DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
4555 OVERLOOK AVE SW
WASHINGTON DC 20375-5320

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From: Commanding Officer, Naval Research Laboratory
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Subj: FIRE FIGHTING PERFORMANCE OF FLUOROSURFACTANT-FREE ALTERNATIVES TO AQUEOUS FILM FORMING FOAM (AFFF): INITIAL EVALUATION OF 3M RF6 AND A DEVELOPMENTAL FORMULATION

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2. The Naval Research Laboratory point of contact is Dr. Ronald Sheinson, Code 6185, (202) 404-8101 and email Sheinson@code6185.nrl.navy.mil.

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FIRE FIGHTING PERFORMANCE OF FLUOROSURFACTANT-FREE ALTERNATIVES TO AQUEOUS FILM FORMING FOAM (AFFF): INITIAL EVALUATION OF 3M RF6 AND A DEVELOPMENTAL FORMULATION

Ronald S Sheinson
Navy Technology Center for Safety and Survivability
Chemistry Division

Scott Ayers
Geo-Centers, Inc.
Arlington, VA

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Introduction

The discontinuation of perfluoro-octanyl sulfate (PFOS) based chemistry by the 3M Company was a significant event for the fire fighting community. PFOS chemistry was found to be environmentally persistent, bio-accumulative, and toxic. 3M used this technology to produce its Military Specification MIL-F-24385F (MilSpec) [1] certified aqueous film forming foam (AFFF). 3M has been a major supplier of AFFF to the Department of Defense since AFFF's joint development with NRL in the 1960s, but due to environmental concerns 3M has withdrawn their AFFF products. In fact, the Environmental Protection Agency (EPA) placed PFOS-based chemicals under a Significant New Use Rule (SNUR) and is investigating potential environmental issues for other chemistries used to produce the remaining MilSpec qualified AFFFs. Further, the European Union, United Kingdom, and Australia placed controls on fire-fighting foams, and proposed regulations are increasingly restrictive. These events have led the Naval Facilities Engineering Service Center and the Navy Technology Center for Safety and Survivability (NTCSS) of the Naval Research Laboratory (NRL) to study new, less environmentally damaging fire-fighting foam options including fluorosurfactant-free foams.

Fluorosurfactant-free fire fighting foam formulas do not carry the burden of extremely long-lived components and degradation products. Hence, they do not have the same persistence and bioaccumulation concerns, as the current AFFF formulations. The test plan for this work is found in reference [2].

Objective

The objective of this work was to evaluate the fire performance of two fluorosurfactant-free fire fighting foam formulas from the 3M company, RF6 and a formulation under development herein referred to as Dev3. RF6 is a 6 % concentrate to be mixed with water, while Dev3 is a 3 % concentrate. Fire performance evaluation followed the MIL-F-24385F protocol; a baseline 3 % MIL-F-24385F-approved AFFF was also tested as a control.

Test Parameters

This test series was conducted at NRL's Chesapeake Bay Section (CBD) facility near Chesapeake Beach, MD. The smaller fires were conducted within a calorimetry facility with an exhaust hood removing the products of combustion. The larger fires were conducted outside on a large concrete pad. All the foam and remaining fire fuels were contained in holding tanks.

A foam generation system used in past MilSpec qualification testing was utilized for this test series. The system consisted of a 10 gallon holding tank pressurized by nitrogen from the top. A hose line off the bottom of the tank led to an air-aspirating nozzle, which supplied 2.0 gallons per minute of foam at 100 psi. Prior to each day's testing the system calibration was checked.

A stopwatch was the primary measurement device used. Fire out times and burn back times were recorded from this. Other maximum time-allowed events set forth in the MilSpec such as fuel pour were verified with the stopwatch. A video camera recorded each fire suppression test. Also a thermometer was used to check the temperature of the solution, water base in the pan, fuel, and the air prior to each test.

Variables

There were five variables in this test series. Dev3 and RF6 were the primary foams studied, and MilSpec approved AFFF tests were conducted as controls. The foam solution strength was varied to examine the more difficult half-strength scenarios; as in the MilSpec protocols, the 6 % concentrate was mixed at 3 % and the 3 % concentrates were mixed at 1.5 %. One Dev3 double strength test was conducted outside the test matrix to assess performance. The water salinity was varied to look at the effects of both fresh and salt water. The fire fuel was varied to explore the foam performance on jet fuel as well as gasoline. Finally the fire area was varied to learn the foam performance in difference energy release rate cases. The test matrix and applicable MilSpec criteria are detailed in Table 1.

Table 1. Test Matrix and Applicable MilSpec Criteria

Foams	Foam Strength	Water Salinity	Fire Area	Fire Fuel	Fire Out Time	Burn Back time
Dev3, RF6, AFFF	Full	Fresh	28 ft^2	Gasoline	≤ 30 s	≥ 360 s
Dev3, RF6	Full	Salt	28 ft^2	Gasoline	≤ 30 s	≥ 360 s
Dev3, RF6	Half	Fresh	28 ft^2	Gasoline	≤ 45 s	≥ 300 s
Dev3, RF6	Half	Salt	28 ft^2	Gasoline	≤ 45 s	≥ 300 s
Dev3, RF6, AFFF	Full	Fresh	28 ft^2	JP-5	-	-
Dev3, RF6, AFFF	Full	Fresh	50 ft^2	Gasoline	≤ 55 s	≥ 360 s

Test Procedure

The pretest procedure included rinsing both the foam generation system and fire pan to remove foam from the previous testing. Once the previous foam had been properly removed, the solution was mixed into the foam generation tank. Finally water was poured into the fire pan to create a level surface; about ten gallons of water was placed in the 28 ft^2 fires and about fifteen gallons was placed in the 50 ft^2 fires.

The test procedure began by starting video recording. The fuel was then poured into the pan within the MilSpec requirement that the fuel be poured in thirty seconds. The fuel was the ignited by match and allowed to spread across the fuel surface. 500 mL of gasoline was used as an accelerant to facilitate ignition of the JP-5. The fully established fire was allowed to burn freely for 10 seconds before the foam application began. The time needed for extinguishment was recorded. During the 50 ft^2 fire, the estimated area coverage of foam was recorded at 10, 20, 30, and 40 seconds and summed together for a "summation"; the MilSpec required a summation of at least 320 for passing. The foam application in all fire cases continued for a total of 90 seconds in preparation of the burn back. One gallon of gasoline in a one foot burn back pan was ignited and placed in the center of the larger fire pan after foam application. The time needed for

the fire to burn back 25 % of the fire surface was recorded. After that point the test ended, the video was stopped, and the post-test fire was extinguished.

Test Results

Full Strength, Fresh Water Results

The full strength, fresh water test results are detailed in Table 2. The results show that both Dev3 and RF6 fell short of the fire out times; however the RF6 was about 10 seconds closer. Also shown is that the RF6 preformed better than the AFFF in the burn back test exceeding the MilSpec criteria, while the Dev3 narrowly missed the criteria.

Table 2. Full Strength, Fresh Water Average plus Minimum Fire Out Times and Average plus Maximum Burn Back Times

Foam	Number of Tests	Fire Out		Burn Back	
		Ave	Min	Ave	Max
MilSpec Requirement:		≤30		≥360	
AFFF	4	30	25	431	444
Dev3	2	51	50	349	350
RF6	3	40	39	476	525

Full Strength, Salt Water Results

The full strength, salt water test results are detailed in Table 3. The results were similar to the fresh water tests, both Dev3 and RF6 failed to meet the fire out criteria while the RF6 was much closer. The RF6 met the burn back criteria although it was much closer than the fresh water case. The Dev3 fell two minutes short of meeting the criteria however.

Table 3. Full Strength, Salt Water Average plus Minimum Fire Out Times and Average plus Maximum Burn Back Times

Foam	Number of Tests	Fire Out		Burn Back	
		Ave	Min	Ave	Max
MilSpec Requirement:		≤30		≥360	
Dev3	1	-	67	-	240
RF6	2	43	41	370	372

Half Strength, Fresh Water Results

The half strength, fresh water test results are detailed in Table . The RF6 performed well in this scenario, meeting both the fire out time criteria and burn back criteria. The Dev3 failed the fire out time considerably and was within 22 seconds of meeting the burn back criteria.

Table 4. Half Strength, Fresh Water Average plus Minimum Fire Out Times and Average plus Maximum Burn Back Times

Foam	Number of Tests	Fire Out		Burn Back	
		Ave	Min	Ave	Max
MilSpec Requirement:		≤ 45		≥ 300	
Dev3	2	87	80	273	278
RF6	2	45	44	340	348

Half Strength, Salt Water Results

The half strength, salt water test results are detailed in Table . The Dev3 failed to extinguish the fire. The RF6 needed 18 more seconds than the criteria to extinguish the fire and was nearly a minute short of the burn back criteria.

Table 5. Half Strength, Salt Water Average plus Minimum Fire Out Times and Average plus Maximum Burn Back Times

Foam	Number of Tests	Fire Out		Burn Back	
		Ave	Min	Ave	Max
MilSpec Requirement:		≤ 45		≥ 300	
Dev3	1	Not Extinguished			
RF6	1	-	63	-	245

JP-5 Results

The JP-5 test results are detailed in Table 6. JP-5 is more difficult to ignite than gasoline and did require 500 mL of gasoline added gently on top of the JP-5 as an accelerant. The gasoline is consumed during the preburn period of the test. Both the Dev3 and the RF6 performed similar to the AFFF in the extinguishment of the fire. Both the Dev3 and the RF6 exceeded 360 seconds of burn back protection.

Table 6. JP-5 Test Results

Foam	Fire Out	Burn Back
AFFF	18	X
Dev3	18	389
RF6	21	560
RF6	18	X

X – Not Attempted

50 ft^2 Results

The 50 ft^2 results (gasoline fuel) are detailed in Table 7. The Dev3 did not extinguish the fire; however it came close as evident by the criteria-exceeding summation. Experimental observation showed that the fire was knocked down but could not be completely extinguished. The fire continued to heat the fuel and the fire grew back in intensity. The RF6 was able to extinguish the fire, although it took 30 seconds longer than allowed in the MilSpec. While the burn back was very poor with the RF6 in this situation, the summation was acceptable.

Table 7. 50 ft^2 Average plus Minimum Fire Out Times, Average plus Maximum Burn Back Times, and Average Plus Maximum Summation

Foam	Number of Tests	Fire Out		Burn Back		Summation	
		Ave	Min	Ave	Max	Ave	Max
MilSpec Requirement:		≤ 55		≥ 360		≥ 320	
AFFF	2	59	55	-	450	358	363
Dev3	1	Not Extinguished				-	340
RF6	2	86	85	-	168	342	349

Conclusion

The objective of this work was to conduct initial evaluation of the fire performance of two fluorosurfactant-free fire fighting foam formulations; not to perform the thorough testing employed for MilSpec certification evaluation. The developmental formulation (Dev3) did not meet MilSpec requirements in any test attempted. It was not able to extinguish the 28 ft^2 fire under half strength, salt water conditions nor the 50 ft^2 fire under full strength, fresh water conditions. The RF6 did meet the MilSpec in one test with half strength, fresh water for the 28 ft^2 fire. The RF6 burn back protection in the 28 ft^2 fire also met the MilSpec criteria in all tested conditions other than the salt water, half strength. The RF6 burn back protection was even better than the AFFF under fresh water, full strength condition. Overall both Dev3 and RF6 had more difficulty with salt water; and both Dev3 and RF6 had more difficulty with the larger fires, compared with AFFF.

The Dev3 at full strength and RF6 at half strength under both fresh and salt water conditions performed similarly. Therefore we experimented with Dev3 mixed at double strength. Dev3 mixed double intended strength at six percent (for one test only) and RF6 at the same concentration of six percent, performed similarly as seen in Table 8.

Table 8. Dev3 and RF6 Comparison

Foam	Number of Tests	Foam Strength	Water Salinity	Fire Out Ave	Fire Out Min	Burn Back Ave	Burn Back Max
Dev3	1	Double	Fresh	-	48	-	583
RF6	3	Full	Fresh	40	39	476	525
Dev3	2	Full	Fresh	51	50	349	350
RF6	2	Half	Fresh	45	44	340	348
DevF3	1	Full	Salt	-	67	-	240
RF6	1	Half	Salt	-	63	-	245

Overall the RF6 performed better than the Dev3 (at design concentrations) in all cases. While the RF6 did not meet the MilSpec fire performance requirements for the challenge fire scenarios evaluated, it may be satisfactory for challenge scenarios not requiring the very rapid, large fire capabilities provided by AFFF, especially for fresh water applications. The applicability of non-AFFF products will depend on the specific fire protection needs, with MilSpec qualified fire fighting foam required for critical uses involving rapid personnel extrication or ordinance.

Gasoline is the threat fuel specified in the MilSpec testing protocol. This presents a difficult challenge against which prospective fire fighting formulations need to prove themselves. Gasoline (Mogas) is employed within DoD, both on land and on weapons platforms. Some facilities may require fire protection only against higher boiling point, less volatile fuels. In this case, the less volatile JP-5 fire tests may be more relevant. Both the Dev3 and RF6 performance against the JP-5 fires was comparable to the AFFF performance.

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References

[1] United States Military Specification "Fire Extinguishment Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water," MILSPEC MIL-F-24385F, 7 January 1992.

[2] Sheinson, R.S. and Ayers, S., "Test Plan for the Fire Fighting Performance of a Fluorosurfactant-Free Alternative to Aqueous Film Forming Form (AFFF): Initial Evaluation", NRL Ltr Rpt Ser 6180/0258, 6 July 2004.

Appendix A: Results Matrix

Table A. Test Results Compilation

Test Number	Foam	Strength	Salinity	Fire Fuel	Fire Area	Fire Out	Burn Back	Summation
1.1	AFFF	Full	Fresh	Gasoline	28 ft^2	32	418	na
1.2	AFFF	Full	Fresh	Gasoline	28 ft^2	36	X	na
1.3	AFFF	Full	Fresh	Gasoline	28 ft^2	28	X	na
2.1	Dev3	Full	Fresh	Gasoline	28 ft^2	50	350	na
2.2	Dev3	Full	Fresh	Gasoline	28 ft^2	52	348	na
3.1	Dev3	Half	Fresh	Gasoline	28 ft^2	94	268*	na
4.1	Dev3	Half	Fresh	Gasoline	28 ft^2	80	278	na
5.1	Dev3	Half	Salt	Gasoline	28 ft^2	Not Ext.	na	na
6.1	Dev3	Full	Salt	Gasoline	28 ft^2	67	240	na
7.1	RF6	Full	Fresh	Gasoline	28 ft^2	40	500	na
7.2	RF6	Full	Fresh	Gasoline	28 ft^2	41	525	na
8.1	AFFF	Full	Fresh	Gasoline	28 ft^2	25	444	na
9.1	RF6	Full	Fresh	Gasoline	28 ft^2	39	403	na
10.1	RF6	Half	Fresh	Gasoline	28 ft^2	46	331	na
10.2	RF6	Half	Fresh	Gasoline	28 ft^2	44	348	na
11.1	RF6	Full	Salt	Gasoline	28 ft^2	45	372	na
11.2	RF6	Full	Salt	Gasoline	28 ft^2	41	367	na
12.1	RF6	Full	Fresh	JP-5	28 ft^2	21	560	na
12.2	RF6	Full	Fresh	JP-5	28 ft^2	18	X	na
13.1	AFFF	Full	Fresh	JP-5	28 ft^2	18	X	na
14.1	Dev3	Full	Fresh	JP-5	28 ft^2	18	389	na
15.1	RF6	Half	Salt	Gasoline	28 ft^2	63	245	na
16.1	Dev3	Double	Fresh	Gasoline	28 ft^2	48	583	na
17.1	AFFF	Full	Fresh	Gasoline	50 ft^2	63	X	363
17.2	AFFF	Full	Fresh	Gasoline	50 ft^2	55	450	353
18.1	RF6	Full	Fresh	Gasoline	50 ft^2	87	168	349
18.2	RF6	Full	Fresh	Gasoline	50 ft^2	85	X	334
19.1	Dev3	Full	Fresh	Gasoline	50 ft^2	Not Ext.	na	340

X – Not Attempted
na – Not Applicable
*120 seconds of foam application rather than 90, as fire not extinguished until 94 seconds. For evaluation purposes only, not MilSpec test protocol.