the fire at 180 seconds.
- The fire intensity and heat release rate were very intense.

Agent #13

- Thick foam and "good" foam blanket.
- Flickering flames persisted and extended the extinguishment time a few seconds.
- For the expansion and drainage test there was no drainage from the foam observed by 12 minutes, at which time the test was halted.

Agent #14

- Good foam blanket and performance.

Agent #15

- Small flickering extended the fire-out time a few seconds.
- Good foam blanket and performance.

CONCLUSIONS

Agents 2, 5, 6, 10, and 14 are recommended for further evaluation. They performed well in the fire extinguishment test and met or exceeded the requirements for burnback, expansion and drainage, and film and seal criteria. All contain fluoro-surfactants.

Agent 4 is recommended for further evaluation. It performed marginally in the fire extinguishment test, and marginally the burnback test, but met or exceeded the requirements for expansion, drainage, film and seal. It contains fluoro-surfactant also.

Agent 13 is recommended for further evaluation. Although it performed poorly in the foamability and sealability test, and gave only marginal extinguishment time, it gave good burnback protection, expansion ratio and drainage time. It shows promise because of its stated improved environmental impact (no fluoro-surfactant content).

Agents 3 (fluorine-containing) is not recommended for further evaluation, because the fire extinguishment time was marginal and it failed the MIL-SPEC criteria for expansion ratio and sealing used for evaluation.

Agent 9 is not recommended for further evaluation as it gave a very long extinguishment time and very poor burnback protection

Agents 1, 7, 8, 11 and 12 are not recommended for further evaluation. They did not extinguish the test fire. The other criteria were not tested.

Summarizing, the list of 14 candidates initially subjected to fire performance testing has been down selected to seven candidates for follow-on program.

RECOMMENDATIONS

The immediate follow-on should be a more detailed evaluation of the environmental issues and benefits of the alternative firefighting foams compared to MIL-SPEC AFFF. The seven down selected products have demonstrated sufficient performance to warrant more detailed investigation of their claimed environmental benefits. They are being analyzed for Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) to assess their biodegradability. A number of additional factors must also be considered in ascertaining a product's environmental impact. These include adquatic toxicity to various species, compatibility with wastewater treatment plants, presence and concentration of solvents (e.g. glycols and glycol ethers) as well as the proportion and composition of the fluorine-containing components. This information will enable meaningful further down selection for achieving environmentally acceptable alternative firefighting foams.

A more general appreciation of the technical issues involved in AFFF reformulation, and correlation between the physical properties (such as dynamic surface tension, viscosity, propensity to produce foam) and the performance tests (such as fire extinguishment time, burnback resistance and drainage rate), should be established. This technology base will greatly facilitate candidate evaluation and future improvements. Discussion on the proposed details of these more detailed studies will be given in a separate report.