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Is Your Foam-Water Proportioner Working Properly?

An in-depth look at NFPA 11 and 25 percent concentration testing and what you can do about it in the field

By Grant Lobdell

The Requirements

According to current, 2017 edition of the National Fire Protection Association (NFPA) 25 *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, foam proportioning equipment should be tested annually to ensure proper mixing of the foam and water according to Table 11.1.1.2 (**Table 1)**.

System/Component	Frequency	Reference
Foam-water solution	Annually	11.3.5

Table 1: A portion of Table 11.1.1.2 from the 2017 edition of NFPA 25 highlighting the foam-water solution testing frequency.

The upcoming, 2020 edition of NFPA 25 *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems* has the following requirements on the allowable percent concentrations in Chapter 11 *Foam-Water Sprinkler Systems*:

11.3.5.4 The foam concentrate induction rate of a proportioner, expressed as a percentage of the foam solution flow (water plus foam concentrate), shall be within minus 0 percent to plus 30 percent of the manufacturer's listed concentration, or plus 1 percentage point, whichever is less.

Note the title of the chapter this section is found in is *Foam-Water Sprinkler Systems*. Currently, the inspection, testing and maintenance (ITM) of other types of foam-water systems falls under NFPA 11 *Standard for Low-, Medium-, and High-Expansion Foam* but the requirement is the same. Chapter 11 *Testing and Acceptance* of the current, 2016 edition of NFPA 11 states the same requirements as NFPA 25:

11.6.4 The foam concentrate induction rate of a proportioner, expressed as a percentage of the foam solution flow (water plus foam concentrate), shall be within minus 0 percent to plus 30 percent of the manufacturer's listed concentration, or plus 1 percentage point, whichever is less. For information tests for physical properties of foam, see Annex D.

While it is true this requirement is technically only for the testing and acceptance of the foam systems as it currently reads in the 2016 edition of NFPA 11, the technical committee for this standard is currently considering adding the following verbiage to Chapter 12 *Maintenance* to the upcoming, 2021 edition:

12.2.3 Proportioning equipment shall be tested annually in accordance with 11.6.

If this verbiage makes it through the 2nd draft process and does indeed appear in the 2021 edition of NFPA 11, both NFPA 11 and 25 will clearly state proportioning equipment needs to be checked for proper mixing annually and both will have the same requirements.

Deciphering the Requirements

Minus 0%

According to both NFPA 11 and 25, the proportioning equipment needs to be mixing the foam at least at its listed concentration (i.e. minus 0%). The foam is not typically tested below its listed concentration when certified and therefore little is known about the performance of the foam below that concentration. As a result, NFPA is not comfortable with a foam being used at a level not listed or approved. This means if a foam is listed as a 3% AFFF, at minimum, it should be used at 3%. It should not be used at 2.9% or lower.

<u>Plus 30 percent or plus 1 percentage point, whichever is less</u>

In a perfect world, the foam concentrate would be mixed at exactly its listed concentration but this can be extremely difficult to achieve. Slight variations in the variables that affect the proportioning equipment performance will result in a percent concentration off from the desired, listed concentration. While it is clear that the foam should not be used below its listed percent concentration, NFPA does allow you to use it slightly above it. NFPA allows your system to mix at maximum 30% beyond its listed percentage OR 1 percentage point, whichever is less. The small increase in the amount of foam will only improve performance but not be enough to deplete your stock of foam concentrate too quickly.

For example, consider a foam listed at 3%. A 30% increase to 3 is 3.9%. This is below a full percentage point (which would be 4% in our example) so that is our maximum. A 3% foam must be mixed at a percentage rate between 3% and 3.9%.

Now consider a foam listed at 6%. A 30% increase to 6 is 7.8. However, NFPA is stating, at maximum, you can only go as high as 1 percentage point (which would be 7% in our example) above the listing. Therefore, a 6% foam must be mixed at a percentage rate between 6% and 7%.

Table 2 highlights some of the more common listed percent options of foam concentrates and the allowed induction rates per NFPA 11 and 25.

Foam Concentrate's Listed Percent	Allowed induction rates per NFPA 11 and 25 (%)
1	1.0 - 1.3
1.5	1.5 - 2.0
2	2.0 - 2.6
2.2	2.2 - 2.9
2.75	2.75 - 3.6
3	3.0 - 3.9
6	6.0 - 7.0

Table 2: The allowed induction rates per NFPA 11 and 25 for various common foam concentrate percentages.

<u>Collecting a solution sample</u>

When collecting a sample of the foam-water solution produced by your proportioning equipment, ensure the system is being run as designed. Failure to use the equipment as designed, such as running the system at a very low flow to avoid the hassle of any required cleanup, may result in improper equipment performance. Also ensure the sample is collected after the system has been allowed to run for some time and reach a steady state. The flow and, as a result, the percent concentration of the produced foam may vary immediately after the system is turned on for some time.

Note that you do not necessarily need to collect a foam-water solution to complete this test. According to the 2017 edition of NFPA 25:

11.3.2.3 Where discharge from the system discharge devices would create a hazardous condition or conflict with local requirements, an approved alternate method to achieve full flow conditions shall be permitted.

The 2016 edition of NFPA 11 has a similar statement:

11.6.3 The foam proportioning system shall be permitted to be tested with a listed or approved method that does not require discharge of foam concentrate. (See Annex D.)

Section D.5.2 in Annex D of the 2016 edition of NFPA 11 goes into further detail on these methods. One option is to use a surrogate liquid – a liquid that is a non-foaming, environmentally acceptable liquid with similar physical flow characteristics as foam concentrate – or by simply using water. According to Section D.5.2 in Annex D of the 2016 edition of NFPA 11:

Both methods employ portable data acquisition instrumentation and software to enable fast, real-time data monitoring and recording. Typically measurements include conductivity (translates to percent injection rate) of the proportioned solution stream, system flow rate, and several pressures on the proportioning system. Conductivity and flow are measured by means of in-line electronic instrumentation installed in flow meters that are placed on the test outlet side of the proportioning system. Pressure transducers are installed temporarily at strategic locations where measurements are desired.

More information on these methods can be found in this annex section.

Note that there are methods that have been evaluated by 3rd parties (i.e. listed or approved). The Planit Safe™ process offered by Vector Fire Technology, Inc., is an example of a listed or approved method utilizing a surrogate test liquid. Foam Solutions LLC™ is a company that has a listed or approved method utilizing water equivalency.

Determining percent concentration of foam in the foam-water solution

According to Annex D of the 2016 edition of NFPA 11, specifically D.2 *Foam Solution Concentration Determination*, there are two ways to determine the percentage of foam in water: by refractometery or by conductivity. Similarly, according to the 2017 edition of NFPA 25:

11.3.5.3 The foam sample shall be inspected by refractometric or other methods to verify concentration of the solution.

There are advantages and disadvantages of each method. The main advantage of conductivity is its accuracy. However, conductivity will not work for solutions made with brackish or sea water. The salt content in these solutions is too great. Note when using conductivity as a means to measuring the concentration of foam, the measurement should be completed the same day as the system solution is generated as the conductivity can change over time.

Note that according to Annex D.5 *Foam Injection Rate Tests* of the 2016 edition of NFPA 11, solution concentration can also be calculated from solution and concentrate flow rates.

Special consideration when choosing refractometery over conductivity

Note that many hand held refractometer units only offer a resolution of 0.0001. This may not be enough to sufficiently differentiate foam-water solution samples of varying degrees of concentration if the concentrate used to make them is diluted or is designed with a fairly low refractive index (RI<1.35). The meter may produce the same reading over a wide range of % concentrations. A refractometer with a resolution of 0.00001 is often preferred if refractometery is used but is generally only available in an expensive, benchtop refractometer such as the one utilized by Dyne Fire Protection Labs.

To visualize this phenomenon, imagine a policeman sitting on the side of the road scanning the cars going by to catch people travelling above the posted 60 MPH speed limit. If his scanner only read the tens digit (10, 20, 30, 40, 50, etc.) and he scanned someone at 60 MPH, were they speeding? Well, they could be going anywhere from 55 MPH to 64 MPH assuming the meter uses normal rounding rules. There are just as many speeds (55-59 MPH) that would be acceptable as there would be (60-64 MPH) unacceptable. To figure out if the car is speeding, the instrument used needs to have a better resolution – it needs to read out to the ones place (10, 11, 12, 13, 14, etc.). With this resolution, the officer is able to determine the speed needed to properly enforce the speed limit. The car that was clocked at going 60 MPH with the instrument with less resolution may only be clocked at 58 MPH with the instrument with more resolution. One result is acceptable, the other is not.

This same situation occurs with scientific instruments. The instrument used must have enough resolution to properly evaluate the requirement set. For refractometers used for foam-water concentration testing, a resolution of 0.00001 is needed in some cases to truly determine acceptability.

The theory behind the refractometery and conductivity for measuring foam concentrate percentage in water

Imagine a number line from 0% to 100% as shown in **Figure 1**.

Figure 1: Number line illustrating all possible values between 0% and 100%.

A 0% foam-water solution is just water. A 100% foam-water solution is your foam concentrate. Your foam-water solution must fall somewhere on this number line as illustrated in **Figure 2**. You can't have less foam than water or more foam than your foam concentrate.

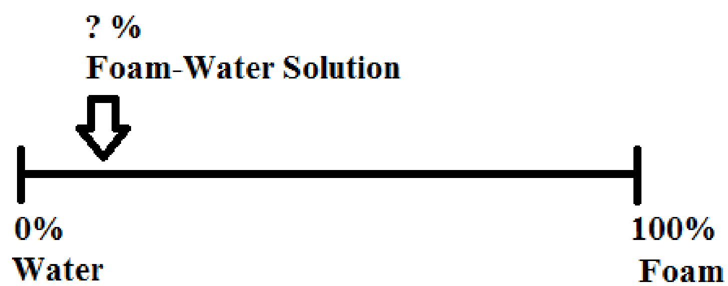


Figure 2: Visual representation of the problem field technicians are faced with.

Where does the foam solution sample fall between 0 and 100%? To determine this, refractometery or conductivity will be used to figure out where the foam solution falls on the number line. For this example, refractometery results will be considered but the same analysis process applies for conductivity. The numbers will just be slightly different.

Water (0%) typically has a refractive index of 1.3330. The foam concentrate (100%) and solution (% unknown) for this example will have refractive index of 1.3630 and 1.3339. These values would be determined via a refractometer. **Figure 3** shows the number line now represented by these refractive index measurements.

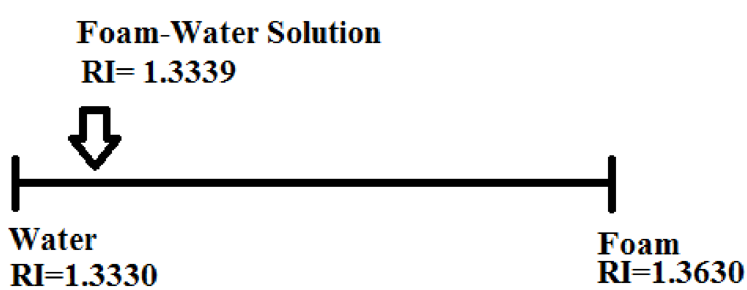


Figure 3: Number line illustrating an example of a foam solution being analyzed by refractive index.

Because the exact location of the foam-water solution on the number line is now known, the percent concentration can be determined. If 1.3330 = 0% and 1.3630 = 100%, then each percent increase from the water is equal to a refractive index increase of 0.0003. If we increase our water to a 1% solution based on this analysis, the RI would be expected to be 1.3333. A 2% solution would be 1.3336 and a 3% solution would be 1.3339, which is what was measured in the example. The example solution would have a percent concentration of 3%.

This example worked out well but that is because of the values chosen for the example. In most cases, the numbers will not work out so conveniently. Consider a foam-water solution with a refractive index of 1.3334, for instance, and try to run through the same math as before – it gets messy very quickly (the percent is somewhere between 1% and 2%). As a result, it is better to not visualize the results on a number line alone, but to utilize a graph. These results can be plotted on a graph and a linear regression (a mathematical expression to define the graph) can be used to obtain an equation to make a conversion for any input as shown in **Figure 4**. This linear regression will make it much easier to convert the less convenient results without hassle.

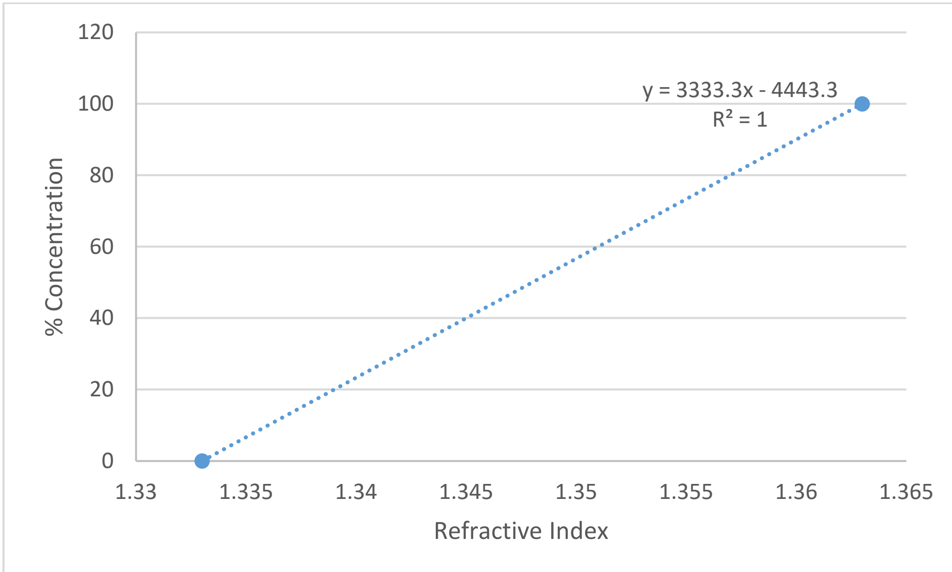


Figure 4: The results of the example water and foam concentrate represented graphically.

The linear regression equation is determined to be *% concentration = 3333.3 x (refractive index) – 4443.3* for this example simply using our Excel or other similar software with graphing capabilities. Note the *x* in the equation shown on the graph represents the x axis which we have defined as refractive index – be very sure to understand what your variables represent as it is possible to graph these results with the x and y axis flipped. If we plug in the refractive index of our solution into the equation, it will determine the percent concentration. For the foam-water solution example of 1.3339, the equation does indeed calculate the percent concentration to be 3%. Given a concentrate refractive index of 1.3334, the result can still be obtained with the same amount of effort as the 1.3339 solution. Simply plug in the value and calculate it. A solution with a refractive index of 1.3334 made from the concentrate and water given as an example would have 1.3% foam concentrate in solution.

<u>How this analysis can be done in the field</u>

The use of graphical software with linear regression tools may not be available to you in the field. Luckily, the result can also be estimated visually without the need for the linear regression equation as illustrated in **Figure 5**.

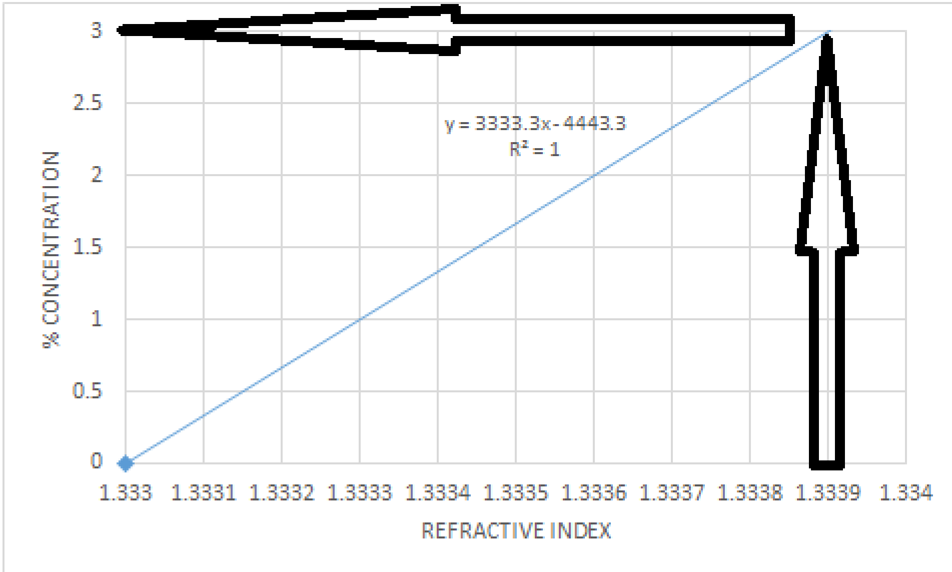


Figure 5: Demonstrating how the percent concentration of can be estimated visually.

Notice how far the graph in **Figure 5** is zoomed in compared to **Figure 4**. Both the X and Y axis of the graph have been decreased considerably to visually see the area of interest. The area of interest is just a very small portion of the graph shown in **Figure 4**. To visually estimate the percent concentration, a graph of appropriate scale must be used. As a result, if the line will used in the field to visually estimate percent concentration in the absence of electronic graphic programs, the points plotted of known concentration and refractive index or conductivity will need to be represented in the area of interest. The area of interest for this testing is the allowed pass range as shown in **Table 2**. Not only does this allow the visual estimation of percent concentration but it also reduces error from interpolation.

<u>Creating Standard Solutions</u>

To determine the refractive index of solutions of known concentration solutions on the pass/fail line you will need to have solution mixed at those appropriate percentages. For instance, for a 3% foam concentrate, solutions of 3% and a 3.9% foam concentrate will need to be obtained and measured to produce the line for the graph. These solutions will need to be made by hand. The following is an example of a procedure similar to Annex D.2.1.2.2 of the 2016 edition of NFPA 11.

Determining Percent Concentration of Foam in Foam-Water Solution in the Field

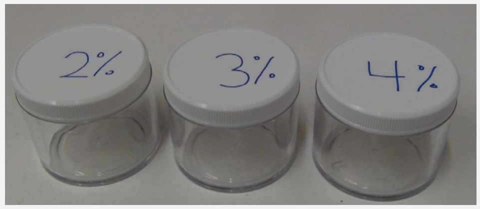
Equipment:

- Four 4 oz. jars with caps, or equivalent
- One 10 cc syringe
- One 100 mL graduated cylinder
- Three plastic-coated magnetic stirring bars
- Conductivity Meter (or refractometer)
- Plastic pipette
- Graph paper/excel

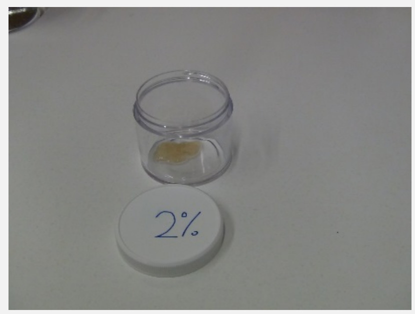
Procedure:

A. Mixing up the standard solutions:

1. Three standards should be mixed in order to create a calibration graph. The 3 standards should include the nominal intended percentage of injection, the nominal percentage plus 1 percent and the nominal percentage minus 1 percent.
   For example: for a 3% proportioned sample, you should create control % of 2, 3, and 4. For a 6% proportioned sample, you should create control % of 5, 6, and 7. For a 1% proportioned sample, you should create control % of 0, 1, and 2.
2. Mark each bottle with the percent solution it will contain.



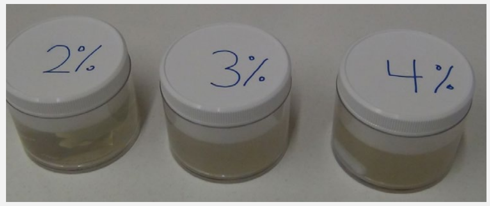
3. Acquire a sample of system water to use for making up the standards.
4. Acquire a sample of foam concentrate from the system you are testing. For best results when testing from a bladder tank, acquire a sample of foam from the top of the tank, near where the proportioner pulls the concentrate.
5. Carefully measure the foam concentrate using the 10 cc syringe. Collect the mL that coincides with the % concentrate of that standard. Use care not to pick up air in the foam concentrate samples.
   For example: For a 2% Standard, use 2 mL of concentrate

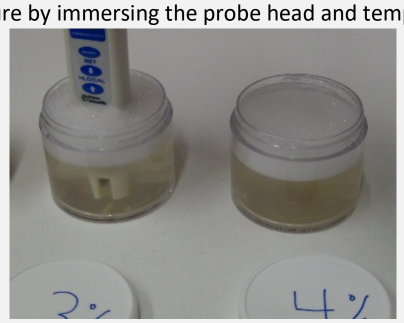
6. Place the concentrate into the appropriate marked jar.
7. Pour the system water in the 100 mL graduate, to figure out how much water to put in each graduated cylinder, use the following equations: 100 mL – Foam Concentrate mL = mL of water. Use a plastic pipette to get the correct amount of water.
   For example: For a 3% standard, 100 mL – 3 mL = 97 mL of water.

8. Pour the measured system water into the appropriate marked jar.
9. Add a plastic stirring bar to the bottle, cap it, and shake it thoroughly to mix the foam solution.

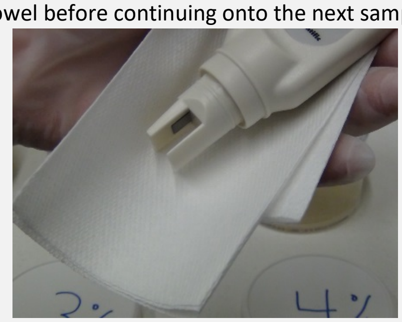

10. Repeat steps 5-9 until all three solutions are created and mixed.



B. Measuring the Solutions with the Conductivity Meter:
1. Remove the protective cover from the probe head.
2. Turn the meter on by pressing the (ON/OFF) button.
3. Place the probe head in the solution to be mixture by immersing the probe head and temperature sensor completely.

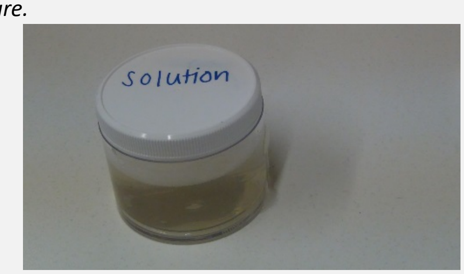


4. Swirl the probe to insure there is adequate movement of the liquid around the tip of the probe head. The temperature sensor must reach equilibrium with the liquid being measured, this could take some time.
5. Record the reading
6. Make sure to wipe off the probe with a paper towel before continuing onto the next sample.



C. Creating Calibration Curve
1. The conductivity readings should be plotted on graph paper. It is best to have the foam standards (%) on the horizontal axis and the conductivity (microsiemens) on the vertical axis. This can be done manually on graph paper or utilizing a graphical program.
2. If the graph does not appear to be straight, or has an R squared value of less than 0.9, repeat the steps in sections A-C to create a new calibration curve to ensure accurate results.

D. Sampling and analysis
1. Collect foam solution from the proportioning system using care to make sure the sample is taken at an adequate distance downstream from the proportioner being tested.
Note: Using foam solution samples that are allowed to drain from expanded foam can produce misleading conductivity readings and therefore not recommended for this procedure.



2. Once one or more samples have been collected, read their conductivity and find the corresponding percentage from the base curve prepared from the control sample solutions.

<u>What if the foam solution is not mixed correctly?</u>

The following is a list of the more common reasons a system may not be proportioning correctly:

<u>Incorrect solution flow</u>

When the sample was taken, the system may have not been flowing within its rated flow range or for the time required for the system to stabilize. All proportioning systems, whether a bladder tank, pump system, or educator, are designed to proportion foam correctly but only when operated at a specific flow range. Many times, inspectors run the system at a low flow for a short time in order to generate less foam solution - which is often costly to dispose of. If this flow is below the rated flow range or if the system has not operated for a long enough time to stabilize, a system will not proportion correctly. To determine the rated flow range and suggested flow time, contact the manufacturer of the proportioning equipment or refer to the foam's listing agency directory (e.g. UL) for the listed flow range.

<u>Foam concentrate in the lab is not representative of what was used in the field</u>

The most common way to determine the percent of foam concentration in solution is to measure the solution's refractive index or conductivity and compare the values to those of standard solutions that are made by mixing the foam concentrate and water at known concentrations. Note that NFPA recommends conductivity in the field due to equipment limitation but the refractive index method is allowed provided the instrument used has enough accuracy to determine solution differences. For IMO solutions that use salt water, the conductivity method will be unreliable due to the salt's extremely conductive properties. Dyne utilizes the refractive index method to determine solution concentration with a laboratory grade refractometer.

When using either method, the foam concentrate and water used to make the standard solutions MUST be representative of the foam concentrate and water proportioned by the system. For example, a bladder tank generally proportions foam by expelling concentrate from the top of the tank. If the foam concentrate samples used to make the standard solutions are pulled from the bottom of the tank, the standard solutions might not be representative of system solution. Similarly, water taken from the shell of the bladder is not representative of the system water that is used to by the proportioner.

<u>Improper concentrate and water pressures</u>

Different systems have varying requirements for the balance between the pressures of the concentrate line and the water line into the proportioner. Systems using a bladder tank require that these pressures are equal, while systems using a pump may have different requirements. If the foam or water pressures are unequal, the resulting solution could have too much foam or too much water. The manufacturer would be able to answer questions about these pressures for your specific equipment.

<u>Equipment and foam compatibility issues</u>

The foam concentrate used in the system should be listed for use with the equipment as recommended by NFPA 11. When a foam and equipment are listed together, it ensures the user that the system was tested by an independent laboratory and the system proportioned that specific foam correctly. There may be cases where the foam has been changed to handle a new hazard. If the new foam is more or less viscous than the previous foam, the orifice may not be sized correctly. Again, check with the equipment manufacturer to make sure the equipment is listed with the specific foam concentrate.

There can be other reasons in addition to those listed here that may cause a system to proportion incorrectly. Training is highly recommended for any technician performing and troubleshooting proportioning tests. To better understand your specific system, it is recommended that you contact the equipment manufacturer.

If you have any questions regarding this article or would just like more information, please contact Dyne Fire Protection Labs at lab@dyneusa.com or (800) 632-2304.