Interactions of Fire-fighting Foam with Hydrocarbon Fuel

Chang Jho
Dynax Corporation, NY USA

Fuel contamination problem of low expansion foams for Class B fires is a serious issue, but it is unavoidable, particularly under direct or forceful applications .

Test Standards/Specs and Modes of Foam Application

Standard/Spec	Test Fuel	Application Mode	
EN 1568	Heptane	Forceful	Gentle
UL-162	Heptane	Forceful	
US Mil-F-24385F	Gasoline → Heptane?	Forceful	
ICAO A/B/(C)	Kerosene (Jet A)	Forceful	

The fuel contamination problem or "fuel pickup" problem leads to:

- **Premature breakdown of foam blankets**
- **Flicker fires → Poor extinguishment**
- **Flashovers, ghosting and re-ignition → Poor Burnback Resistance**

Laboratory Experiments: Two Effects of Fuel Contamination

Flammability of Fuel-contaminated Foams

Stability of Fuel-contaminated Foams

Products Tested:
- Five F3 Agents
- Four AFFF (1)/AR-AFFF (3) Agents

Test Fuels:
Iso-Octane, Gasoline, Heptane, Cyclohexane, Jet A1

For experimental details see: **Chang Jho*, International Fire Fighter*, 41, Issue 36 (2012)**

Foam Flammability Test Results

Table 1. Comparison of Flammability of Fuel-Contaminated Fluorine-free Foams and AFFF/AR-AFFF

Test Foam Agent	Flammability and Sustained Burning			
	Iso-Octane	Gasoline	n-Heptane	Cyclohexane
Fluorine-Free Foam (F3) Agents				
Product A (6%) Product B (3%/6%) Product C (3%) Product D (3%/3%) Product E (3%/6%)	All ignited and burned away			
AFFF/AR-AFFF Agents				
Product 1 (AFFF-3%) Product 2-AR-AFFF-3%/3% Product 3-AR-AFFF-3%/3% Product 4-AR-AFFF-1%/3%	None ignited or burned at all			

Note: Due to its high (>38°C) flash point, Jet A1-contaminated foams could not be ignited at ambient temperature.

Visit www.Youtube.com: "Flammable Firefighting Foams"

Foam Stability Test Results

Table 2. Stability Test Results of Fuel-Contaminated Foams

Test Foam Agent	50% Foam Collapse Time (min)				
	Iso-Octane	Gasoline	n-Heptane	Cyclohexane	Jet A1
Fluorine-Free Foam (F3) Agents					
Product A (6%)	>30	4.6	13.4	9.5	>30
Product B (3%/6%)	>30	9.5	7.1	6.3	>30
Product C (3%)	>30	4.5	23.0	8.7	>30
Product D (3%/3%)	12.8	5.5	3.7	7.4	>30
Product E (3%/6%)	14.1	6.7	9.3	8.7	20
AFFF/AR-AFFF Agents					
Product 1 (AFFF-3%)	>30				
Product 2 (AR-AFFF-3%/3%)					
Product 3 (AR-AFFF-3%/3%)					
Product 4 (AR-AFFF-1%/3%)					

Visit www.Youtube.com: "Flammable Firefighting Foams"

Why did all the Fluorine-free Foams become flammable when contaminated with hydrocarbon fuel while all AFFF/AR-AFFF Foams did not??

↓

Spreading and Sealability of Foam Solution over Fuel	Spreading of Fuel over Foam Solution

"Upside Down Screw Test"

Spreading and Sealability Test Results: Foam Solution over Fuel

Table 3. Spreading and Sealability Tests of Foam Solution over Fuel

Test Foam Agent	Foam Solution over Fuel				
	Gasoline	n-Heptane	Iso-Octane*	Cyclohexane	Jet A1
Fluorine-Free Foam (F3) Agents					
Product A (6%) Product B (3%/6%) Product C (3%) Product D (3%/3%) Product E (3%/6%)	None of the foam solutions spread or sealed (All burned)				
AFFF/AR-AFFF Agents					
Product 1 (AFFF-3%) Product 2 (AR-AFFF-3%/3%) Product 3 (AR-AFFF-3%/3%) Product 4 (AR-AFFF-1%/3%)	All foam solutions spread and sealed (No burning)				

*Spreading on Iso-Octane was hard to detect, but sealing was confirmed by no burning.

AFFF Foam Solution
Fuel

F3 Foam Solution
Fuel

Spreading Test Results: Fuel over Foam Solution

Table 4. Spreading Tests of Fuel over Foam Solution

Test Foam Agent	Fuel over Foam Solution				
	Iso-Octane	Gasoline	n-Heptane	Cyclohexane	Jet A1
Fluorine-Free Foam (F3) Agents					
Product A (6%)	Spreading (30%)*	Spreading (100%)	Spreading (40%)	Spreading (20%)	Spreading (20%)
Product B (3%/6%)	Spreading (40%)	Spreading (80%)	Spreading (20%)	Spreading (15%)	No Spreading
Product C (3%)	Spreading (20%)	Spreading (100%)	Spreading (20%)	Spreading (20%)	Spreading (20%)
Product D (3%/3%)	Spreading (40%)	Spreading (80%)	Spreading (20%)	Spreading (15%)	Spreading (15%)
Product E (3%/6%)	Spreading (20%)	Spreading (80%)	Spreading (15%)	Spreading (15%)	No Spreading
AFFF/AR-AFFF Agents					
Product 1 (AFFF-3%)	**None of the fuels spread**				
Product 2 (AR-AFFF-3%/3%)					
Product 3 (AR-AFFF-3%/3%)					
Product 4 (AR-AFFF-1%/3%)					

* **Numbers in parentheses Indicate % spread area.**

Fuel
F3 Foam Solution

Fuel
AFFF Foam Solution

Some Basic Concepts about Fire-fighting Foam

Foam: A mass of air-filled bubbles. To create a stable foam, foam solution must contain a foaming agent which is a SURFACTANT (Surface Active Agent).

Surfactant: A chemical substance containing a balance of both oleophilic (oil-loving) and hydrophilic (water-loving) groups. Due to this structural property, surfactant molecules adsorb (aggregate) spontaneously onto the bubble surface.

Two Types of Surfactants Used in Fire-fighting Foams

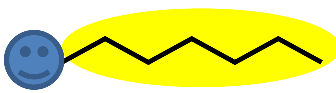
- **Hydrocarbon Surfactants (used mainly as foaming agent)**
  - "Man-made" Hydrocarbon Surfactants: Synthetic detergents
  - "Natural" Hydrocarbon Surfactants: Alkyl polyglycosides, Protein hydrolysates

- **Fluorosurfactants*(used mainly in aqueous film-forming foams)**
  - PFOS-based fluorosurfactants (banned and no longer used)
  - Fluorotelomer-based surfactants

*contain Oleophobic (oil-repellent) and Hydrophilic groups

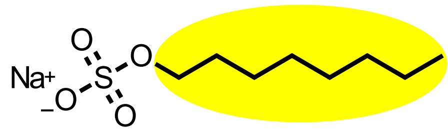
Examples of Hydrocarbon- and Fluoro-surfactants Used in Fire-fighting Foams

Hydrocarbon Surfactants (Foaming Agents)

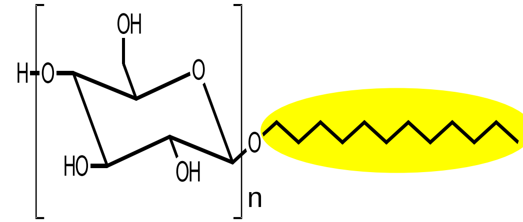


Oleophilic (oil loving) "tail"

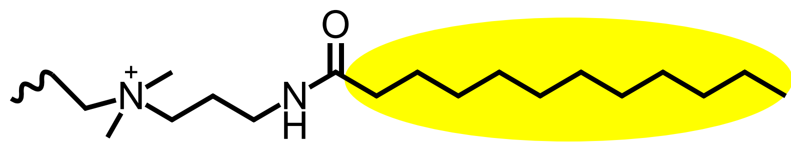
Heptane



Sodium Octyl Sulfate
(Anionic surfactant)

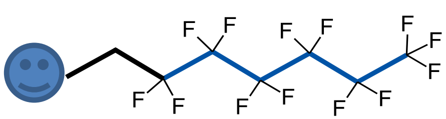


Lauryl Polyglycosides
(Nonionic surfactant)

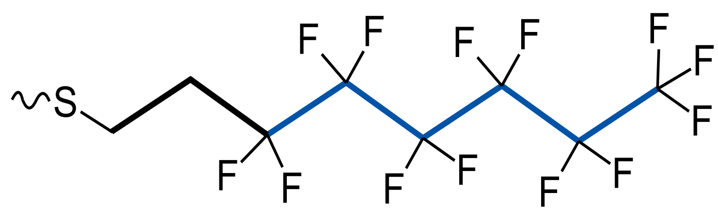


Cocamidopropyl Betaines and Hydroxy Sultaines
(Amphoteric surfactants)

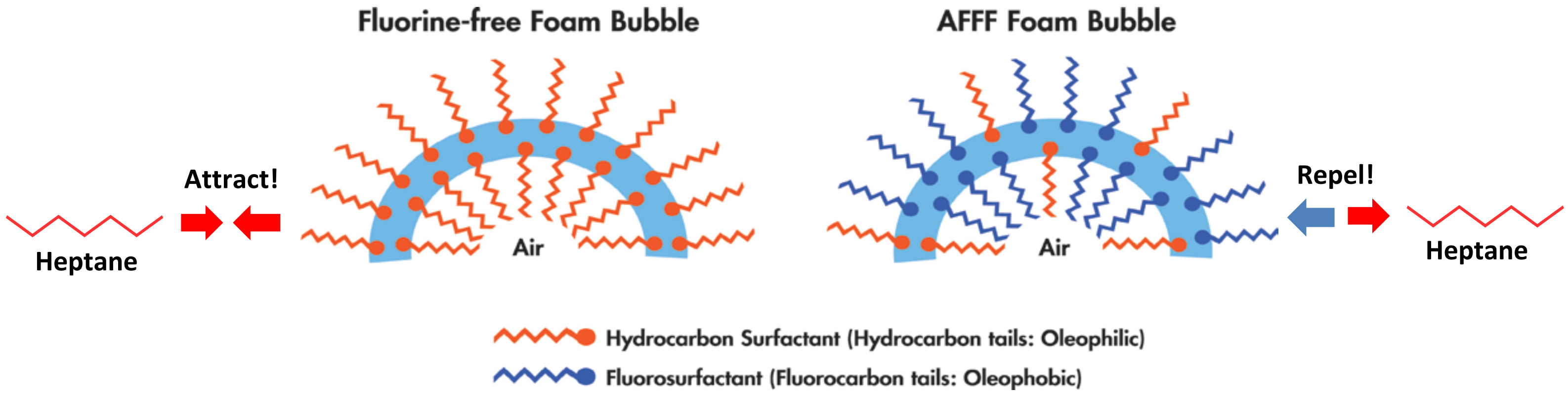
C6-telomer-based Fluorosurfactant



Oleophobic (oil repellent) "tail"



Interactions of Fuel with Surfactant Molecules on the Foam Bubble Surface



Hydrocarbon surfactants attract hydrocarbon fuels

Fluorosurfactants repel hydrocarbon fuels

Conclusions: F3 Foams

- All F3 foams tested became flammable and burned away when contaminated with a hydrocarbon fuel.
- This fuel contamination was also found to degrade the stability of F3 foams.
- Test results proved that the oleophilicity (fuel attraction) of hydrocarbon surfactant foaming agents causes flammability and degradation of fuel-contaminated F3 foams.
- This oleophilicity fundamentally limits what can be achieved to reduce the fuel contamination problem in all F3 foams.
- The positive spreadability of fuel on F3 foaming solutions is as important as their lack of film formation on fuel in understanding the flammability of fuel contaminated F3 foams.

Conclusions: AFFF Foams

- None of the AFFF foams tested became flammable when contaminated with a hydrocarbon fuel.
- Effects of the fuel contamination on the stability of AFFF foams were minimal.
- The oleophobicity (fuel repellency) of fluorosurfactants reduces fuel contamination of AFFF foams and resists flammability, while maintaining foam stability.
- The positive spreadability of AFFF foam solutions on fuel is critical in protecting the contaminated foam from ignition and premature degradation.
- The negative spreadability of fuel on AFFF foam solutions is as important as their positive spreadability on fuel for AFFF foam's resistance to fuel contamination and flammability.
- Further research is needed to better understand the quantitative relationship between the surface/interfacial tensions and the distribution of fuel particles in fuel contaminated foams.

Video: Demonstration of Flammability of Fuel-contaminated Foams

Thank you!

Dynax Contact Info:
Chang Jho, 79 Westchester Avenue, PO Box 285, Pound Ridge, NY 10576 USA
Tel: 914 764-0202 Fax: 914 -764-0533 e-mail: chang.jho@dynaxcorp.com