Foam Concentration Measurement Techniques

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Abstract

Three types of foam concentration measurement techniques are examined: total fluorine content, optical absorption, and specific conductivity. Specific conductivity was found to be the most useful for field measurements and was therefore compared with the traditional refractive index approach. It was found that electrical conductance provides a more accurate method of estimating the concentration of AFFF solution than does the refractive index technique described in NFPA 11.

Introduction

This paper examines an alternative method to that described in NFPA 11, "Low Expansion Foam and Combined Agent Systems," for determining the concentration of Aqueous Film Forming Foam (AFFF).

AFFF is a fluorocarbon foam which suppresses liquid fuel fires by forming a film over the fuel surface that inhibits the release of flammable vapors. AFFF in Australia has primarily been used in fixed systems, portable units, and hand-held extinguishers for the protection of fuel farms and aircraft hangars, etc. In these systems the foam concentrate is mixed (water and foam concentrate are drawn together from separate supplies and mixed in proportions) or pre-mixed (water and concentrate already mixed to the required proportions) with fresh or sea water in either 1, 3 or 6% V/V concentration.

In Australia the quality of the foam produced by these fire suppression systems is determined in accordance with NFPA 11. This code requires the measurement of:

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Foam concentration: The volume ratio of AFFF concentrate to water used to generate foam.
Foam expansion: The ratio of volume of foam formed to the volume of solution used to generate the foam.
25% drainage time: The time taken for 25% of the solution to drain from the foam.
Film forming capacity: The ability of the foam solution to form a film over a flammable liquid to inhibit vapor emission.

NFPA 11 requires the AFFF concentration to be determined by comparison of the refractive index of solutions of unknown concentration with that of solutions of known concentration. However, difficulties have been experienced in obtaining accurate results using this method, and thus three alternative methods were proposed: total fluorine content; optical absorption; and specific conductivity.

Preliminary investigations found that of these proposals only specific conductivity could be used for field measurements of AFFF concentration. This paper therefore concentrates on comparing the relative performance of the specific conductivity method with the traditional refractive index approach, although the other methods are briefly described.

Foam Concentration Measurement Techniques

The methods examined all share the same principle that a property of the foam solution that varies with concentration is measured. Calibration graphs of the property (refractive index, optical absorption, fluorine content and conductivity) with concentration were produced using solutions of known concentration.

For the refractive index method the NFPA code suggests the use of a hand-held juice refractometer (0–25% sugar content) or a bench refractometer covering the range 1.3330 to 1.3723. This laboratory used a bench Atago ABBE type 1, 4 refractometer which has a range from 1.3000 to 1.7000.

The refractometer is suited to the task of determining the concentration of foam solutions both in a laboratory and on site while testing foam systems. On-site measurements are an important part of testing and commissioning, allowing the system installer to modify the proportioning if the concentration results are low or high (generally low). However the accuracy of the results from the refractive index method is poor, at best being ±0.5%; so that, for example, the foam concentration result would be 5 ± 0.5%. The inaccuracy with the refractometer arises from:

1. focusing and setting the refracted light junction on the cross hairs of the viewing window, and

2. reading the graduated scale to 4 decimal places, the scale only being graduated to 3.

Total fluorine content is a laboratory method originally derived by the 3M company for measuring the fluorine content of paper. It involves foam solution being absorbed into filter paper, dried and burnt in oxygen and the fluoride then being absorbed into solution. The fluoride ions are measured with a fluoride electrode and ion meter which can be related to foam concentration.

Optical absorption measures the attenuation of light through a sample of solution of known path length. The method does provide accurate results if the foam solutions are filtered to remove any suspended particles.

Neither the total fluorine content or optical absorption methods are suited to on-site measurement due to the technique (fluorine content) and equipment required (optical absorption).

The specific conductance method measures the electrical conductance of solutions and can be performed on site. It is a fast and accurate method. Although the conductivity meter used by this laboratory was a bench type (CDM3 from Radiometer, Copenhagen) and not truly portable, hand-held portable units are available. One unit tried (ICI Instruments 303 Conductivity Meter) has an equivalent sensitivity to the bench type used in this investigation.

Characterization Tests

Having eliminated the total fluorine content and optical absorption methods from consideration due to their unsuitability for site measurement, this laboratory conducted the following experiments to characterize the relative performance of the refractive index and specific conductance methods for determining AFFF concentration:

Variation with concentration;
Variation with salinity;
Temperature dependence; and
Sensitivity of measurement techniques.

Variation with Concentration and Salinity

Using "tap" water (Melbourne's domestic supply), "sea" water (Melbourne's Port Phillip Bay), and water to the maximum potable limit (as set by the World Health Organization using 1000 mg NaCl per liter) as bases, a number of AFFF solutions were made to cover the range 0–100% concentration. These solutions were made to an accuracy of greater than ±0.1%.

The refractive index of each solution was then measured at a temperature as close as possible to 23°C; i.e., the refractometer body was connected to a constant-temperature water bath maintained at 23°C and the laboratory temperature was controlled to 23 ± 2°C. The specific conductivity of each solution was also measured in a temperature environment controlled to 20 ± 2°C.

Tables 1, 2, and 3 contain the results of the refractive index and conductance measurements for the tap water, sea water, and maximum potable water solutions respectively. These have also be presented graphically in Figures 1 and 2 for the refractive index method and conductance method.

Table 1. AFFF foam samples—tap water.

Concentration	Refractive Index	Conductance (mS)
0.0	1.3329	0.060
3.0	1.3337	0.318
6.0	1.3343	0.558
9.0	1.3352	0.776
20.0	1.3384	1.46
40.0	1.3341	2.46
60.0	1.3496	3.18
80.0	1.3549	3.69
100.0	1.3602	4.05

Table 2. AFFF foam samples—maximum potable water.

Concentration	Refractive Index	Conductance (mS)
0.0	1.3330	1.83
3.0	1.3338	1.97
6.0	1.3349	2.13
9.0	1.3357	2.30
25.0	1.3400	2.80
50.0	1.3470	3.38
75.0	1.3537	3.75
100.0	1.3607	4.02

Table 3. AFFF foam samples—sea water.

Concentration	Refractive Index	Conductance (mS)
0.0	1.3387	41.4
3.0	1.3392	40.0
6.0	1.3397	38.4
9.0	1.3407	36.4
25.0	1.3442	29.0
50.0	1.3499	19.0
72.7	1.3549	11.2
100.0	1.3607	4.0

Temperature Dependence

The Scientific Services Laboratory then measured both specific conductance and refractive index of the tap water solutions at the nominal temperatures of 20, 25 and 30°C.

All the samples and the conductance meter probe were placed in a "Tabai" controlled environment chamber at 20.0°C for at least six hours before taking a set of results. The water bath for the refractometer had its temperature set to 20°C for the same period. The temperature of each solution was measured before reading using a thermocouple meter. This was repeated for temperatures of 25.0°C and 30.0°C.

The refractometer was calibrated originally at 25°C with a crystal of known refractive index. The refractometer was not recalibrated at the other two temperatures, the purpose being to obtain a value for the temperature dependence of the procedure for changes in temperature while measuring the refractive index of a set of solutions.

The results for both refractive index and conductance have been presented in Tables 4 and 5 and Figures 3 and 4.

Sensitivity of Measurement Techniques

The "sensitivity" of the two methods can be shown by comparing the difference between readings for solutions of 3 and 6% divided by the reading at 6%. This has been presented in Table 6, based on measurements using the tap water solutions.

To demonstrate this, the concentrations of a set of unknown solutions, made using "tap water" up to an accuracy of ±0.01%, were determined by both methods. The results are presented in Table 7. An error estimate has been produced for the foam concentration results by considering the variation in repeated readings of refractive index and conductance and converting these to percent concentration. A minimum of five separate

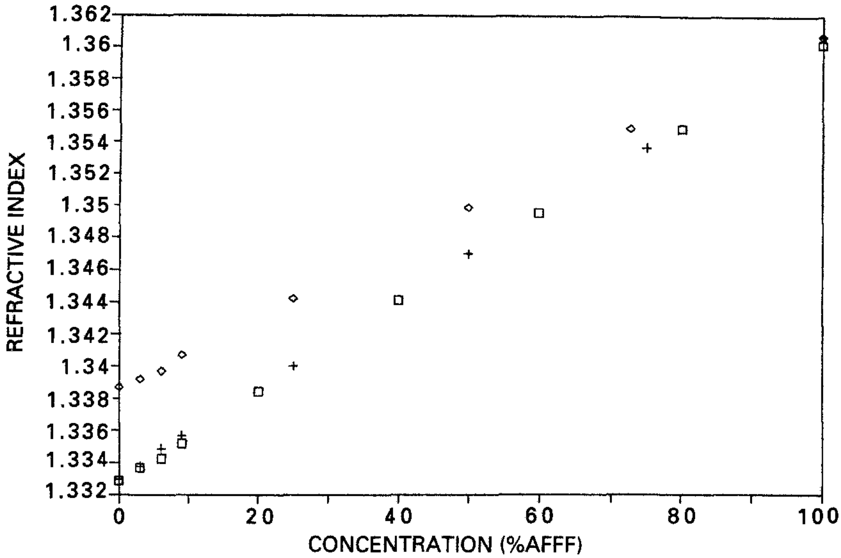

Figure 1. Refractive index versus concentration. Squares indicate tap water; crosses indicate potable water; diamonds indicate sea water.

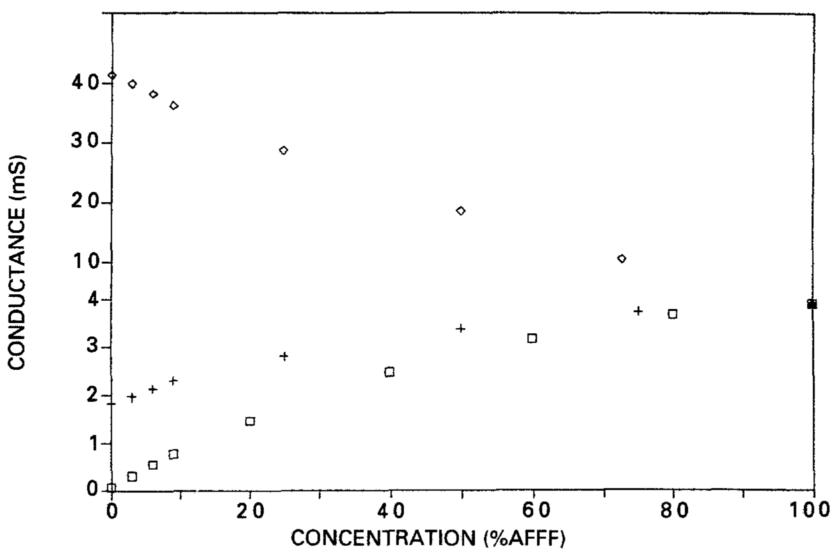

Figure 2. Conductance versus concentration. Legend as in Figure 1.

Table 4. AFFF foam samples—tap water.

Concentration	Refractive Index 20°C	Refractive Index 25°C	Refractive Index 30°C
3.0	1.3337	1.3336	1.3328
6.0	1.3347	1.3342	1.3337
9.0	1.3356	1.3350	1.3346

Table 5. AFFF foam samples—tap water.

Concentration	Conductance 20°C	Conductance 25°C	Conductance 30°C
3.0	0.292	0.325	0.373
6.0	0.503	0.554	0.598
9.0	0.677	0.773	0.828

Table 6.

	Refractive Index	Conductance (mS)
3%	1.3337	0.318
6%	1.3343	0.558
Difference	0.0006	0.240
"Sensitivity"	0.0005 (0.5 in 1000)	0.43 (430 in 1000)

Table 7.

Solution	Refractive Index	Electrical Conductance	Actual
A	4.3% ± 0.8%	3.5% ± 0.1%	3.50 ± 0.01%
B	5.1% ± 0.8%	5.5% ± 0.1%	5.50 ± 0.01%
C	8.7% ± 0.8%	8.5% ± 0.1%	8.50 ± 0.01%

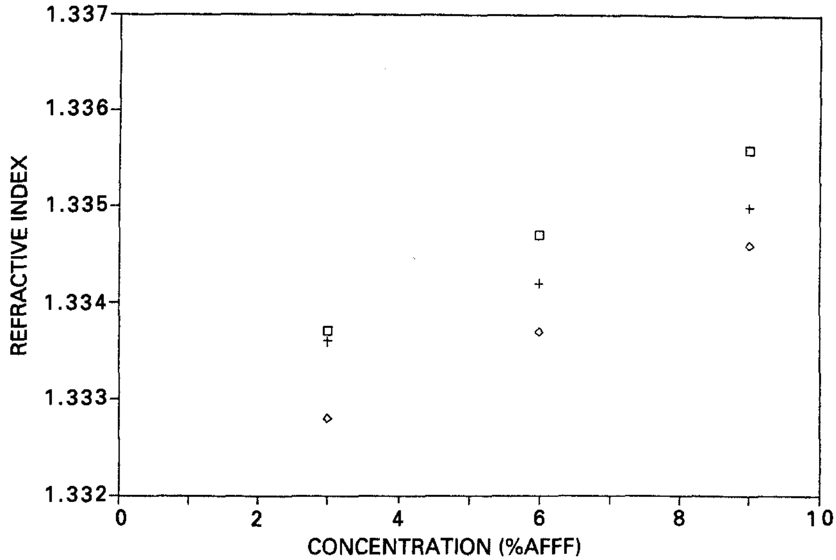

Figure 3. Refractive index versus concentration. Squares indicate 20°C; crosses indicate 25°C; diamonds indicate 30°C.

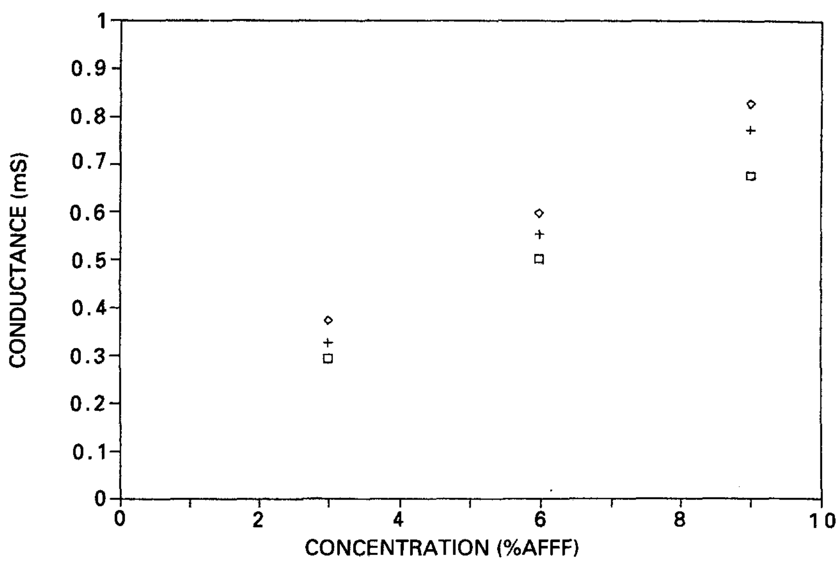

Figure 4. Conductance versus concentration. Legend as in Figure 3.

readings were performed on each solution for the refractive index measurements and twice for the conductance measurements.

Interpretation of Results

Variation with Concentration and Salinity

The results presented here are for one type of foam concentrate only. However, the trends predicted by these results should hold for different types of concentrate with different refractive indices and conductances.

The refractive index of foam solutions increases linearly with concentration for both fresh and sea water samples. (See Figure 1).

The change in electrical conductance with increasing foam concentration is not a linear function as it is for refractive index. The relationships between conductance and foam concentration are shown in Figure 2 for solutions made from fresh water, sea water, and water of the maximum potable limit set by the World Health Organization. It can be seen that the form of the relationship varies quite dramatically with different water samples. The sensitivity of the conductance method decreases as the conductance of the water base approaches that of the AFFF concentrate.

Whilst testing a foam system in the field, concentrate and water samples are taken to produce the known solutions for the calibration graph. As Figures 1 and 2 show, it is important the water samples used be representative of the water used by the suppression system. For the conductance method this is even more important, as totally inaccurate results could be obtained if other than the local water normally supplied to the suppression system is used.

Temperature Dependence

Both the refractive index and electrical conductance of foam solutions vary with temperature. Figures 3 and 4 show the temperature dependence of both methods for the sets of tap water foam solutions between 3 and 9%.

Although these methods only need to show relative differences between the solutions and it does not matter at which temperature the solutions are, it is important that they are all held at the same temperature during the foam concentration measurement. Figures 3 and 4 show that a solution of a different temperature would result in an error of 0.3% per °C for the refractive index method and 0.1% per °C for conductance. However this effect for the refractometer is somewhat reduced due to its large thermal mass.

Sensitivity of Measurement Techniques

The electrical conductance method for determining the concentration of AFFF foam samples has been shown in Table 6 to be far more sensitive to changes in concentration than the refractive index method. For foam samples made using tap water as the base, the sensitivity of the two methods were shown to be 0.5 in 1000 and 430 in 1000 for refractive index and conductance respectively. Even for foam samples made using the maximum potable water the sensitivity of the conductance method at 75 in 1000 is still greater than that of the refractive index.

The concentrations for the three unknown samples made using tap water were estimated by both methods. The result obtained by conductance predicted foam concentration to an accuracy of ±0.1%, whereas the refractive index method was only ±0.8%.

Further Work Proposed

It is proposed to compare the accuracy of these two methods for determining the concentration of other types of foam solutions such as protein, FFFP, and Alchohol Resistant types.

Preliminary work suggests that conductance maintains a similar accuracy with protein-based foams, while the accuracy of the refractive index method increases to be similar to that of the conductance method.

Conclusions

Electrical conductance provides a far more accurate method of estimating the concentration of AFFF solutions than does the refractive index method described in NFPA 11.

The temperatures of the solutions for both methods must all be the same to accurately determine the concentration of unknown solutions. An estimate of the temperature dependence of the two methods in terms of percent foam concentration are 0.3% per °C and 0.1% per °C for refractive index and conductance respectively.

Both methods require the water sample used to create the known solutions to be the same as the water used by the foam system being tested. However, due to the increased sensitivity of the conductance method, this is even more important than for the refractive index method.

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