NATIONAL WORKSHOP
on
"FIRE RESEARCH IN PROPULSION SYSTEMS"
Organised by
National Centre for Combustion Research & Development
IIT Madras, under the auspices of
AR & DB (Propulsion Panel) & Combustion Institute (Indian Section)

Analysis of Fire Test Results at FCRC

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23rd January 2020

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Overview

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Introduction

- Fire & Combustion Research Center (FCRC) has collaborated with Underwriters' Laboratories (UL) to test fire suppression products such as fire fighting foams, extinguishing media,etc.
- In this connection the center has established a testing facility, UL- Jain Fire Lab (ULJFL) at its global campus near Kanakapura situated Bangalore outskirts
- ULJFL has so far conducted >100 out door pool fire tests since 2010
- A new facility with state-of –the art Indoor fire testing porous wall configuration designed and architected by Prof Mukunda and Dr Dixit got inaugurated during August 2016 which is currently in operation
- Till now more than 150 pool fire tests have been successfully conducted and more tests are planned in the coming years

The analysis of the fire test results along with few ideas for possible improvement are presented here…

Motivation

- Aqueous film forming foam (AFFF) is a low expansion fire fighting foam used in refineries, chemical and material Industries in huge quantities to combat liquid fuel fires
- They have expansion ratio up to 1: 20
- Perfluoro surfactant is one of the active ingredient in AFFF that has *high heat stability* besides *hydrophobicity*
- For decades till 2016, C8 perfluoro surfactants such as Perfluoro octane sulfonate (PFOS, C_8F_{17} SO_3X) were used
- Since C8 type foams are bio-accumulative , toxic in nature (USEPA 2010/2015), C6 foams were developed and are considered safe alternative
- But the nature of C6 towards environment is yet to be confirmed and so, fire protection industries are in search of fluorine free alternatives and very few have succeeded in producing a sort of close alternative to perfluoro surfactants
- In this connection fire tests are being conducted at high frequency globally which requires intensive studies using pool fire studies of large scale resulting in high fuel consumption
- Lattimer et al (2003) have carried out few studies in small scale radiating apparatus for measurement of mass loss of static foam layer of 6% AFFF foam for MIL SPEC application while its suitability to replicate the popular standards like UL162 are yet to be explored

The composition of AFFF and the various testing methods available across globe to test its efficacy…….

Typical composition* of AFFF

Compound	%
Water	98.1-98.5
Diethyl glycol butyl ether	0.9-0.12
Alkyl sulphate salts	0.03-0.15
Amphoteric fluoroalkylamide derivative	**0.03-0.15**
Perfluoroalkyl sulfonate salts	**0.03-0.15**
Hydrocarbon surfactant	0.03-0.18

- **It can be seen that the % of fluorosurfactants can be varied widely**
- **Manufacturers makes use of this to work on the cost and is therefore important for the buyer to ensure the performance of the foam according to the standards**

**Source: Katherine Hinnant, Art Snow, John Farley, Spencer Giles, Ramagopal Ananth, Comparison of Firefighting Performance between Commercial AFFF and Analytically Defined Reference AFFF Formulations SUPDET 2017*

Standard Testing methods across Globe

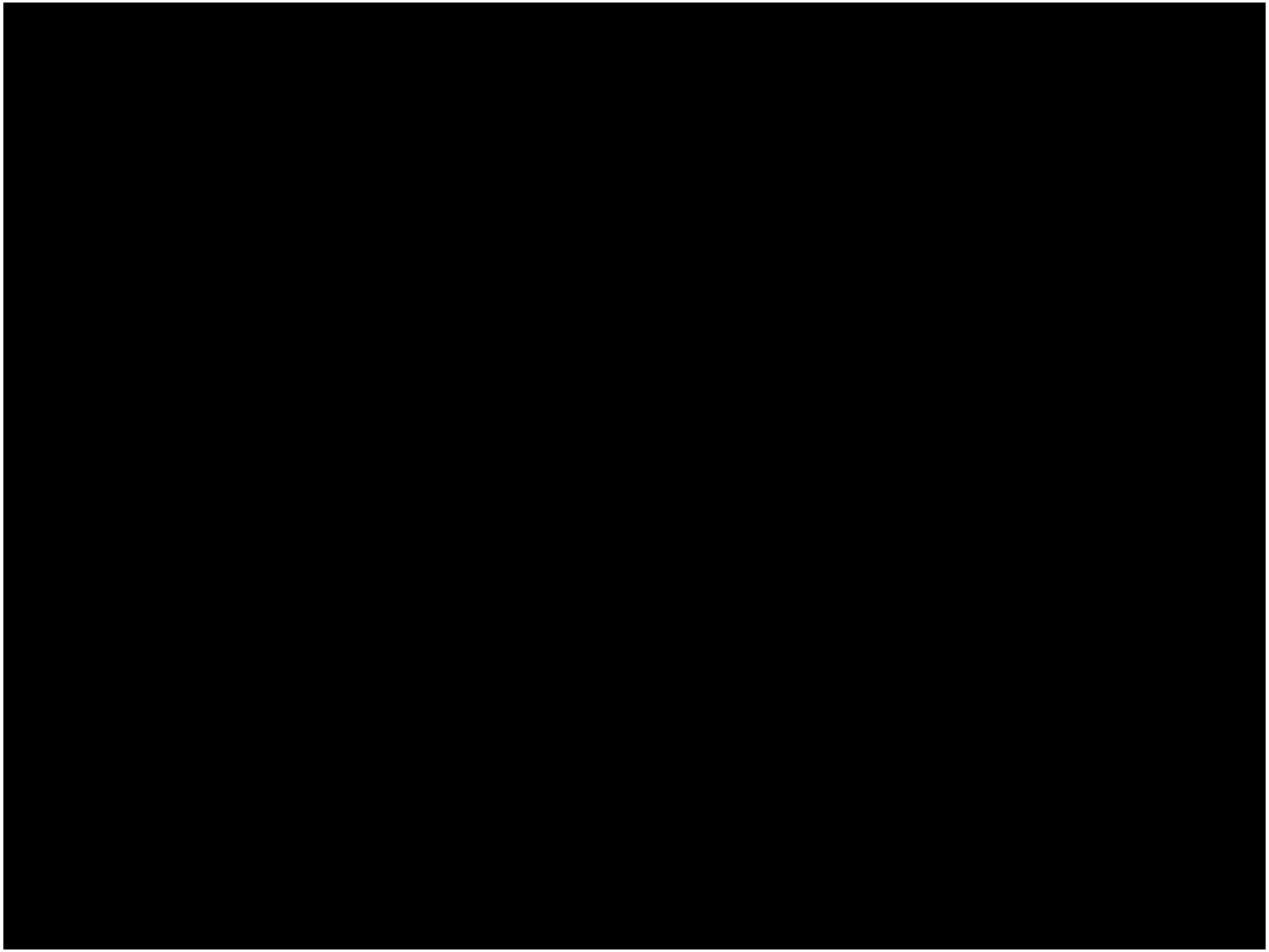
Standard/ Parameters	LAST FIRE	ISO 7203-1	NFPA-11	BS-EN 1568-3	FM 5130	MIL F 24385F	IS 4989 part-1	UL-162
Pan shape	Circular	Circular	Square	Circular	Square	Circular	Circular	Square
Pan area m^2	4.64	4.46	9.29	4.46	4.64	4.64	2.5	4.64
Pan depth inch	24	8	36	8	12	4	24	12
Wind speed, m/s	<3	<3	<3	<3	<3	<4.5	<3	<3
Fuel	Heptane	Heptane	Gasoline	Heptane	Heptane	Gasoline	Heptane	Heptane
Fuel Level inch	1.66	3.7	1.25	3.7	2	1	0.87	2
Water level inch	2.5	1.8		1.8	2	1	3.93	2
Free board inch	19.9	1.96	24	1.96	8	2	18.6	8
Flow rate litres/min	17	11.4	22.2	11.4	7.5	7.5	7.5	7.5
Nozzle pressure psi	100-120	90-100	100	90-100	-	100	100	-
Application Density (LPM/m^2)	**3.69**	**2.58**	**2.41**	**2.58**	**1.64**	**1.64**	**3.02**	**1.64**

UL 162 and FM 5130 are identical, and stringent considering the choice of square pan and the lowest foam application density. The choice of pure fuel – heptane is also important.

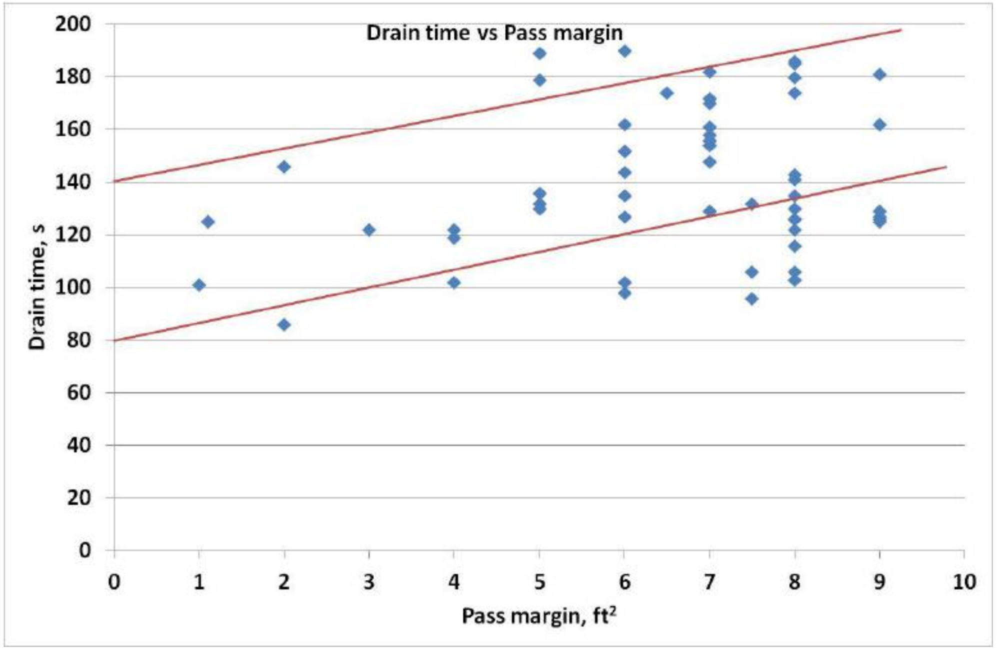
Fire test according to UL 162 –important steps

Step	Test Activity
1	**Flow rate calibration** to 2 gpm (7.5 litres/minute)
2	**Foam quality** a. Quarter drain time – time required for 25% of the foam to drain as liquid foam solution (min. 2 minutes) b. Expansion ratio - The ratio of final foam volume to original foam solution volume before adding air (6 to 10)
3	**Fire test performance**: **Pan** 20B-50ft^2 (square),12 inches height; **n-heptane-** 2”; **water** – 2”;**Free Board-** 8”)
4	**Ignition and pre-burn** up to 1 min
5	**Foam application** from nozzle mounted on a stand till 90% control and thereafter by test fire fighter for 3 minutes
6	**Sealability Check** using torch twice within 7 minutes of foam application
7	**Burn back test**- 10 minutes from foam application a stove pipe is inserted inside the weak spot of foam applied and the foam is scooped out and fire is lit again. Foam blanket should be able to restrict the fire to not more than 10 sq. ft for a period of 5 minutes

A short video on UL 162 test



Analysis of the test results and learning so far



- Quarter drain time is the time required for 25% of the foam to drain as liquid foam solution
- This 25% volume is dependant on mass of foam expanded and higher foam mass indicate more drain volume and lower expansion ratio
- **This leads to higher side of pass margin**

•It can be observed from the plot that **Foams with higher drain time have higher side of pass margin which is critical and narrow pass**

•It is observed that about 17% of the AFFF tested most of them failed in the burn back test and is due to poor expansion ratio and drain time

•A decent performing foam is found to have expansion ratio **of ~ 7 to 9 with drain time of ~120 s**

Scale down approach

- In view of supporting non bio accumulative AFFF development and ascertaining its performance at the manufacturers' location prior to large scale testing, a scale down approach for testing the low expansion fire fighting foam is thought over and few experimental studies were carried out at FCRC
- The method involves adapting the popular UL 162 standard topside discharge fire test method with minor changes
- The principle makes use of pool fire studies carried at FCRC (*Shivakumar Annaiappa et al*)and the findings thereof related to bulk boiling of the fuel
- It is observed through the experiments that at bulk boiling the mass flux for n- heptane reaches 70 to 75 $g/m^2.s$ and this roughly matches the peak burn rate of 2.1 m^2 pan used for UL 162 tests
- Details of these studies will be presented by Mr. Shivakumar in his presentation

The steps involved in scale down approach are …

Table of Comparison- UL 162 vs C200

Item	UL 162	C200	Remarks
Pan (Area)	Square (4.65 m^2)	Circular (0.0314 m^2)	C200 pan area is ~0.7% of the original
Depth	12”	2”	
Fuel	2 ”n-heptane over 2”water	1”n- heptane; no water	Usage without water may be more severe
Pre burn time	1 min	~350 s	Burn rate is matched by reaching to bulk boiling stage
Application density, LPM/m^2	1.64	1.64	
Foam discharge rate	7.5 litres per minute	51 ml per minute	
Stove pipe dia.	305 mm	30 mm	selected in terms of Pan diameter

Fire testing of LE foam using 200 mm pan

Step	Test Activity
1	**Flow rate calibration** to 51 ml per minute
2	**Fire test performance**: **Pan** 200 mm dia. (circular with area 0.0314 m^2), 2" height; **n-heptane-** 1"; **Free Board-** 1")
3	**Ignition and pre-burn** till bulk boiling which is achieved in about 350 secs for this pan
4	**Foam application** from sprayer mounted on a dispensing bottle and is dispensed using compressed air for 3 mins
5	**Burn back test**- after about 5 minutes from foam application a stove pipe is inserted inside the weak spot of foam applied and the foam is scooped out and fire is lit again. Foam blanket should be able to restrict the fire or quench within a period of 5 minutes

The foam is qualified to be Pass if it meets the above else it is declared fail

A video of the same follows ….

Videos of scale down test

Passed

failed

Comparison of the test results

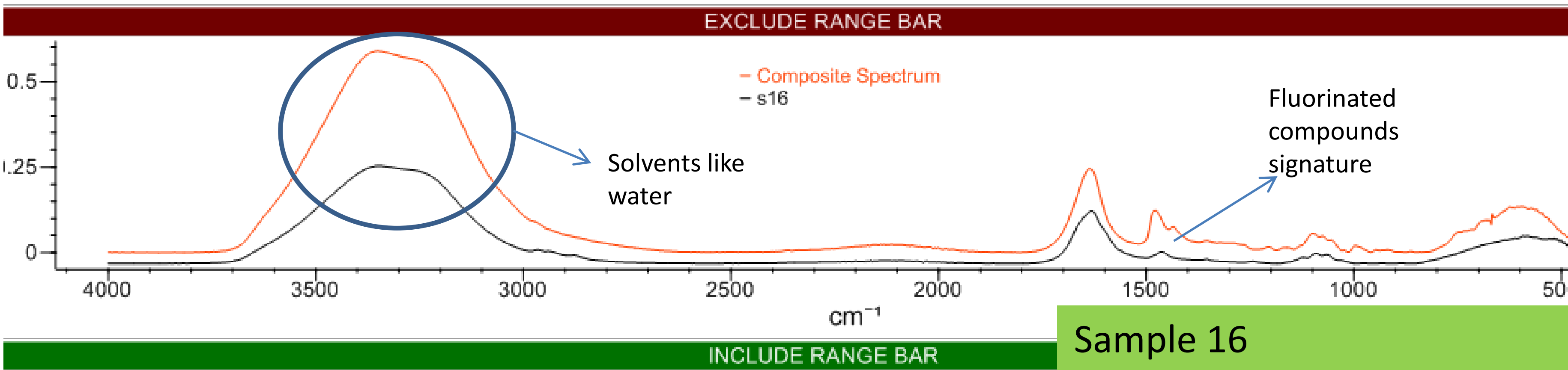
- Experiments were carried with about 10 samples and the results were found to be 90% matching that of large scale fire tests with the exception of sample no.10

Sample no.	UL 162 method						Scale down method			
	Expansion Ratio	Drain Time(m:s)	90% Control (m:s)	Extinguish (m:s)	Pass/ Fail	Area(ft2)	Flow rate (ml /s)	90% Control (s)	Extinguish (m:s)	Pass/ Fail
1	12.3	02:12	00:56	01:32	Pass	2.50	49.0	01:58	01:50	Pass
2	7.06	02:10	02:49	03:50	Fail	25.00	51.4	Not cont.	Not ext.	Fail
3	7.33	02:41	01:22	02:18	Fail	>25	51.0	02:40	Not ext.	Fail
6	7.96	01:42	01:12	01:53	Pass	2.00	50.0	01:20	01:45	Pass
7	6.89	02:28	01:00	01:28	Pass	3.00	49.0	01:30	02:15	Pass
8	12.9	02:28	00:57	01:20	Pass	3.00	51.4	00:55	02:35	Pass
10	9.6	01:47	00:54	01:28	Fail	>20	51.0	01:20	02:05	Pass
11	10.15	01:52	00:44	01:30	Fail	12.00	51.0	02:00	blanket opened	fail
12	10.06	02:02	01:00	01:35	Pass	9.00	50.5	01:20	02:15	Pass
13	8.29	01:50	01:00	01:32	fail	>20	51.0	02:10	Not ext.	Fail
16	7.8	01:46	01:12	01:53	pass	2.00	50.0	01:55	01:50	Pass

- More samples need to be compared with to add strength to this methodology
- For this it is planned to conduct similar experiments with 500 mm dia and 1 m dia pan with suitable nozzles
- Failed samples are mostly found to be fluorine alternative foams
- *This is ascertained through following FTIR studies* .....

FTIR studies

- Observations from FTIR analysis of Pass and fail samples indicate that the pass samples have fluorosurfactant more than 0.16% where as the failed foam samples have less than 0.13% or found to be development of fluorine free foams

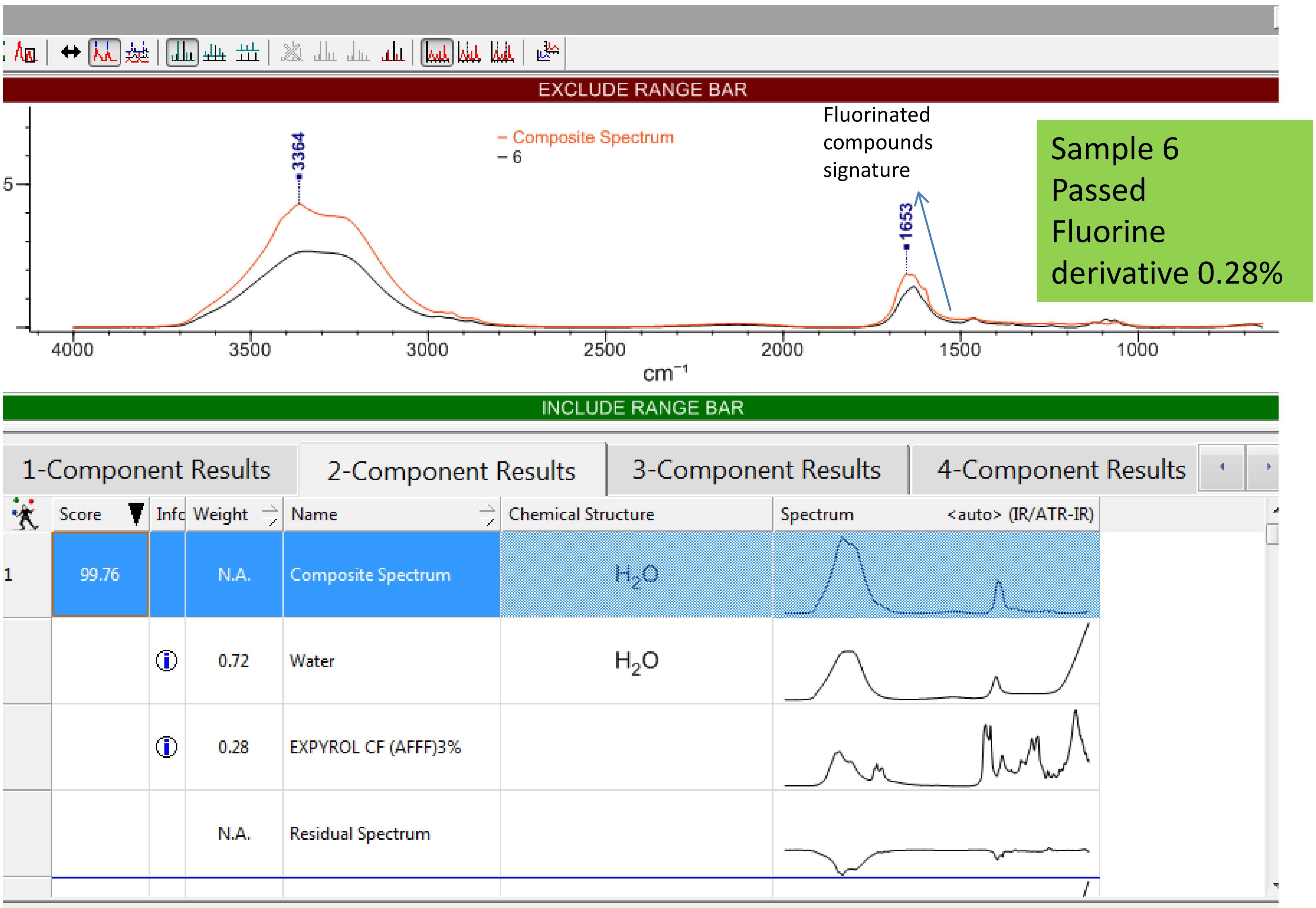


Sample 16
Passed
Fluorine derivative 0.16%

1-Component Results | 2-Component Results | 3-Component Results

	Score	Info	Weight	Name	Chemical Structure	Spectrum <auto> (IR/ATR-IR)
			N.A.	Residual Spectrum		
50	98.92		N.A.	Composite Spectrum	Na_2TiF_6	
		ⓘ	0.84	Poly(dimethylamine-co-epichlorohydrin), quanternize 36.40% in H2O		
		ⓘ	0.16	SODIUM HEXAFLUOROTITANATE	Na_2TiF_6	

FTIR studies



FTIR studies

Sample 3
Failed
Fluorine
alternatives
0.17%

Display Profiles: <no profile>

ATR-IR

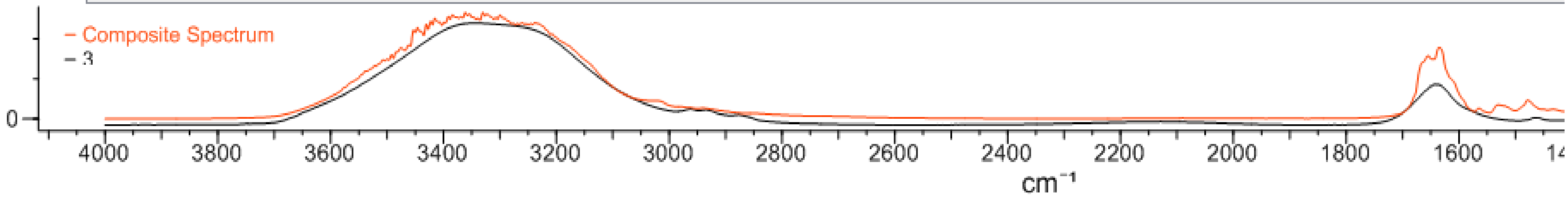
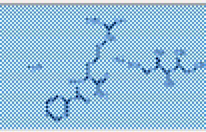
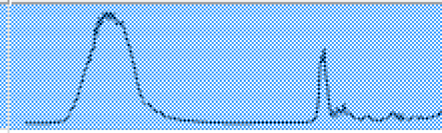
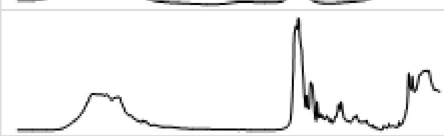
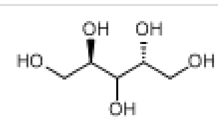


Table | Plot

	HQI	Weight	Exclude	Cor	DB	ID	Name	Chemical Structure	Spectrum <auto> (IR/ATR-IR)
1	98.94	N.A.		i			Composite Spectrum		
		0.37	○	i	LX	1391	WATER, DISTILLED	H_2O	
		0.36	○	i	SAX	32814	L-N-(1-CARBAMOYL-4-GUANIDINOBUTYL)BENZAMIDE, MONOHYDROCHLORIDE		
		0.17	○	i	CMX	1458	CHEMCOL T-10		
		0.10	○	i	SAX	1563	D-(+)-ARABINITOL		

Conclusions

- Details of AFFF foam, its typical composition and standard methods towards qualifying the same such as UL 162 have been presented
- An alternative scale down approach to ensure the efficacy of the foam at manufacturers' location before confirming through large scale clearance methods proposed
- Reason for success/failure can be ascertained through FTIR studies results of which indicate that it requires a minimum flurosurfactant of more than 0.15% to qualify the large scale tests
- Leaving behind some arguments if fluorine free fire fighting foams are necessary, it is important to develop the fluorine free alternatives as there is no solid confirmation of the existing C6 fluorine alternatives being non bio accumulative
- Considering this it is planned to continue the studies with more passed and failed foams with larger sized pans like 500 mm diameter size to strengthen the methodology
- Also the studies need to be conducted if the same can be applied to dry chemical powders as well
- It is hoped that this will benefit the Indian fire suppression Industry to develop more non-bio accumulative fire suppression agents

References

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Thank You