# Interactions of Fire-fighting Foam with Hydrocarbon Fuel

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**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%)<br>Product B (3%/6%)<br>Product C (3%)<br>Product D (3%/3%)<br>Product E (3%/6%) | All ignited and burned away | | | |
| **AFFF/AR-AFFF Agents** | | | | |
| Product 1 (AFFF-3%)<br>Product 2-AR-AFFF-3%/3%<br>Product 3-AR-AFFF-3%/3%<br>Product 4-AR-AFFF-1%/3% | None ignited or burned at all | | | |

Note: Due to its high (>38$^{o}$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%)<br>Product B (3%/6%)<br>Product C (3%)<br>Product D (3%/3%)<br>Product E (3%/6%) | None of the foam solutions spread or sealed (All burned) | | | | |
| **AFFF/AR-AFFF Agents** | | | | | |
| Product 1 (AFFF-3%)<br>Product 2 (AR-AFFF-3%/3%)<br>Product 3 (AR-AFFF-3%/3%)<br>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 |

<table>
<tr><td colspan="2">AFFF/AR-AFFF Agents</td></tr>
<tr><td>Product 1 (AFFF-3%)</td><td rowspan="4">None of the fuels spread</td></tr>
<tr><td>Product 2 (AR-AFFF-3%/3%)</td></tr>
<tr><td>Product 3 (AR-AFFF-3%/3%)</td></tr>
<tr><td>Product 4 (AR-AFFF-1%/3%)</td></tr>
</table>

* 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

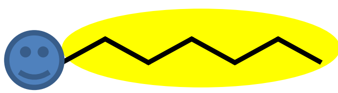
- **Hydrocarbon Surfactants (used mainly as foaming agent)**
  - "Man-made" Hydrocarbon Surfactants: Synthetic detergents
  - "Natural" Hydrocarbon Surfactants: Alkyl polyglycosides, Protein hydrolysates

- **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

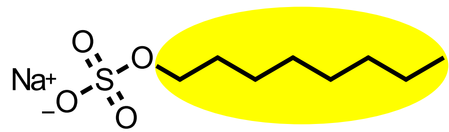
# Examples of Hydrocarbon- and Fluoro-surfactants Used in Fire-fighting Foams

## Hydrocarbon Surfactants (Foaming Agents)

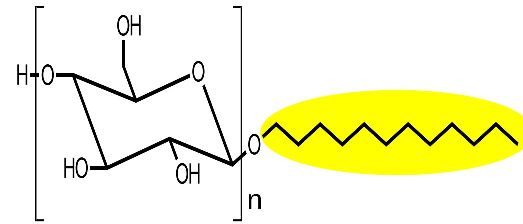


**Oleophilic (oil loving) "tail"**

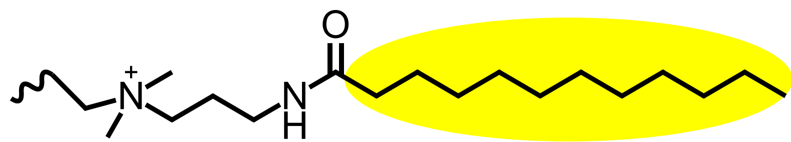
**Heptane**



**Sodium Octyl Sulfate**
(Anionic surfactant)

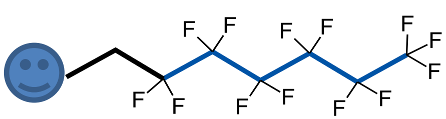


**Lauryl Polyglycosides**
(Nonionic surfactant)

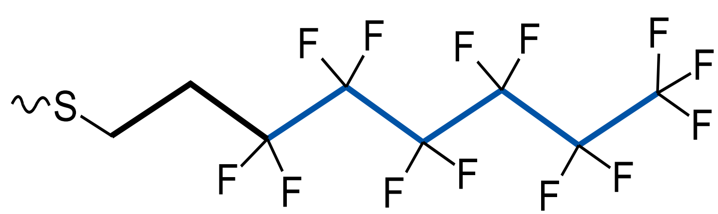


**Cocamidopropyl Betaines and Hydroxy Sultaines**
(Amphoteric surfactants)

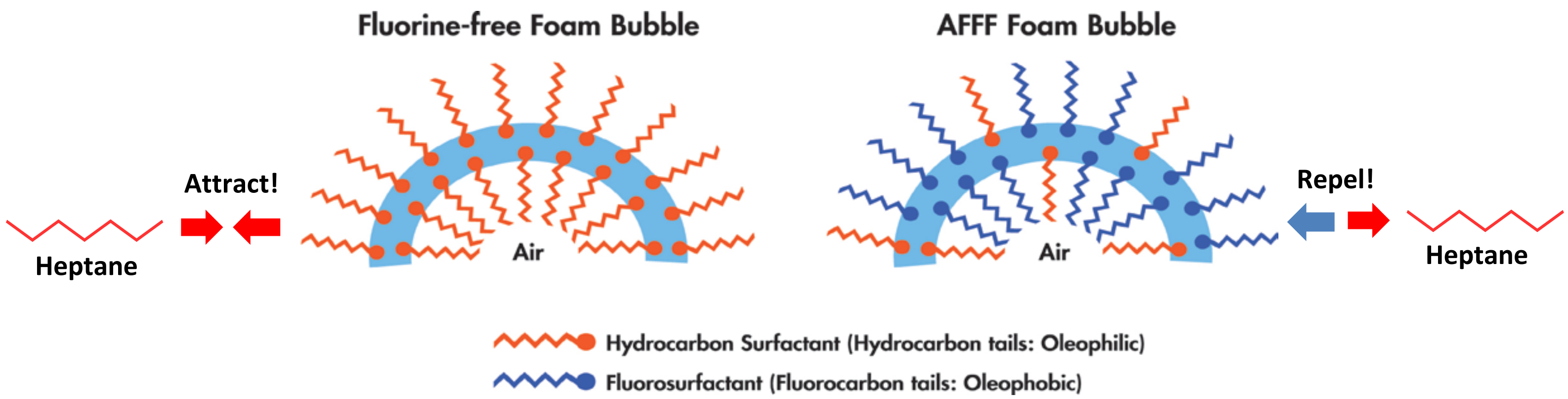
## C6-telomer-based Fluorosurfactant



**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!

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