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16. Abstract

The Evaluation of Input-Based Foam Proportioner Testing Systems research effort was initiated to examine the viability and accuracy of input-based methods for confirming foam proportioner system functionality on aircraft rescue and firefighting (ARFF) vehicles. Output-based tests were conducted using test methods defined in National Fire Protection Association 412, "Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment." Input-based tests were performed according to manufacturer guidelines.

Output-based test results showed a small variation in measured proportioning percentage between different discharges and between different measurement methods. An error range was used to determine the accuracy of the input-based systems compared to output-based tests. The error range was based on the measurement error of the digital refractometer device used and the measured concentration of the discharge sample for each output test. If the results from an input-based testing method fell within this range, it was considered to correlate to the output-based results for this research effort.

Overall, a greater correlation and testing accuracy exists at a 3% proportioning rate than at a 6% proportioning rate. Similarly, there is a greater correlation when using electronic proportioning systems than when orifice plate proportioning systems are used with input-based proportioning test methods. This is thought to be as a result of the system's ability to dynamically respond to any operational variations (e.g., pump pressure or flow rate). All testing was conducted using around-the-pump proportioning systems, and conclusions may not be applicable to other types of foam proportioning systems.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AFFF	Aqueous Film Forming Foam
ARFF	Aircraft rescue and firefighting
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
GFCI	Ground fault circuit interrupter
GPM	Gallons per minute
HRET	High-reach extendable turret
Mil-Spec	Military Specification
nD	Refractive Index
NFPA	National Fire Protection Association
PANYNJ	Port Authority of New York and New Jersey
PFOS	Perfluorooctane sulfonate
PFOA	Perfluorooctanoic acid
WJHTC	William J. Hughes Technical Center

EXECUTIVE SUMMARY

The Evaluation of Input-Based Foam Proportioner Testing Systems research effort was initiated to examine the viability and accuracy of input-based methods for confirming foam proportioner system functionality on aircraft rescue and firefighting (ARFF) vehicles. The input-based systems that the testing specifically focused on were E-ONE® ECOLOGIC® and the NoFoam System. Both systems function using similar principles: by replacing the Aqueous Film Forming Foam (AFFF) concentrate with a substitute and measuring its flow—although the method of measurement is different between the two systems. These evaluations used two Federal Aviation Administration (FAA) ARFF research vehicles with differing proportioning technologies. Each test scenario used the same operational conditions for both input- and output-based tests. Output-based tests were conducted using test methods defined in National Fire Protection Association (NFPA) 412, "Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment." Input-based tests were performed according to manufacturer guidelines.

Output-based test results showed a variation in measured proportioning percentage between different discharges and between different methods of measurement. The measurement methods used were conductivity measurement, refractive index measurement, and Brix measurement. The observed variation was more pronounced on orifice plate proportioner systems, while electronic proportioning systems showed less variation. To determine correlation between results of input- and output-based test methods, an error range was established based on the accuracy of currently accepted output-based test methods. The results of input-based proportioning test methods were found to correlate with output-based results if they were within the established error range. This calculation only considered the standard methods and configuration of each input-based system at the time of this research effort.

For the ECOLOGIC system, testing was performed before and after output-based testing on the FAA ARFF research vehicle equipped with an orifice plate-type proportioning system. This was to check for any variations in proportioning rate as a result of physical changes in the vehicle, such as the removal and re-installation of orifice plates. Testing was performed at 3% and 6% proportioning rates on plate and electronic proportioner systems.

For the NoFoam system, tests were performed using alternative system configurations in addition to testing the system in the standard configuration. These included the use of viscosity-modified fluid, variations in tank level, and multiple measurement methods. This was to check for any changes in accuracy when using these alternative configurations. Testing was performed at 3% and 6% proportioning rates on plate and electronic proportioner systems.

In addition to the two systems tested at the William J. Hughes Technical Center (WJHTC), testing of the Oshkosh® EcoEFP™ system was observed at an Oshkosh facility in Oshkosh, Wisconsin. This testing consisted of output-based testing as well as input-based testing using the EcoEFP system on a modified Oshkosh Striker© 6x6. Testing was repeated by the ARFF research team at the Port Authority Fire Training Facility at John F. Kennedy International Airport using an unmodified Oshkosh Striker 6x6 with output-based testing methods that

matched those used at the WJHTC. Testing was performed only at a 3% proportioning rate using the Oshkosh electronic foam proportioning system.

Overall, input-based test results correlated to output-based results in 64% of tests. The correlation rate of input-based test results to output-based test results was primarily affected by the proportioning rate and the type of proportioning system. Input-based tests had a greater correlation at a 3% proportioning rate than at a 6% proportioning rate. For tests conducted at a 3% proportioning rate, input-based results correlated in 83% of cases. At a 6% proportioning rate, only 48% of input-based tests correlated to output-based results.

Input-based test results showed a smaller variation based on the type of proportioning system than on the proportioning rate. Input-based results with an electronic proportioning system showed correlation in 76% of tests. Results using an orifice plate proportioning system only showed correlation in 61% of tests. At a 3% proportioning rate, electronic foam proportioning systems had a correlation rate of 91% compared to 79% for an orifice plate proportioner system. At a 6% proportioning rate, electronic proportioning systems had a correlation rate of 58% compared to 46% for an orifice plate proportioner system. The input-based systems in all cases demonstrated significant repeatability, even if they did not always correlate to output-based tests. Confirmation testing performed at the time of delivery and installation that compares input- and output-based tests may help offset this difference by establishing reference values that represent the current state of the vehicle. With this approach, substantial deviations from the reference value in future measurements can indicate changes in the operating condition of the vehicle. It is highly recommended that airports utilizing the 6% foam proportioning rate have the vendor perform the confirmation testing at the time of delivery.

In general, a greater correlation and testing accuracy exists at a 3% proportioning rate than at a 6% proportioning rate. Similarly, there is a greater correlation when using electronic proportioning systems than with orifice plate proportioning systems used with input-based proportioning test methods. This is thought to be as a result of the system’s ability to dynamically respond to any operational variations (e.g., pump pressure or flow rate). All testing was conducted using around-the-pump proportioning systems, and conclusions may not be applicable to other types of foam proportioning systems.

1. INTRODUCTION

Aqueous Film Forming Foam (AFFF) is the primary firefighting agent used in extinguishing Class B liquid-fuel pool fires. AFFF is an aqueous solution made by mixing AFFF concentrate with water at the specified proportion. AFFF concentrate is available in both 3% and 6% formulations, which denotes the appropriate mixing ratio with water. The solution is either premixed and stored or made on demand using a foam proportioning system. AFFF creates a film on the surface of a liquid hydrocarbon that envelopes the liquid between itself and the ground. This film prohibits the liquid from releasing the flammable, gaseous vapors that allows a pool fire to burn, while simultaneously prohibiting oxygen from reaching the vapors. This effectively extinguishes the fire as well as provides a barrier against reignition. Because AFFF is a liquid, the film can flow easily and re-envelope the liquid hydrocarbon if the layer is disturbed.

AFFF contains surfactants, which allow it to have a low surface tension and film-forming properties. The Environmental Protection Agency (EPA) has guidelines regarding the maximum allowable environmental concentration of certain components of AFFF and recommends minimizing releases of AFFF [1]. The fluorinated surfactants' byproducts are the main chemical type that causes concern, because they were discovered to be toxic and environmentally persistent.

National Fire Protection Association (NFPA) 412, "Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment," dictates the criteria for aircraft rescue and firefighting (ARFF) vehicle performance and testing, including foam proportioning systems [2]. An addition to the 2014 edition of NFPA 412, Section 6.2.4, allows the foam proportioning system to be tested using input-based rather than output-based methods. Output-based testing methods involve using actual AFFF to test the ARFF vehicles foam proportioning performance. Once discharged, an AFFF sample is collected and measured using a refractometer or conductivity meter. Input-based testing uses an AFFF concentrate substitute to measure the foam proportioning system's performance. The AFFF substitute flow rate is measured as the discharges are flowing; since the discharges need to be flow tested, they are flowing at a known rate. Using both of these values and basic math, the performance of the system can be confirmed to be in compliance with NFPA 412 [2]. Input-based testing does not use any AFFF concentrate when testing the proportioning system, eliminating the need for expensive cleanup and environmental harm.

1.1 BACKGROUND

AFFF concentrates contain fluorinated surfactants that historically are made by one of two processes: telomerization and direct electrochemical fluorination [3]. Perfluorooctane sulfonate (PFOS) is found in AFFF concentrate, which is made by using direct electrochemical fluorination. Products containing PFOS were voluntarily removed from the market because of their toxicity and environmental persistence. Telomerization, the current standard for AFFF surfactant manufacturing, produces alternate fluorinated surfactants with similar film forming properties, generally referred to as fluorotelomers. The main difference between the surfactants made in these processes is that fluorotelomers are not entirely fluorinated, and therefore less toxic [3]. Early fluorotelomer-based foams had a primary molecular chain length of 8 carbon atoms (referred to as C8), while still containing homologous molecules of C4, C6, C10, and C12 chain lengths. These fluorotelomers degrade into perfluorooctanoic acid (PFOA) under certain conditions [3]. PFOA, similar to PFOS, is highly toxic and environmentally persistent, and therefore, it is classified as a possible carcinogen by the EPA. Recent advancements have allowed for the development of substantially pure C6 length fluorotelomers, which cannot degrade into PFOA and are less toxic than C8 fluorotelomers [3]. However, C6 fluorotelomers are still environmentally persistent. As a result of the fluorinated surfactants similarity, the EPA scrutinizes the use of AFFF. The EPA recommends minimizing discharges of AFFF due to possible environmental effects, and as a result, state environmental agencies are providing additional guidelines regarding release and containment of AFFF [1]. These restrictions and guidelines makes testing the foam systems found on ARFF vehicles potentially expensive and environmentally hazardous.

The Federal Aviation Administration (FAA) requires annual testing of ARFF vehicles' foam proportioning system performance as dictated in NFPA 412 [2]. Until recently, foam system testing required AFFF to be discharged from the ARFF vehicle, referred to as output-based testing. However, NFPA 412 Section 6.2.4 [2] permits the use of input-based test methods for testing foam proportioning systems. This test method does not require AFFF concentrate to be used in proportioning testing; instead a substitute is used, typically water or water containing a dye for visual aid. For input-based testing to be effective, the flow rates of each discharge must be in compliance with NFPA 414 [4] and known values. This allows for a calculation to be made to determine if the foam proportioning system is operating properly and in accordance with NFPA 412 standards [2]. The basis for input-based testing relies on measuring the amount of AFFF concentrate substitute that is drawn through the pump system. The flow rate of AFFF concentrate is directly proportional to the rate of water being discharged. NFPA 412, section 5.2, specifies the acceptable range a proportioner must be within to meet the performance requirements [2]. Table 1 shows these ranges for each nominal proportioning percentage [2].

Table 1. Acceptable Proportioning Ranges for AFFF per NFPA 412

Nominal Proportioning Percentage (%)	Primary Turret Acceptable Range (%)	Hand Line and Under Truck Nozzle Acceptable Range (%)
1	1.0 - 1.3	1.0 - 1.3
3	2.8 - 3.5	2.8 - 4.0
6	5.5 - 7.0	5.5 - 8.0

NFPA 412 specifies that in addition to proportioning testing, foam quality tests must also be performed as they are required to ensure the AFFF concentrate is still performing to its potential and is within its operational specifications [2]. The foam quality tests include expansion ratio and 25% drainage time. Expansion ratio is the ratio between the volume of foam produced and the volume of solution used in its production. Quarter life, or "25% drainage time", is the time in minutes that it takes for 25% of the total liquid contained in the foam sample to drain from the foam. These tests are not able to be performed using input-based test methods. This means that AFFF must still be discharged for these tests. Both of these tests can be run in the same trial, drastically reducing the amount of AFFF required.

1.2 PURPOSE

Present output-based foam proportioner testing methods require discharging the AFFF into the environment, which has both financial and environmental impacts. AFFF is not discharged into the environment with input-based testing, eliminating part of the financial strain and all of the environmental concerns in foam proportioning testing. The purpose of this research effort is to determine if input-based testing is a viable and accurate alternative to the output-based method, as well as determine any benefits or disadvantages.

2. OBJECTIVES

The objectives for this report were to:

- determine the accuracy and repeatability of input-based foam proportioner testing.
- compare the results of input and output-based testing to determine if input-based testing is a viable alternative.
- determine the advantages and disadvantages of each method.

3. EQUIPMENT AND MATERIALS

This section describes the equipment and materials used in the scope of this research effort. This covers equipment both for output-based testing and evaluation of input-based methods.

3.1 TEST SITES

Testing was conducted at the outdoor ARFF test facility at the William J. Hughes Technical Center (WJHTC), as shown in figure 1. This facility has a drainage culvert with hazardous material storage tanks that collected any discharged AFFF for proper disposal. As a result of tank capacity limitations, testing was performed over multiple days.

Figure 1. The FAA Outdoor Fire Test Facility

Oshkosh® EcoEFP™ system testing was performed by Oshkosh engineers at an Oshkosh facility in Oshkosh, Wisconsin and observed by the ARFF research team. Additional testing of the EcoEFP system was performed by the ARFF research team and Port Authority personnel at the Port Authority Fire Training Facility at John F. Kennedy International Airport.

3.2 TEST VEHICLES

The ARFF vehicles used for testing at the WJHTC were FAA ARFF research vehicles. The first was a 1992 E-ONE® Titan™ 4x4 equipped with a Snozzle 501 high-reach extendable turret (HRET) and Feecon® Around-the-Pump proportioning system with an orifice plate, as shown in figure 2. The second was a 2005 Oshkosh Legacy Striker® 3000 equipped with a Snozzle® 651 HRET and Nordic Systems Corp. Foam Boss® electronic proportioning system, as shown in figure 3. In this report, these two vehicles are referred to by their call signs: “Crash 9” for the E-ONE Titan and “Crash 5” for the Oshkosh Striker.

Figure 2. The 1992 E-ONE Titan 4x4 FAA ARFF Research Vehicle “Crash 9”

Figure 3. The 2005 Oshkosh Legacy Striker 3000 FAA ARFF Research Vehicle “Crash 5”

Oshkosh EcoEFP system testing was performed using two Oshkosh Striker 6x6’s. One vehicle model was modified by Oshkosh engineers to include an external foam tank, tank level indicator, and electrical connections for additional data collection. The other vehicle was an unmodified

Oshkosh Striker 6x6 with a Snozzle R65 HRET, which was owned and operated by the Port Authority of New York and New Jersey (PANYNJ).

3.3 OUTPUT-BASED TESTING EQUIPMENT

A digital refractometer and conductivity meter were used for output-based testing of the proportioning rate as per NFPA 412 [2]. Both provide a reading that when compared to a hand-mixed bench sample, can determine the amount of AFFF concentrate in the AFFF solution. The refractometer uses light refraction to measure the concentrate ratio, while a conductivity meter measures the electrical conductivity of the AFFF solution to determine its concentrate ratio. Chemguard® Military Specification (Mil-Spec) AFFF C306-MS and C606-MS foam concentrates were used for the 3% and 6% proportioning rates, respectively, during testing at the WJHTC.

A digital refractometer was selected for the purpose of this research effort to eliminate any user bias inherent to the use of an analog refractometer. An analog refractometer produces a line set against an analog scale, requiring the user to take the measurement. The perceived position of this line can change based on the user’s alignment with the viewing window, causing measurement errors. The digital refractometer produces the measurement value on a liquid-crystal display to eliminate user bias in readings. For these tests, a Misco® PA202 digital refractometer was used, as shown in figure 4. The Misco PA202 has a range of 1.3330-1.5000 for refractive index, with a resolution of 0.0001 units. The range for Brix measurements is 0-85, with a resolution of 0.1 units. Similar analog measurement devices can measure similar ranges, but at the cost of precision given the restrictions of the physical markings on the device.

Figure 4. Misco PA202 Refractometer

The conductivity meter is a Traceable® 4169 Dual-Display, as shown in figure 5. This model has user-selectable ranges, as well as automatic temperature compensation. The meter’s calibration procedure was performed before each round of testing.

Figure 5. Traceable 4169 Dual-Display Conductivity Meter

NFPA 412 also requires a minimum of three graduated cylinders, at least six clean beakers, and clean measuring pipettes [2]. The graduated cylinders are necessary for preparation of the control samples, while the beakers are required for the AFFF sample collection. A foam sample collector is also required to collect the sample from the vehicles' discharge. The sample collector is an angled metal plate on a stand, with two to four "guides" that act as funnels for the graduated cylinders underneath. A diagram of a foam sample collector is shown in figure 6 [2]. Figure 7 shows the foam sample collector in use at WJHTC.

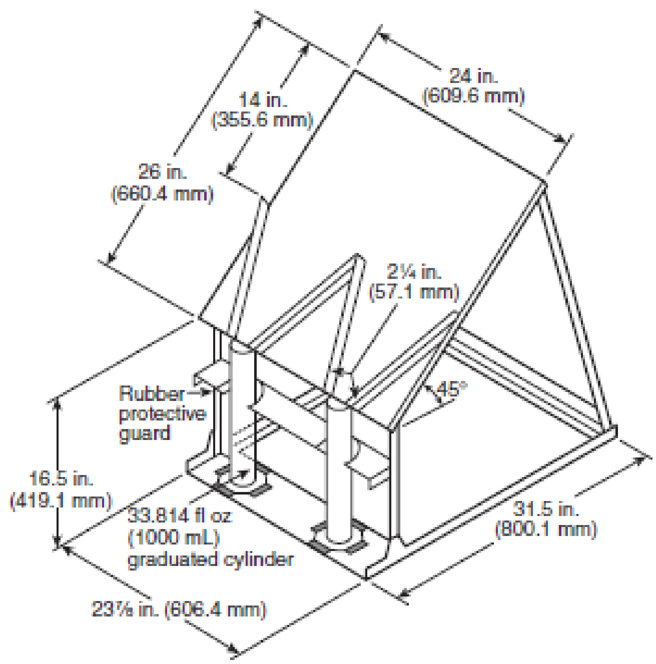


Figure 6. Foam Sample Collector Diagram [2]

Figure 7. Foam Sample Collector

<u>3.4 INPUT-BASED TESTING EQUIPMENT</u>

For input-based testing, the ARFF research team evaluated two systems at the WJHTC and one system offsite. The two systems evaluated at the WJHTC were supplied by E-ONE® and NoFoam Systems. The E-ONE product was the ECOLOGIC® Mobile Cart System [5], as shown in figure 8. The NoFoam Systems product was the NoFoam system, with trailer and portable configurations, as shown in figures 9 and 10. Although the method of measurement differs between the NoFoam and ECOLOGIC systems, the units function similarly by replacing the AFFF concentrate with a substitute and measuring its flow. Both units required slight modification to the ARFF vehicles being tested.

Figure 8. E-ONE ECOLOGIC Mobile Cart System

Figure 9. NoFoam Trailer System

Figure 10. NoFoam Portable System

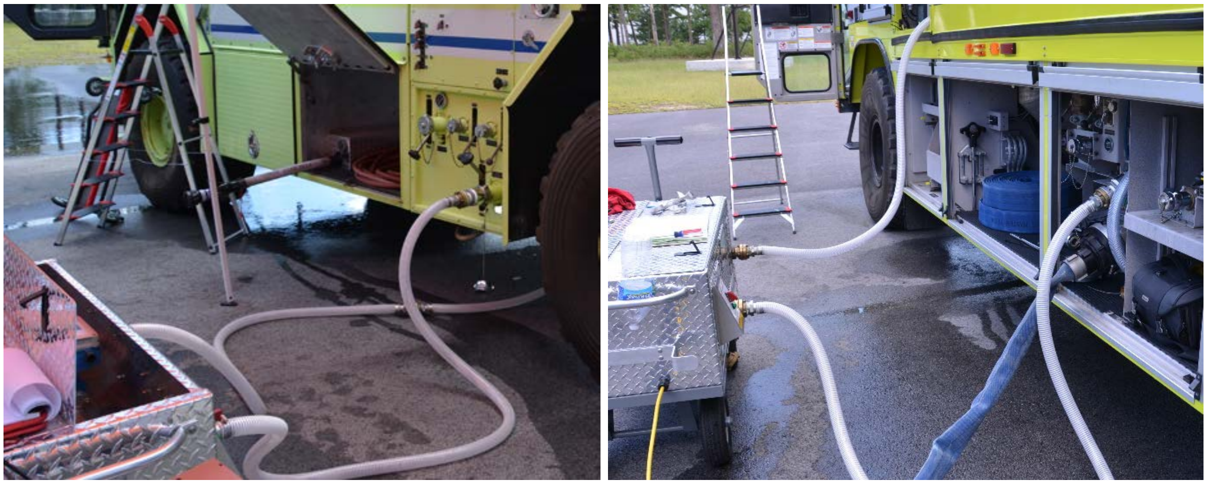
In addition to these two systems, Oshkosh engineers at an Oshkosh facility performed testing of the Oshkosh EcoEFP system as the ARFF research team observed. The ARFF research team performed additional testing of the EcoEFP system at the Port Authority Fire Training Facility at John F. Kennedy International Airport using a PANYNJ ARFF vehicle. The EcoEFP system is an integrated input-based testing system available on Oshkosh Strikers with electronic proportioning systems. During testing, the truck diverts water through the onboard foam concentrate flow meter and uses readings from the foam concentrate and solution flow meters to calculated proportioning percentage. An example of the interface panel is shown circled in red in figure 11.

Figure 11. EcoEFP System Interface Panel

3.4.1 ECOLOGIC Testing Requirements

During tests of the ECOLOGIC system, the vehicle's foam tanks were cut off by disconnecting the pneumatic actuators that open the tanks during testing to prevent foam concentrate from being accidentally released. An inlet connection was installed by replacing a section of pipe on the ARFF vehicle's plumbing with a hose connection.

In addition, the ARFF vehicle was required to have a water tank fill/drain connection. The substitute AFFF concentrate is provided by the ARFF vehicle's onboard water tank through the water tank fill/drain connection. The water flows from the ARFF vehicle's water tank, into the hose connected to the water tank fill/drain connection, through the unit, through the newly installed inlet connection, and into the foam proportioner, while the system measures the total volume of foam concentrate substitute. The connections for the installed ECOLOGIC system for Crash 9 and Crash 5 are shown in figure 12.



(a) (b)

Figure 12. ECOLOGIC System Connections on Crash 9 (a) and Crash 5 (b)

3.4.2 NoFoam Testing Requirements

The NoFoam system configurations, shown in figures 9 and 10, require air line cut-offs and a ball valve inlet connection to be installed between the foam tank and the proportioner, and the pipes and proportioner must be drained prior to testing. The residual AFFF concentrate must be collected into a container for proper disposal. The air line cut-off prevents the foam tank valves from opening during testing. The ball valve inlet connection allows the NoFoam System to supply the AFFF concentrate substitute from the system's storage tank. Both NoFoam System configurations have two onboard flow meters, which measure the flow of water to the proportioner. The flow meters correspond to two ranges of AFFF concentrate substitute flow and are selected based on the discharge being tested. In the NoFoam Trailer System, the water flows from the onboard tank, through the flow meter, into the newly installed inlet connection, and then into the proportioner, supplying the ARFF vehicle's foam system with AFFF concentrate substitute. The onboard water tank allows for the addition of dye to the water, which aids in visual verification that the system and ARFF vehicle are performing to specifications. Other additives may be used to change the physical properties of the water, such as viscosity or conductivity, to simulate the AFFF concentrate. In the NoFoam Portable System, instead of an onboard tank, the water is stored in a tank separate from the system. Additives can still be used with the portable system. The installed trailer system on Crash 9 is shown in figure 13, and the portable system in use is shown in figure 14.

Figure 13. NoFoam System Connections on Crash 9

Figure 14. NoFoam Portable System in Use

3.4.3 EcoEFP Testing Requirements

Because of the construction of the system, the EcoEFP is only available on new models of Oshkosh Strikers with electronic foam proportioning and cannot be retrofit to other models or trucks from other manufacturers. However, because the system is entirely integrated in the truck, there are no external connections needed. Output-based and EcoEFP testing were both performed on the modified Oshkosh Striker 6x6 used in this series of tests. The foam concentrate used during the output-based testing by Oshkosh engineers was Buckeye Platinum 3% AFFF concentrate, which meets the requirements of UL 162.

Testing performed at the Port Authority Fire Training Facility used an unmodified Oshkosh Striker 6x6 and Chemguard Mil-Spec 3% AFFF, the same formulation used for the 3% proportioning rate at the WJHTC.

4. TEST PROCEDURE

Evaluations were performed in three parts. The first part was preparation and baseline testing. The second and third parts were testing using the ECOLOGIC and NoFoam system, respectively, at the WJHTC. The Oshkosh EcoEFP system testing began following the other tests and was conducted at an Oshkosh facility and the Port Authority Fire Training Facility.

4.1 PREPARATION AND BASELINE TESTING

Sample standards were prepared to correlate foam proportions with the values measured from the conductivity meter and refractometer. The standards were made using AFFF concentrate and water from the ARFF vehicle's supply tanks. The samples were taken directly from the vehicle's tank, which was accessed through the hatches on top of the vehicle. The standards were measured with pipettes and mixed manually in graduated cylinders. In addition to the actual proportions of 3% and 6%, standards were also made using ±1/3 the nominal concentration of AFFF concentrate. This means for each proportion being tested, there were three standards available. For instance, for a 3% proportion, there were 2%, 3%, and 4%. This allowed for an accurate calibration curve to be produced. The process for producing the calibration curve was as follows:

1. Collect a water and AFFF concentrate sample from the ARFF vehicles supply tanks into a clean container. Ensure there is enough to produce all 3 standards.

2. Measure AFFF concentrate and tank water samples three times nonconcurrently and record the average measurement of each sample using both the refractometer and conductivity meter. Ensure each instrument is thoroughly cleaned between measurements.

3. Using 100-mL graduated cylinders and measuring pipettes, mix the AFFF concentrate and water to the desired proportion. If 3% foam solution is desired, then 97 mL of water and 3 mL AFFF concentrate.

4. Repeat for all desired sample standards.

5. Measure each sample three times nonconcurrently and record the average measurement of each sample using both the refractometer and conductivity meter, ensuring each instrument is thoroughly cleaned between measurements.

6. Plot measurements onto a percentage vs measurement graph. Separate graphs must be used for the conductivity and refractometer.

7. Using a linear best fit approximation, determine a calibration curve to be used to interpret AFFF measurements.

Baseline testing was conducted using the output-based proportioner testing method in NFPA 412 [2] using the calibration curves produced in the process above. As measurements were taken of the non-mixed water and foam concentrate, the calculation described in NFPA 412, Section 6.2.3.3 (from Method B) [2] was also performed to give another point of reference. Discharges representative of the different discharge methods for each truck were selected. For Crash 9, this was a hand line discharge, an HRET discharge and a bumper turret discharge. These discharges will be referred to as “Hand Line,” “Snozzle,” and “Bumper,” respectively. These corresponded to nominal flow rates of 60, 375, and 750 gallons per minute (gpm), respectively. On Crash 5, a low-flow bumper turret discharge and a high-flow bumper turret discharge were used. These discharges will be referred to as “Bumper Low” and “Bumper High,” respectively. These corresponded to nominal flow rates of 500 and 1000 gpm respectively. Hand line testing on Crash 5 was omitted because of problems encountered with discharge consistency at low flow rates.

For each set of tests, a new set of sample standards and calibration curves were created. They were also recreated every time the truck was refilled with water or foam concentrate to account for small changes in readings. For baseline tests, each discharge was tested at least two times nonconcurrently at each desired proportioning rate. The process for baseline testing was as follows:

1. Place the foam sample collector in a suitable location to collect the discharged foam.

2. Enable the ARFF vehicle’s pump and foam systems and prepare for discharge. Ensure the discharge is not oriented towards the sample collector. Check that pump pressure has stabilized at the correct value.

3. Open the discharge that is to be tested and allow foam to flow.

4. Angle the discharge over the foam collector and continue to discharge until a sample of at least 1000 mL is obtained.

5. Angle the discharge away from the sample collector.

6. Shut down the discharge

7. Collect sample and clean foam sample collector. Replace sample container with an empty and clean container.

8. Refill ARFF vehicle’s water and foam concentrate tanks if necessary.

9. Repeat for all desired discharges.

10. Repeat for all desired foam proportioning percentages.

11. Take and record measurements for all obtained samples using both the conductivity meter and the refractometer three times, ensuring each instrument is thoroughly cleaned between measurements.

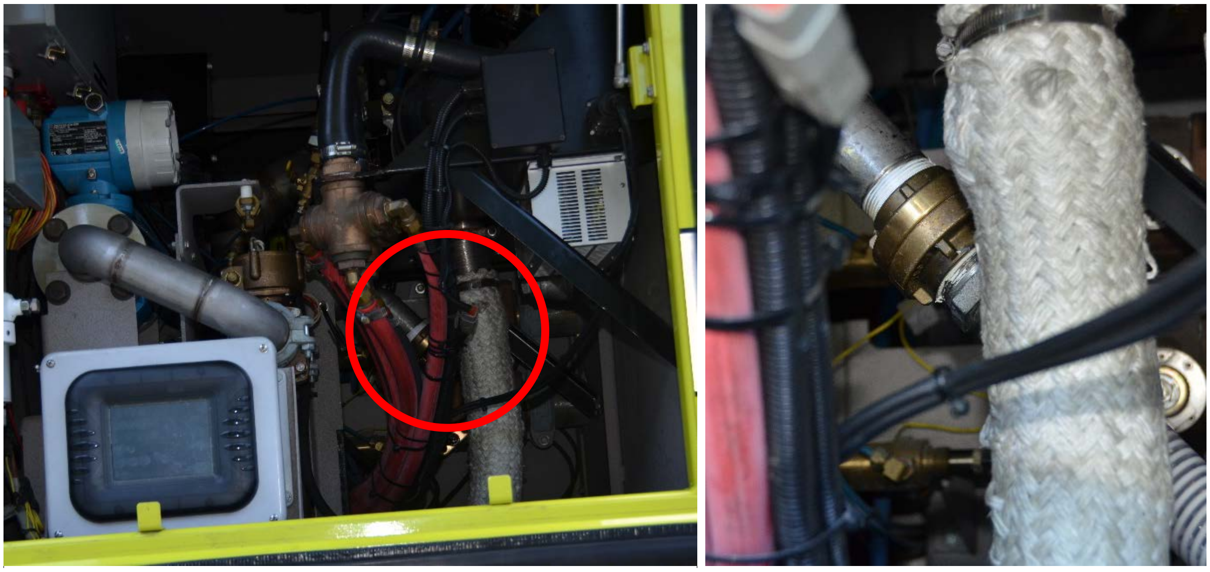
In the case of Crash 9, changing the proportioning rates required the removal and installation of different orifice plates. Switching proportioning rates on Crash 5 was much simpler as it did not require any physical changes to the foam proportioning system, and could be changed electronically. Baseline tests for similar proportioning rates were done concurrently, with nonconcurrent discharges of each discharge range.

4.2 ECOLOGIC INPUT-BASED TESTING

With all vehicle modifications completed, the flow rates of the various discharges needed to be measured. This was accomplished using the ECOLOGIC system and a stopwatch. The ECOLOGIC outlet was attached to the vehicle's water tank fill/drain connection and a water source was connected to the inlet. The discharge (without the foam system activated) was opened and allowed to flow for 5 minutes for the hand line discharge and 1 minute for all others. Discharge time was recorded using the stopwatch. The vehicle was then refilled through the ECOLOGIC system until the tank begins to overflow (taking care to stop filling immediately upon overflow), and the total volume of water filled was recorded. The volume of water was then divided by the time of the discharge (in minutes) to determine the average flow rate for that discharge.

The ECOLOGIC system [5] required three connections. There are two hose connections on the cart itself, one labeled "INLET" and one labeled "OUTLET." The inlet connection supplies the cart with an AFFF concentrate substitute (in this case, water from the ARFF vehicle's onboard storage tank). The outlet connection on the cart connected to an added inlet installed before the foam proportioner. On Crash 9, a section of pipe was replaced before the proportioner plate, and on Crash 5, a portion of the foam flush line was replaced with the ecologic fitting. The setups are shown in figures 15 and 16, respectively, with the connections circled in red. This connection supplied the foam system with water instead of AFFF concentrate.

Figure 15. Crash 9 ECOLOGIC Connection



(a) (b)

Figure 16. Crash 5 ECOLOGIC Connection (a) With Close-up View (b)

The third connection was an electrical connection to power the cart. The electrical connection must be connected to a ground fault circuit interrupter (GFCI) outlet. A GFCI was built into the power cord on the cart provided. After ensuring these three connections were made and checked to be secure, testing began.

The steps for the ECOLOGIC input-based testing are as follows:

1. Enable the ARFF vehicle's pump and prepare for discharge, taking care to ensure the foam system is not activated.

2. Ensure there is no air in the system by following the normal operating procedures to prime the system.

3. Switch the ECOLOGIC system to on.

4. Record the value displayed on the totalizer as "F1" using the worksheet in appendix A.

5. Ensure pump pressure has stabilized and record value as "P."

6. Using two stopwatches activate desired discharge and begin timing. Timing is started when the discharge is activated, not when water begins to flow.

7. Continue discharging for the amount of time specified below:

    a. Hand line discharge for 5 minutes.
    b. Snozzle or low-flow bumper turret discharge for 1 minute.
    c. High-flow bumper turret discharge for 1 minute.

8. Record the actual discharge time as “t_f”, taking the average of the readings from the two stopwatches, and the reading on the totalizer as “F2”.

9. Use the included worksheet for determination of foam percentages.

10. Refill ARFF vehicle’s water tank.

11. Repeat steps 4-10 for all desired discharges.

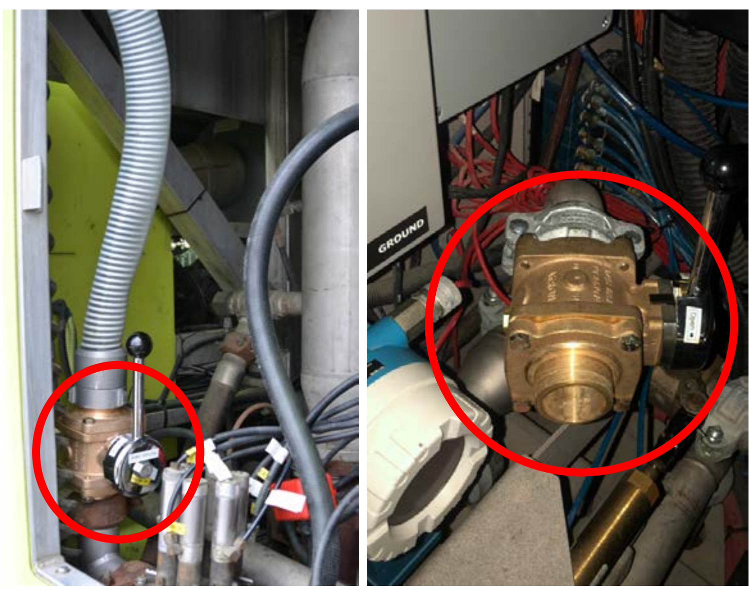
12. Close all valves and remove hoses from ARFF vehicle and ECOLOGIC unit.

13. Return ARFF vehicle to ready-for-service condition.

This process was the same on both ARFF vehicles being tested. The results were analyzed and compared to the baseline testing to check for consistency. Each desired discharge range was tested a minimum of 3 times for each proportioning percentage.

4.3 NOFOAM INPUT-BASED TESTING

With all vehicle modifications completed, the NoFoam System required two connections to the ARFF vehicle: an outlet from the NoFoam trailer and an inlet into the truck’s foam system to supply the AFFF concentrate substitute. The inlet in this case was a ball valve added onto each truck’s foam system directly before the proportioner. Figure 17 shows the NoFoam connections (circled in red) on Crash 9 and Crash 5, respectively.



(a) (b)

Figure 17. NoFoam Connections on Crash 9 (a) and Crash 5 (b)

During testing using the NoFoam System, the AFFF substitutes used were water or water with a proprietary additive. The additive was used to modify the viscosity of the substitute, and was mixed on location by the NoFoam Systems representative. The second connection was a mechanical gallon counter attached to the tank fill valve. For the portable configuration, there is one additional connection from the system's inlet to the fluid source. In this series of tests, the fluid source was a 55-gallon barrel with a ball valve installed at the bottom.

The steps for the NoFoam system input-based testing method are as follows [6]:

1. Ensure the air line cut-offs are activated.

2. Ensure the truck water tank is filled and mark tank level.

3. Connect the NoFoam system to the newly installed inlet ball valve and open the valve.

4. Open on-board valve on trailer system.

5. Switch on NoFoam System display.

6. Enable the ARFF vehicle's pump and foam systems and prepare for discharge.

7. Ensure there is no air in the system by following the normal operating procedures to prime the system. The trailer system has a bleeder valve installed after the meter to assist in removing air bubbles. Disable vehicle pump when priming is complete.

8. Refill tank to marked level, and note starting value on gallon counter using worksheet in appendix B

9. Ensure that the correct meter is selected for the respective flow rate and zero meter readings when recording total substitute concentrate flow.

10. Enable the ARFF vehicle's pump and ensure pump pressure has stabilized.

11. Using two stopwatches, activate desired discharge and begin timing. Timing is started when the discharge is activated, not when water begins to flow.

12. Continue discharging for at least 30 seconds until flow stabilizes.

13. Record digital flow monitor value from NoFoam System display and total elapsed discharge time, averaging the readings from the two stopwatches.

14. Refill ARFF vehicle's water tank to the marked level through a mechanical gallon counter and record the total value, and refill the NoFoam tank.

15. Use the included worksheet for determination of foam percentages.

16. Repeat steps 7-15 for each desired discharge at each desired proportioning rate.

17. Close inlet ball valve and disconnect NoFoam System from ARFF vehicle.

18. Deactivate air line cut-offs.

This process was the same on both ARFF research vehicles. The results were analyzed and compared to the baseline testing to check for consistency. Each desired discharge range was tested a minimum of three times for each proportioning percentage.

Tests were also repeated for the NoFoam trailer system using viscosity-modified fluid. All tests recorded both the flow rate during discharge and the total foam flow during discharge to compare the two readings. In addition, discharges with water were performed the same day to give a more direct comparison. During testing, a surplus of viscosity modified fluid allowed for additional tests to be performed in low tank level configurations to determine if any effects from head pressure could be observed. Viscosity-modified fluid could not be refilled between tests as this would change the solution viscosity.

4.4 OSHKOSH ECOEFP TESTING

EcoEFP system testing was performed by Oshkosh Engineers at an Oshkosh facility. There were two phases of testing performed: output-based testing and input-based testing. Output-based testing was performed similarly to tests performed at the WJHTC; however, Oshkosh used a test vehicle with an added tank level indicator and data recording system. This allowed for the collection of additional data for comparison to the input-based system. All testing was only performed at a 3% proportioning rate, as this was the only type of foam concentrate that was available at the Oshkosh facility. Output-based tests were only measured using an electronic Brix refractometer. Only one test was performed for each discharge on each system.

The procedure for output-based testing at the Oshkosh facility was as follows:

1. Place the foam sample collector in a suitable location to collect the discharged foam.

2. Enable the ARFF vehicle's pump and foam systems and prepare for discharge. Ensure the discharge is not angled towards the sample collector.

3. Open the discharge that is to be tested, and allow foam to flow until flow stabilizes.

4. Angle the discharge over the foam collector and continue to discharge until the sample container has been filled.

5. Shut down the discharge.

6. Collect sample and clean foam sample collector. Replace sample container with an empty and clean container.

7. Save all data recorded electronically by the vehicle's foam proportioner system.

8. Refill ARFF vehicle's water and foam concentrate tanks if necessary.

9. Take and record measurements for all obtained samples using the refractometer three times.

10. Repeat for all desired discharges.

Testing using the EcoEFP system was performed by following the prompts on the system's screen. The general procedure for the EcoEFP testing is as follows:

1. Activate the foam system cut-off.

2. Select the discharge to be tested on the screen.

3. Begin the discharge, continuing until the system indicates the end of the test.

4. End the discharge.

5. View test results.

Timing of sample data collection is handled by the system. The system allows a stabilization period then measures the proportioning rate over a set period. All testing results are stored on the system for three years, and can be downloaded using a Universal Serial Bus connection. In addition to these results, data from the data collection system used during the output-based testing was recorded as the EcoEFP testing was being performed.

Following the testing observed by the ARFF research team at the Oshkosh facility, testing was repeated at the Port Authority Fire Training Facility using a PANYNJ ARFF vehicle. EcoEFP testing followed the same process as testing performed at the Oshkosh facility, while output-based testing of the vehicle was performed following the procedures outlined in section 4.1.

4.5 DATA COLLECTION

The measurements from the sample standards were recorded and then plotted onto graphs: one with refractive index measurements, one with Brix measurements, and one with conductivity measurements. This allowed for the creation of a set of calibration curves. Examples of calibration curves are shown in figures 18 through 20.

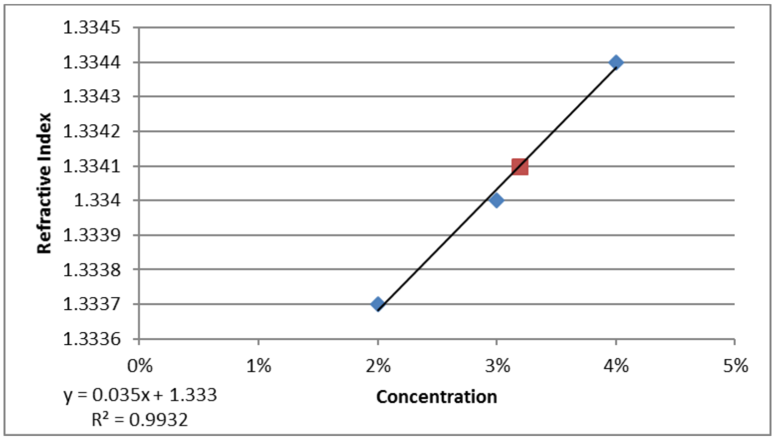


Figure 18. Refractive Index Calibration Curve

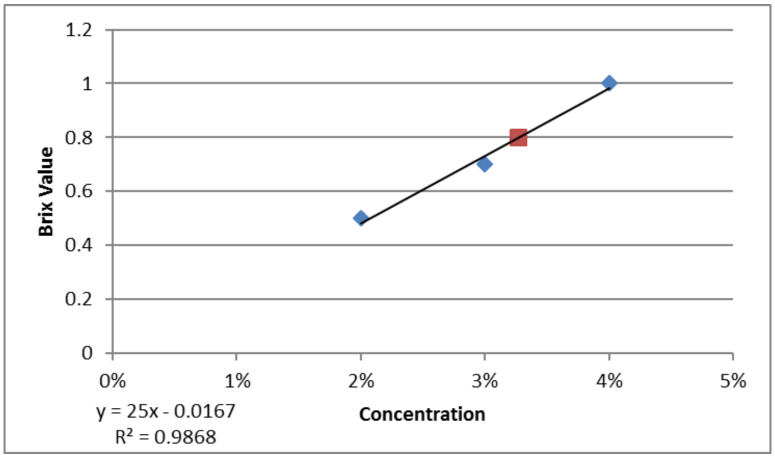


Figure 19. Brix Calibration Curve

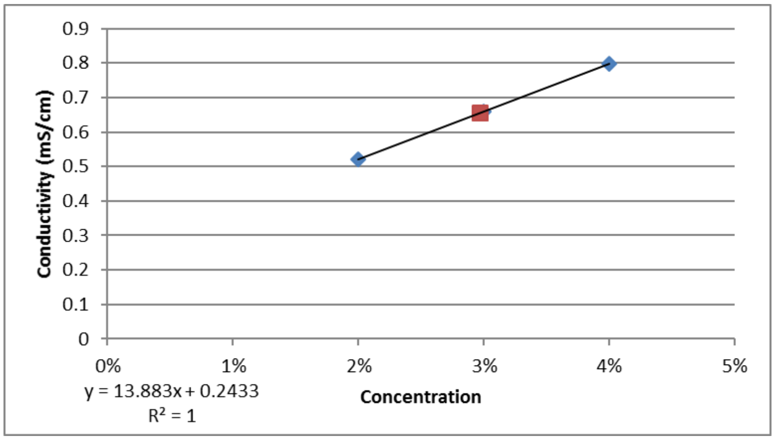


Figure 20. Conductivity Calibration Curve

Data analysis comprised of comparing the results of the output- and input-based testing. The output-based testing was used as a baseline for comparisons. To determine the proportioning rate for output-based testing, the discharged AFFF measurements were compared to the calibration curves prepared from the sample standards to determine the percentage of AFFF concentrate in the solution, which is the proportioning rate. Each discharge on each ARFF vehicle was tested a minimum of 2 times at each proportioning rate, nonconcurrently.

Input-based testing used measured flow rates or volume in conjunction with timed discharge periods. Discharge times were measured using a stopwatch and recorded on the worksheets included in appendices A and B. The ECOLOGIC system measured the total volume of AFFF concentrate substitute across an entire discharge period, requiring both the beginning and end values to be recorded. In addition, the time and the rate of each discharge were required to be recorded for each test. The proportioning rate was then calculated using the assumed flow rate measured prior to the test.

Flow rate and total volume of AFFF concentrate substitute during each discharge period were recorded from the values shown on the NoFoam System's display, in addition to the discharge flow rate and time of discharge. Calculations using the total volume of AFFF concentrate is not a standard calculation method, but was included as a point of comparison.

The main analysis compared the concentrations of AFFF concentrate measured during output tests to the concentrations of AFFF concentrate substitute measured during the input tests for each desired proportioning rate in each discharge range. The purpose of this comparison was to determine equivalency of results between output and input tests. Additional analysis was performed to determine if the desired proportioning rate has an effect on equivalency of input tests to output tests. For example, if the measured concentrations of output-based testing produce a tightly grouped set of results at 3% and 6% desired concentrations while the concentrations from input-based testing are similar at only 3% and more varied at 6% across all discharge ranges, then the proportioning rate may have an effect on the accuracy of input-based testing. Similarly, if the results show a discrepancy based on flow rate or proportioning system type, then those may have an effect on the accuracy of the input-based testing.

5. RESULTS

This section presents the results of the testing by system and test performed.

5.1 OUTPUT TESTS

A sample calculation sheet for the output tests is shown in appendix C. Values for refractive index, Brix, and conductivity were calculated using the method described in section 4.1. The average of the three readings taken was then used with the calibration curves described in section 4.5 to find the calculated proportioning rate based on each type of measurement. The calculation from NFPA 412 Method B [2] is labeled as "Meth. B" in the data.

The results for Crash 9, shown in table 2, include readings using refractive index (nD), Brix, conductivity (Cond.), an average of those three methods (Avg.), and a value from using NFPA 412 Method B (Method B). The results for Crash 5, shown in table 3, include the same values as Crash 9 with one additional column showing the percentage reported by the truck's electronic proportioning system (Foam Boss). These values are calculated using the total foam flow and solution flow measured by the system over each discharge. Hand line testing on Crash 5 was omitted as a result of problems encountered with the proportioning system at low-flow rates. It was found that at the flow rate required for the hand line, the proportioning rate was inconsistent because of fluctuating solution flow measurements when the pump's pressure relief valve was operating. The research team deemed these results varied too much to be considered for comparative tests.

Table 2. Crash 9 Output Test Results

#	Discharge Type	Proportioning Rate	Date	nD (%)	Brix (%)	Cond. (%)	Avg. (%)	Method B (%)
18	Bumper	3%	1/24/18	3.82	3.81	3.78	3.80	3.74
19	Bumper		1/24/18	3.80	3.99	3.85	3.88	3.86
15	Hand Line		1/24/18	3.30	3.22	3.45	3.33	3.45
22	Hand Line		1/24/18	3.33	3.46	3.54	3.44	3.38
16	Snozzle		1/24/18	3.62	3.67	3.71	3.67	3.74
21	Snozzle		1/24/18	4.01	3.92	4.09	4.00	4.05
1	Bumper	6%	11/17/17	7.28	7.59	7.56	7.48	7.13
4	Bumper		11/28/17	7.66	7.35	7.53	7.51	7.38
3	Hand Line		11/28/17	6.80	6.54	6.65	6.66	7.01
5	Hand Line		11/28/17	7.03	6.81	7.23	7.02	6.77
2	Snozzle		11/28/17	6.66	6.40	6.29	6.45	6.27
6	Snozzle		12/07/17	6.40	6.54	6.72	6.55	6.53

Table 3. Crash 5 Output Test Results

#	Discharge Type	Proportioning Rate	Date	nD (%)	Brix (%)	Cond. (%)	Avg. (%)	Method B (%)	Foam Boss (%)
30	Bumper High	3%	6/21/18	2.84	2.82	2.97	2.88	2.95	3.54
33	Bumper High		6/29/18	2.91	2.87	3.16	2.98	2.89	3.76
31	Bumper Low		6/29/18	3.19	3.26	2.97	3.14	3.19	4.39
32	Bumper Low		6/29/18	3.09	3.13	3.28	3.17	3.09	4.38
27	Bumper High	6%	5/24/18	6.31	6.44	6.70	6.48	6.31	6.48
29	Bumper High		6/21/18	6.82	7.00	6.69	6.83	6.77	6.49
25	Bumper Low		5/24/18	6.39	6.49	6.34	6.41	6.30	7.02
26	Bumper Low		5/24/18	6.39	6.49	6.34	6.40	6.30	7.22

5.2 ECOLOGIC

ECOLOGIC testing was performed as outlined in section 4.2. On Crash 9, readings were taken both before and after foam testing. Pre-foam discharge tests were performed to ensure that all repairs and adjustments done on the vehicle were completed, and the proportioning system was working as expected. It has the additional benefit of showing if any physical changes to the truck (such as the removal and installation of orifice plates) affected the observed proportioning rates.

The pre-foam discharge tests were not performed on Crash 5 because the electronic system on that truck did not require any physical changes to be made to change proportioning rates.

Proportioning rates were calculated using solution flow rates found through a timed discharge and measured refill performed prior to testing, and measured total foam substitute flow through the ECOLOGIC system. Discharge times were recorded simultaneously by two separate stopwatches and averaged. Table 4 shows the measured average solution flow rates on Crash 9, and table 5 shows the proportioning results of pre-foam discharge testing on Crash 9. Table 6 shows the proportioning results of post-foam discharge testing. Table 7 shows the measured average solution flow rates of Crash 5, and table 8 shows proportioning results from Crash 5.

Table 4. Crash 9 Measured Average Solution Flow Rates

Discharge	Pre-Foam Solution Flow Rate (gpm)	Post-Foam Solution Flow Rate (gpm)
Hand Line	61.00	61.00
Snozzle	390.00	378.88
Bumper	788.67	789.33

Table 5. Crash 9 ECOLOGIC Pre-Foam Proportioning Results

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Discharge Type	Proportioning Rate	Date	Recorded Percentage
Bumper	3%	10/12/17	3.30	Bumper	6%	10/11/17	5.12
Bumper		10/12/17	3.33	Bumper		10/11/17	5.19
Bumper		10/12/17	3.31	Bumper		10/11/17	5.21
Bumper		10/12/17	3.31	Bumper		10/11/17	5.20
Bumper		10/12/17	3.31	Bumper		10/11/17	5.25
Bumper		10/12/17	3.32	Bumper		10/11/17	5.21
Hand Line	3%	10/16/17	3.57	Hand Line	6%	10/16/17	7.08
Hand Line		10/16/17	3.56	Hand Line		10/16/17	7.11
Hand Line		10/16/17	3.57	Hand Line		10/16/17	7.10
Hand Line		10/16/17	3.57	Hand Line		10/16/17	7.15
Hand Line		10/16/17	3.58	Hand Line		10/16/17	7.16
Hand Line		10/16/17	3.58	Hand Line		10/16/17	7.01
Snozzle	3%	10/12/17	3.86	Snozzle	6%	10/11/17	6.07
Snozzle		10/12/17	3.90	Snozzle		10/11/17	6.10
Snozzle		10/12/17	3.89	Snozzle		10/11/17	6.10
Snozzle		10/12/17	3.93	Snozzle		10/11/17	6.09
Snozzle		10/12/17	3.91	Snozzle		10/11/17	6.05
Snozzle		10/12/17	3.89	Snozzle		10/11/17	6.01

Table 6. Crash 9 ECOLOGIC Post-Foam Proportioning Results

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Discharge Type	Proportioning Rate	Date	Recorded Percentage
Bumper	3%	2/16/18	3.39	Bumper	6%	2/22/18	5.01
Bumper		2/16/18	3.34	Bumper		2/22/18	5.03
Bumper		2/16/18	3.37	Bumper		2/22/18	5.02
Hand Line	3%	2/21/18	3.74	Hand Line	6%	2/22/18	7.26
Hand Line		2/21/18	3.95	Hand Line		2/22/18	7.26
Hand Line		2/21/18	3.73	Hand Line		2/22/18	7.25
Snozzle	3%	2/28/18	4.13	Snozzle	6%	2/27/18	6.34
Snozzle		2/28/18	4.18	Snozzle		2/27/18	6.35
Snozzle		2/28/18	4.19	Snozzle		2/27/18	6.35
Snozzle		2/28/18	4.19	Snozzle		2/27/18	6.40
Snozzle		2/28/18	4.14	Snozzle		2/27/18	6.33
Snozzle		2/28/18	4.16	Snozzle		2/27/18	6.36

Table 7. Crash 5 Measured Average Solution Flow Rates

Discharge	Solution Flow Rate (gpm)
Bumper High	1027.84
Bumper Low	575.56

Table 8. Crash 5 ECOLOGIC Proportioning Results

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Discharge Type	Proportioning Rate	Date	Recorded Percentage
Bumper High	3%	2/20/18	3.21	Bumper High	6%	2/21/18	5.31
Bumper High		2/20/18	3.22	Bumper High		2/21/18	5.33
Bumper High		2/20/18	3.19	Bumper High		2/21/18	5.30
Bumper High		2/21/18	3.25	Bumper High		2/21/18	5.31
Bumper High		2/21/18	3.26	Bumper High		2/21/18	5.27
Bumper High		2/21/18	3.30	Bumper High		2/21/18	5.25
Bumper Low	3%	2/20/18	3.42	Bumper Low	6%	2/21/18	6.29
Bumper Low		2/20/18	3.45	Bumper Low		2/21/18	6.12
Bumper Low		2/20/18	3.42	Bumper Low		2/21/18	6.13
Bumper Low		2/21/18	3.55	Bumper Low		2/21/18	6.20
Bumper Low		2/21/18	3.54	Bumper Low		2/21/18	6.18
Bumper Low		2/21/18	3.47	Bumper Low		2/21/18	6.17

5.3 NOFOAM

The ARFF research team evaluated two different variations of the NoFoam system: the trailer system and the portable system. The following sections detail the results from tests using variations of the NoFoam system.

5.3.1 NoFoam Trailer System

Table 9 shows the results from the trailer system on Crash 9. For each discharge, the selection of the meter was based on the assumed foam flow rate from the solution flow rate and proportioning percentage.

Table 9. Crash 9 NoFoam Trailer System Results

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)	Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)
Bumper	3%	3/20/18	3.36	3.37	Bumper	6%	3/23/18	6.32	6.24
Bumper		3/20/18	3.43	3.51	Bumper		3/23/18	6.26	6.35
Bumper		3/20/18	3.36	3.42	Bumper		3/23/18	6.12	6.23
Bumper		7/17/18	3.46	3.55	Bumper		4/4/18	6.35	6.27
Bumper		7/17/18	3.42	3.48	Bumper		4/4/18	6.27	6.36
Bumper		7/17/18	3.34	3.39	Bumper		4/4/18	6.14	6.24
Hand Line	3%	3/20/18	3.18	3.17	Hand Line	6%	3/23/18	6.00	5.99
Hand Line		3/20/18	3.26	3.29	Hand Line		3/23/18	5.98	5.98
Hand Line		3/20/18	3.28	3.31	Hand Line		3/23/18	5.92	5.92
Hand Line		7/17/18	3.25	3.24	Hand Line		4/4/18	6.48	6.49
Hand Line		7/17/18	3.23	3.25	Hand Line		4/4/18	6.23	6.27
Hand Line		7/17/18	3.24	3.21	Hand Line		4/4/18	6.17	6.18
Snozzle	3%	3/20/18	3.09	3.13	Snozzle	6%	3/23/18	5.74	5.85
Snozzle		3/20/18	3.00	3.02	Snozzle		3/23/18	5.59	5.70
Snozzle		3/20/18	2.91	2.94	Snozzle		3/23/18	5.64	5.71
Snozzle		7/17/18	3.15	3.09	Snozzle		4/4/18	5.78	5.86
Snozzle		7/17/18	3.20	3.20	Snozzle		4/4/18	5.80	5.90
Snozzle		7/17/18	3.16	3.14	Snozzle		4/4/18	5.63	5.68

The 3% Snozzle discharge had a foam flow rate that was between the ranges of the two flow meters in the system. As a result, the discharges previously shown that were originally measured using the low-flow meter were repeated using the high-flow meter. Table 10 shows these results.

Table 10. Crash 9 Snozzle Discharge Through NoFoam High-Flow Meter

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)
Snozzle	3%	7/19/18	3.95	3.97
Snozzle		7/19/18	3.98	3.98
Snozzle		7/19/18	4.05	4.03

Table 11 shows the results from the trailer system on Crash 5. All discharges at both proportioning rates were measured using the high-flow meter.

Table 11. Crash 5 NoFoam Trailer System Results

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)	Foam Boss Percentage
Bumper High	3%	7/18/18	2.93	3.22	3.25
Bumper High		7/18/18	2.98	3.20	3.25
Bumper High		7/18/18	3.03	3.28	3.42
Bumper Low	3%	7/18/18	2.91	3.36	3.47
Bumper Low		7/18/18	2.87	3.32	3.58
Bumper Low		7/18/18	2.82	3.20	3.55
Bumper High	6%	7/18/18	5.97	6.15	6.20
Bumper High		7/18/18	6.01	6.12	6.16
Bumper High		7/18/18	5.94	6.09	6.18
Bumper Low	6%	7/18/18	6.20	6.43	6.36
Bumper Low		7/18/18	5.61	6.10	6.32
Bumper Low		7/18/18	5.66	6.15	6.36

5.3.2 NoFoam Portable System

Due to time restrictions, the NoFoam Portable System was only tested on Crash 9 and only at the 6% proportioning rate. Although the portable system was not originally part of the scope of this report, the results (table 12) are a confirmation that the portable system, which has the same sensor configuration as the trailer system, performs similarly.

Table 12. Crash 9 NoFoam Portable System Results

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)
Bumper	6%	3/23/18	5.77	5.86
Bumper		3/23/18	5.71	5.80
Bumper		3/23/18	6.64	6.74
Hand Line	6%	3/23/18	5.90	5.90
Hand Line		3/23/18	5.90	6.07
Hand Line		3/23/18	6.21	6.24
Snozzle	6%	3/23/18	5.36	5.40
Snozzle		3/23/18	5.99	6.07
Snozzle		3/23/18	5.89	6.01

5.3.3 NoFoam Trailer System With Viscosity-Modified Fluid

The results from viscosity-modified fluid testing in the NoFoam trailer system is shown in table 13. As this was not within the original scope of this report, testing using this material was limited. Testing was performed only on Crash 9, but a full set of discharges on both 3% and 6% proportioning rates were completed.

Table 13. Crash 9 NoFoam Trailer System With Viscosity-Modified Fluid Results

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)
Bumper	3%	7/17/18	3.56	3.56
Bumper		7/17/18	3.42	3.42
Bumper		7/17/18	3.45	3.49
Hand Line	3%	7/17/18	3.69	3.76
Hand Line		7/17/18	3.83	3.81
Hand Line		7/17/18	3.85	3.82
Snozzle	3%	7/17/18	2.96	2.97
Snozzle		7/17/18	2.95	2.93
Snozzle		7/17/18	2.86	2.82
Bumper	6%	4/4/2018	6.24	6.32
Bumper		4/4/2018	6.24	6.36
Bumper		4/4/2018	6.28	6.36

Table 13. Crash 9 NoFoam Trailer System With Viscosity-Modified Fluid Results (Continued)

Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)
Hand Line		4/4/2018	6.42	6.43
Hand Line	6%	4/4/2018	6.60	6.64
Hand Line		4/4/2018	6.95	6.96
Snozzle		4/4/2018	5.98	6.11
Snozzle	6%	4/4/2018	5.94	5.99
Snozzle		4/4/2018	5.69	5.81

As with previous tests with the NoFoam trailer system, the 3% Snozzle discharge was repeated using the high-flow meter. Because this set of discharges was the last series performed, there was a limited amount of viscosity-modified fluid left in the tank. To provide a point of comparison, the discharges from table 10 were repeated, matching the tank levels as closely as possible. To match tank levels, a container of water was lifted using a forklift to match the level of fluid in the tank installed on the trailer. This external tank was connected through the NoFoam system using a bypass connection, and the connection to the internal tank was shut off. The tank level test connection is shown in figure 21. Results of the tests are shown in table 14. Tests were run as many times as possible to use up the remaining viscosity-modified fluid, which resulted in an odd number of samples.

Figure 21. NoFoam Tank Level Test Connection

Table 14. Crash 9 Snozzle Discharge With Modified Fluid Through High-Flow Meter

Input Fluid	Discharge Type	Proportioning Rate	Date	Recorded Percentage	Recorded Percentage (Total Foam)
Viscosity-modified	Snozzle	3%	7/19/18	4.11	3.86
Viscosity-modified	Snozzle		7/19/18	3.99	3.97
Viscosity-modified	Snozzle		7/19/18	3.71	3.67
Viscosity-modified	Snozzle		7/19/18	3.92	3.95
Viscosity-modified	Snozzle		7/19/18	3.77	3.54
Water	Snozzle	3%	7/19/18	3.19	3.30
Water	Snozzle		7/19/18	3.09	3.47
Water	Snozzle		7/19/18	3.15	3.61
Water	Snozzle		7/19/18	3.48	3.52
Water	Snozzle		7/19/18	2.78	3.12

5.4 OSHKOSH ECOEFP RESULTS

Oshkosh engineers provided results from observed testing at the Oshkosh facility. Readings from output-based testing and EcoEFP testing are below in table 15. Discharges tested were the hand line, bumper turret, and high-flow roof turret (referred to as Hand Line, Bumper, and Roof High, respectively). Similarly to the testing done at the WJHTC, output-based testing was performed to compare the results from the two measurement methods. A different digital refractometer (the ATAGO® Pocket PAL-1) was used; however, it had the same accuracy as the refractometer used in the rest of the output-based tests. Instead of Chemguard Mil-Spec 3% AFFF, Buckeye Platinum 3% AFFF was used, which meets the UL 162 standard. Although the performance standards are different, there should be no effect on the proportioning rate. However, for the measurement of proportioning rate with output-based methods, the measured Brix value for the Buckeye Platinum AFFF foam concentrate was lower than that of the Mil-Spec AFFF. This caused the range of readings on the calibration curve to be smaller than the curves created from the output tests performed at the WJHTC, which could introduce additional error in measurement of proportioning percentage. The tighter range of Brix values meant that a 0.1 change in Brix caused the average for the hand line results to drop significantly.

Table 15. Oshkosh Proportioner Test Results

Discharge	Solution Flow (GPM)	Refractometer (%)	EcoEFP (%)
Hand Line	100	2.67	3.00
Bumper	520	3.00	3.10
Roof High	1300	3.47	3.20

Figure 22 shows graphs plotting the recorded proportioning percentages from the ARFF vehicle's electronic system during both the output-based testing and the EcoEFP testing.

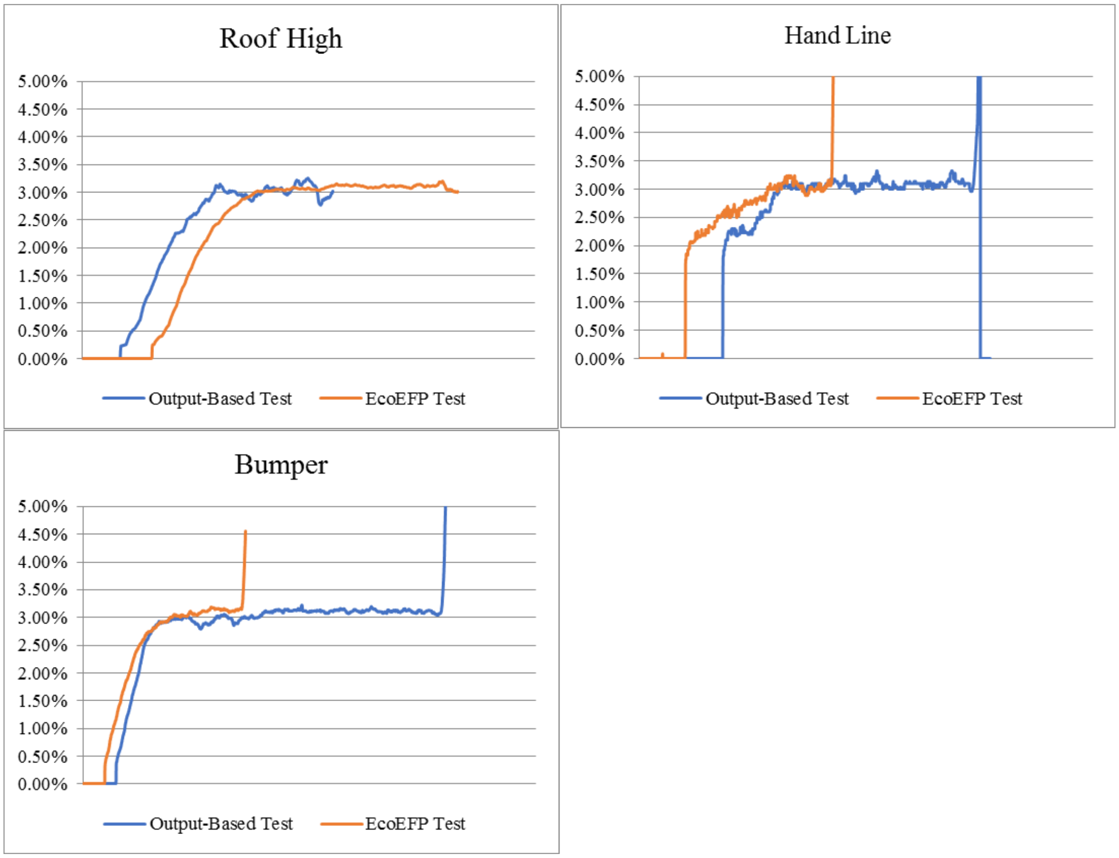


Figure 22. Oshkosh EcoEFP Proportioning Percentages

Testing at the Port Authority Fire Training Facility consisted of both output-based testing and EcoEFP system testing, shown in table 16. Because the vehicle used did not have connections to view and record instantaneous flow data, only the results from output-based testing and the final result from the EcoEFP could be used. Output-based test results are presented here in the same format as in tables 2 and 3.

Table 16. The PANYNJ EcoEFP Test Results

Discharge	nD (%)	Brix (%)	Cond. (%)	Avg. (%)	Method B (%)	EcoEFP (%)
Snozzle	3.12	2.96	3.04	3.04	3.25	3.20
Bumper	3.29	3.20	3.16	3.21	3.43	3.10
Hand Line	4.42	4.37	4.36	4.38	4.64	2.90

6. DISCUSSION

This section covers analysis of output-based results, comparison of output-based results to various configurations of input-based test methods, as well as possible factors that may lead to measurement errors. All uses of percentages in this section refer only to foam proportioning percent.

6.1 OUTPUT TESTS

The output test results on Crash 9 were higher than expected. When the system was calibrated before testing, the truck was experiencing then-undiagnosed problems causing the system to be calibrated too high, which explains the relatively high measured proportioning rate observed in the 3% Bumper and Snozzle discharges. The error in calibration led to both the 3% and 6% Bumper discharges and the 3% Snozzle discharge to be outside the acceptable range set out in NFPA 412 [2]. Figure 23 shows graphs of the results from Crash 9. Similar markers represent the same sample measured using each of the different methods. Each discharge has two samples.

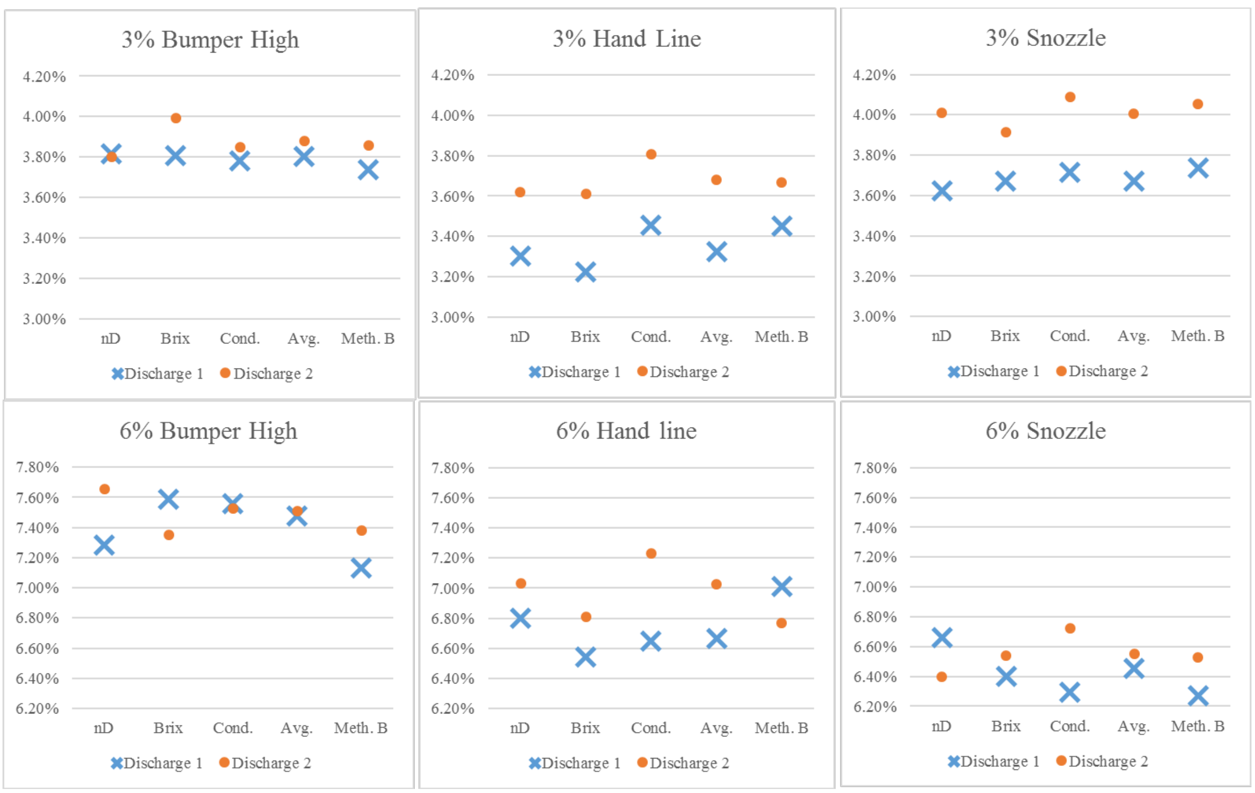


Figure 23. Crash 9 Output Tests Results

These results, which fall outside the NFPA 412 acceptable range, were not thought to affect the outcome for this analysis. In this case, the input-based systems should show equivalency with the output-based testing, regardless of the results of the output-based testing. If an input-based testing method showed a discharge to be within the NFPA 412 acceptable range while output-based testing did not, then that would indicate that the input-based system is not showing equivalency with output-based results.

The orifice plate system on Crash 9 appears to show more inconsistency in its results than the Foam Boss system on Crash 5. This is to be expected in a purely mechanical system, as the orifice plate system is unable to dynamically respond to slight changes in pressure or flow. Figure 24 shows graphs of the results from Crash 5.

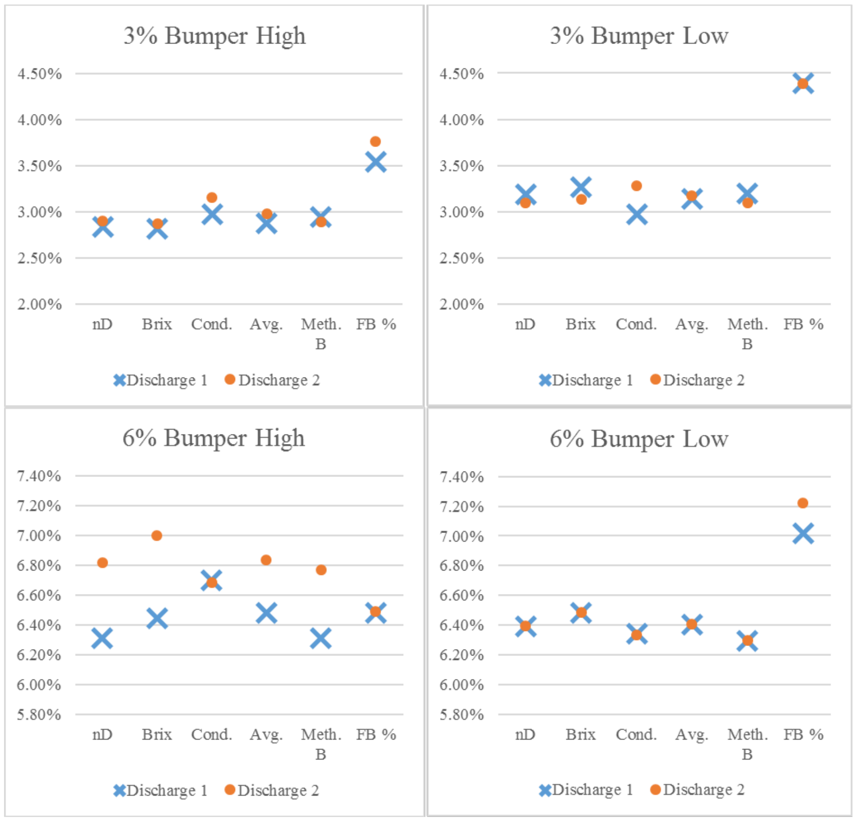


Figure 24. Crash 5 Output Tests Results

The readings directly from the Foam Boss system on Crash 5 appear to be much higher than the measured values of the discharge, but this is possibly due to the way the proportioning system operates. When the system begins a discharge, the foam proportioning valve immediately opens all the way, then closes until the measured proportioning rate matches the set value. As a result, the readings from the Foam Boss system are skewed because the proportioning rate is calculated using the entire duration of the discharge. Output-based testing only measures an instantaneous proportioning value from the discharge, meaning it is not affected by this system behavior. The only data set where this did not appear was for the 6% Bumper High discharge, where the foam flow rate was the highest. Other than the Foam Boss readings, the data from Crash 5 was very consistent. Again, the only outlier was the 6% Bumper discharges, where refractometer readings were not consistent between the two discharges. It is possible that this was a result of the accuracy of the measurement device, which will be discussed in depth in section 6.4.

6.2 ECOLOGIC

The ECOLOGIC system showed consistent readings across most discharges and proportioning rates, both on the orifice plate system and the electronic Foam Boss system. The system observed a variation in proportioning rate of approximately 0.1% over all readings for each type of discharge during both pre-foam and post-foam discharges. However, the post-foam readings on Crash 9 were slightly higher than the pre-foam readings in most cases, showing an increase of approximately 0.2% on all but the Bumper discharges. It is unclear if this was due to variance in the truck or external variables.

Comparing the ECOLOGIC to the output results in the Hand Line and Snozzle discharges on Crash 9, the results both pre-foam and post-foam were within 0.1% of the range of output results. The Bumper discharges on both 3% and 6% showed a large decrease in proportioning rate from the output results. On the 3% discharge, the readings were approximately 0.5% below the output results, and on the 6% discharge, the readings were approximately 2.0% below the output results. Graphs of these results are shown in figure 25. These graphs display the maximum, minimum, and average values for each set of discharges.

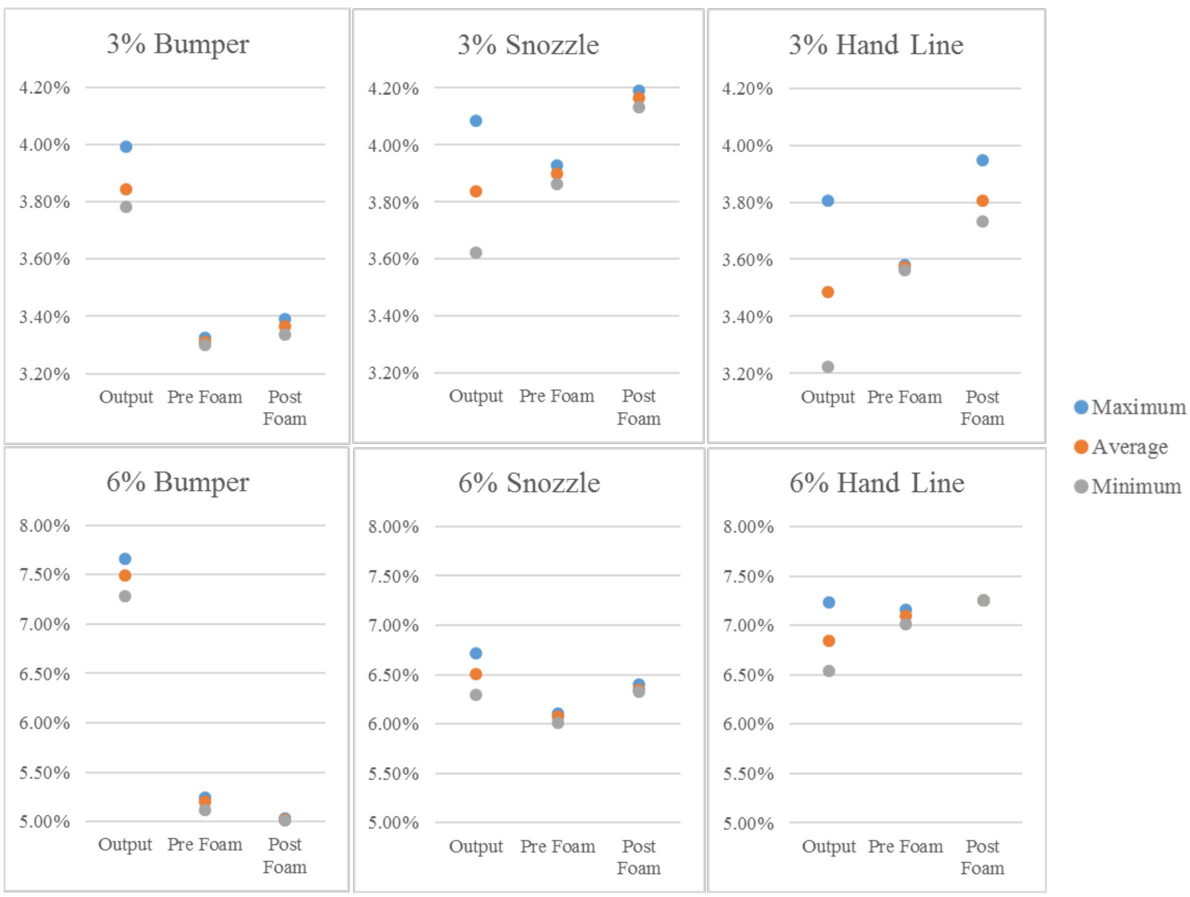


Figure 25. Crash 9 ECOLOGIC Test Results

It is possible that the drop on the 6% Bumper discharge was due to a flow restriction caused by the internal size of the ECOLOGIC piping. The reduced pipe size could have caused increased friction losses, which may have been exacerbated by the length of pipe required to connect the system to the truck. If not the size of the pipe, then the increased pipe length may have caused losses that may have affected the performance of the proportioning system. On high-flow discharges the reduction in flow by the measuring system in addition to the reduction from the orifice plate may have caused a greater than expected reduction of foam concentrate flow.

An unexpected benefit of the input-based systems is the ability to diagnose system problems that would otherwise be difficult to notice. On Crash 9 specifically, the initial ECOLOGIC system testing assisted in diagnosing issues with the proportioner plate, such as bad seals on a non-seated plate. It is believed that any input-based system would be able to similarly diagnose problems. However, the truck experienced issues that were not diagnosed with the input-based systems, such as malfunctioning check valves allowing mixed foam solution to flow back into the water tank. Because this happened after the proportioner, it would not be visible to input-based systems. All problems discovered on Crash 9 were fixed immediately after discovery, and testing prior to those discoveries was repeated to ensure that the data was not affected.

On Crash 5, the 3% results were slightly above the output results by approximately 0.3%. The 6% results were below the output results. The low-flow Bumper discharge was lower than the output results by approximately 0.3%, while the high-flow Bumper discharge was lower than the output results by approximately 1.5%. This system most likely experienced the same effect as the system on Crash 9. However, it is possible that the electronic system was able to somewhat adjust for this restriction, on all but the highest flow rates. Behavior of the Foam Boss system was not analyzed in this series of tests, and thus that possibility is unconfirmed. Graphs of these results are shown in figure 26. These graphs display the maximum, minimum, and average values for each set of discharges.

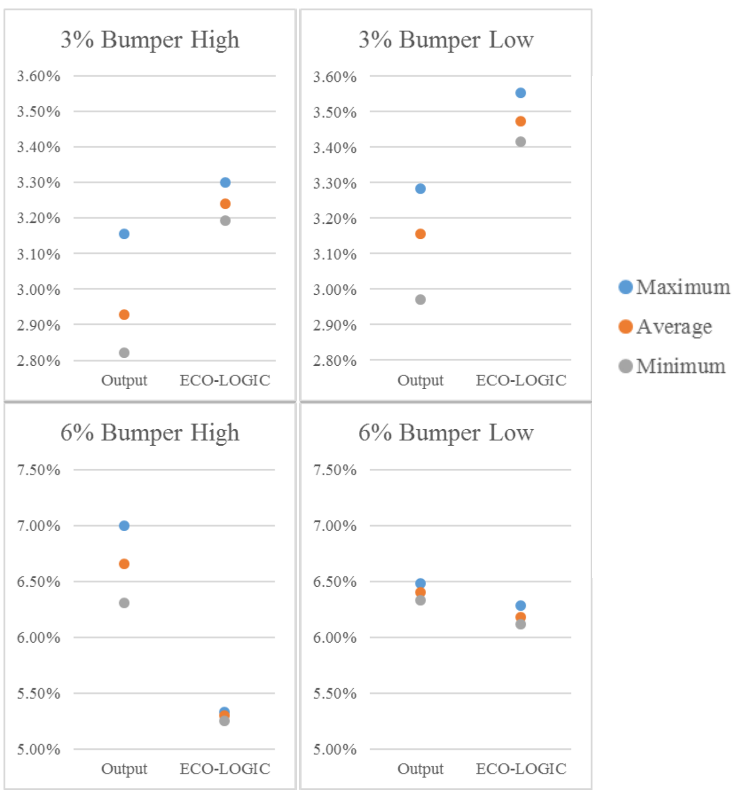


Figure 26. Crash 5 ECOLOGIC Test Results

6.3 NOFOAM

This section will discuss the results of the NoFoam system testing in all experimental configurations. All graphs in this section display the maximum, minimum, and average values for each set of discharges.

6.3.1 NoFoam Trailer System

Readings were lower than output results across most discharges on the NoFoam trailer system, except for 3% Snozzle on Crash 9 and 3% Bumper High on Crash 5. On most discharges, averages of results were off from the output results by approximately 0.5% to 0.8%. The 3% Hand Line on Crash 9 was within the range of results from output tests but was on the lower end of the range, being below the average by approximately 0.2%. The 3% Bumper High on Crash 5 was centered within the range of output results. Readings for each discharge were fairly consistent, showing a variance of approximately 0.2% to 0.5% on Crash 9 and 0.1% on Crash 5. Graphs of the results are shown in figures 27 and 28. For the 3% Snozzle discharge on Crash 9, results using the high-flow meter with a full tank were used, as results using the low-flow meter were unstable. The results using the high-flow meter were determined to be the best representation of the No Foam trailer system.

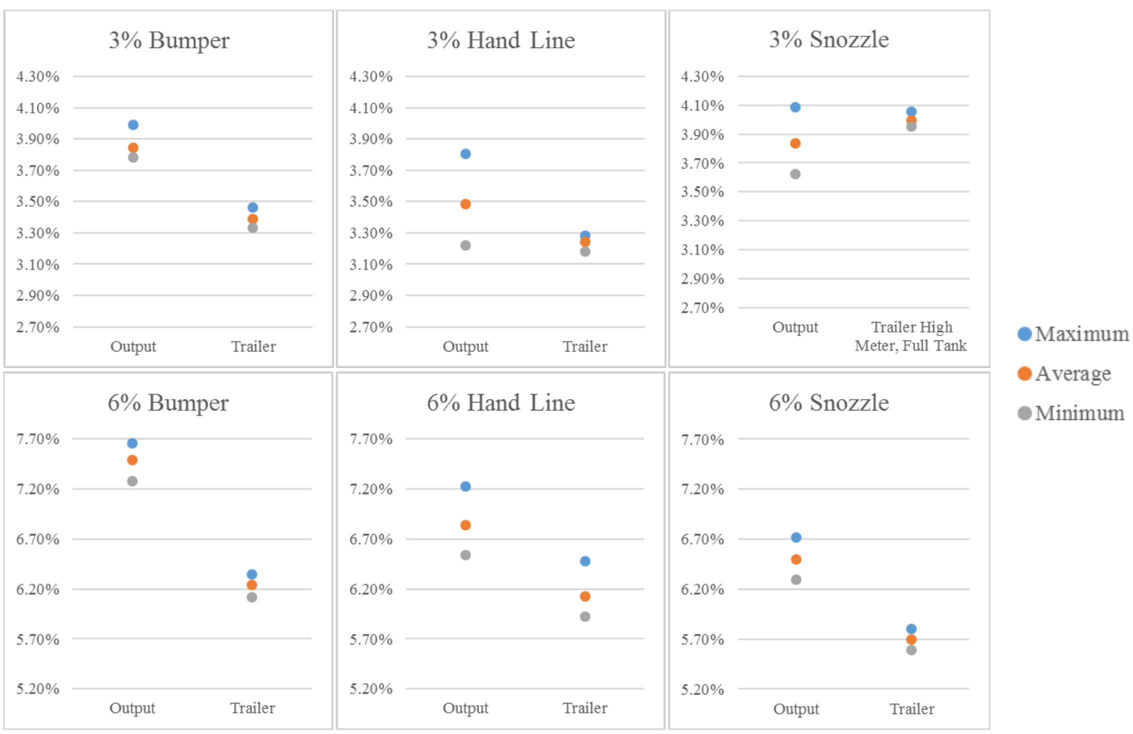


Figure 27. Crash 9 NoFoam Trailer Results

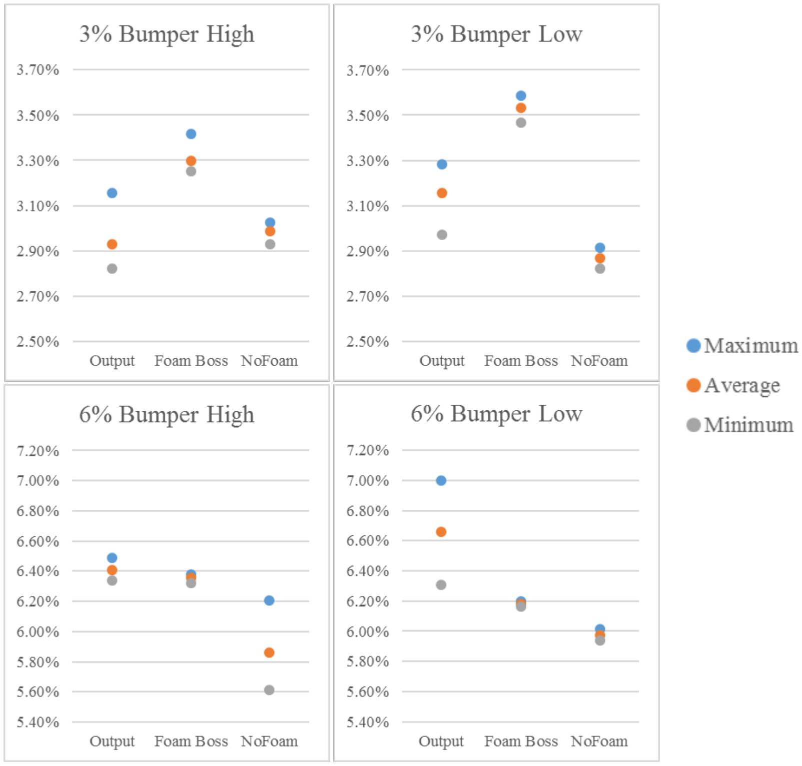


Figure 28. Crash 5 NoFoam Trailer Results

The results obtained with the NoFoam system were possibly caused by a similar flow restriction as observed on the ECOLOGIC; however, since the system uses a slightly larger internal pipe diameter and is connected to the foam systems in a slightly different configuration, this may have had less of an effect. The system may have also been negatively impacted by head pressure from the trailer's tank level, which is discussed further in section 6.3.5.

6.3.2 NoFoam Portable System

While the metering setups of the systems are similar, different results were observed between the NoFoam trailer and portable systems. They both recorded a similar value for the proportioning rate; however, the portable system showed a higher variance across readings than the trailer system. While the trailer system shows a variance of 0.2% to 0.5%, the portable system showed a variance of 0.3% to 1.0%; yet the average measured values for both systems were close. The portable system was only tested on Crash 9, and the results are shown in figure 29.

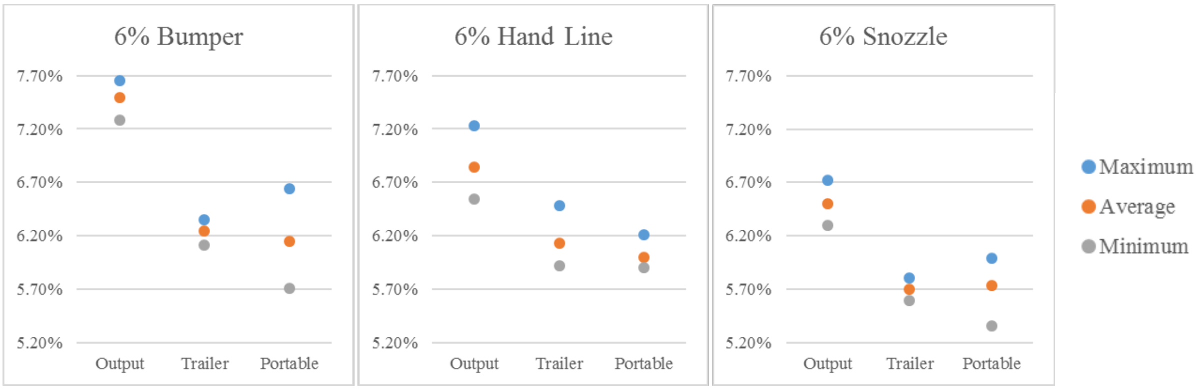


Figure 29. Crash 9 NoFoam Portable System Results

It is possible that this variance came from the change in source tank. The trailer system draws its water from an onboard storage tank, which held approximately 300 gallons. The portable system drew its water from a smaller tank, holding approximately 55 gallons. As the amount of fluid flowing from the tank is the same in both cases, the rate of change in head pressure was greater when using a smaller tank. The effects of this are discussed in section 6.3.5.

6.3.3 NoFoam Trailer System With Viscosity-Modified Fluid

Changes in fluid viscosity (through the use of an additive) generally increased the measured foam proportioning rate, but the degree to which it increased was not consistent. All but one discharge showed an increase in the range of 0.1% to 0.6% higher using the viscosity-modified fluid as compared to regular water, with each discharge increased by a different amount. The 6% Bumper discharge on Crash 9 did not show any difference, and instead was measured as consistent with readings using nonmodified water. Graphs of the results are shown in figure 30. For the 3% Snozzle discharge, results using the high-flow meter with a full tank were used, as results using the low-flow meter were unstable. The results using the high-flow meter were determined to be the best representation of the system. However, as tests using the viscosity-modified fluid with the low-flow meter were performed first, there was only one third of a tank of fluid left for testing with the high-flow meter. More could not be produced due to time and material constraints.

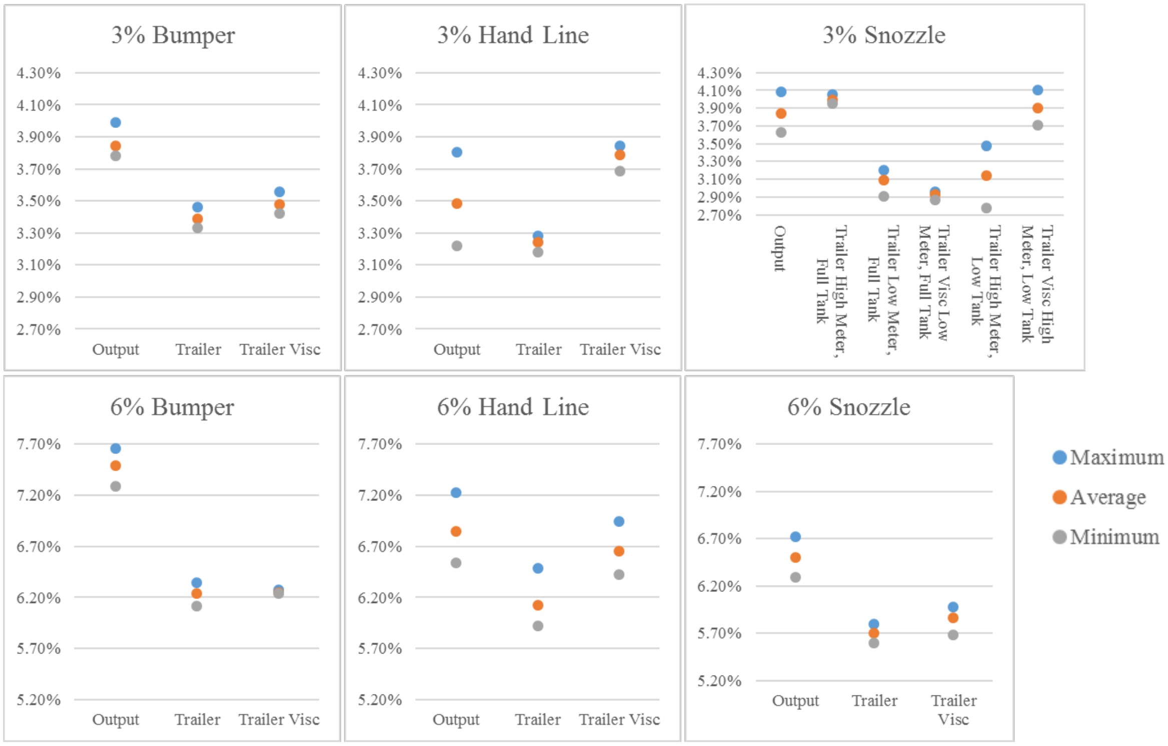


Figure 30. Crash 9 NoFoam Viscosity-Modified Fluid Results

6.3.4 Effect of Meter Ranges

Ranges of the two flow meters caused some anomalies in the readings. For some discharges, the concentrate substitute flow rate was directly between the two meters’ ranges. This could lead to measurement errors, as meters of this type have problems reading accurately at the edges of their range. This can be observed in the readings from the 3% Snozzle discharge on Crash 9 in tables 9 and 10, where switching from the low-flow meter to the high-flow meter caused the reading of the proportioning rate to increase approximately 1%. These readings are shown in figure 31.

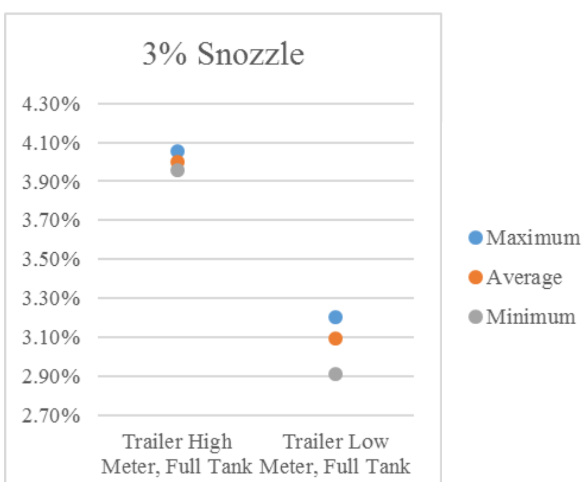


Figure 31. Effect of Meter Range

It is important to note that this increase may not have been caused by the meter itself, but by the change in pipe size allowing for greater flow through the system. Because the system piping is sized according to the truck's discharges, this may be avoided on other configurations of this system.

6.3.5 Effect of Tank Level

A key component of foam proportioning systems on current ARFF vehicles with around-the-pump foam systems is the eductor, which is used to draw in foam concentrate. Eductors (also known as "ejectors" or "inductors") work using the Venturi effect. By creating a flow restriction, fluid velocity increases and pressure decreases to preserve a constant mass flow rate. The suction inlet of the eductor is connected to the low-pressure area in the device. Atmospheric pressure on the input fluid along with that lower pressure creates a pressure-driven flow, which is then restricted by either an orifice plate or a proportioning valve to allow for the correct amount of fluid flow [7 and 8]. This effect is reduced by introducing a "head" or height difference between the tank level and the eductor inlet. This head creates a negative net pressure between the tank and eductor due to gravity, which works against the pressure-driven flow created by the eductor. In the truck's standard configuration, the tank level is always higher than the eductor inlet, but in the NoFoam system, it is possible for the tank level to drop below the eductor inlet.

Similarly, losses may also be introduced through friction in piping between the source and the eductor inlet. This loss is dependent on the fluid in the pipe, the pipe size, type of pipe, and the flow velocity. For most configurations this loss is minimal, but once the hose lengths needed for each input system are introduced, it is possible that this effect is slightly exaggerated.

Thus, head pressure can affect the flow rate of the input fluid, as the eductor has a set vacuum it creates at a given pump pressure. [8] On orifice plate systems such as the one on Crash 9, the system is unable to adjust for changes in supply, and therefore, it may pull less fluid through the eductor, ultimately creating a lower output foam proportion.

The NoFoam system seemed to have been affected by changes in head pressure on the input side, which was also observed with the tests performed on a full tank compared to a quarter-full tank, as shown in figure 32. This change in head pressure is displayed here as a difference between the averages of nearly 1% in the measured foam proportioning percent. The readings using a low tank also show a much greater variance in results.

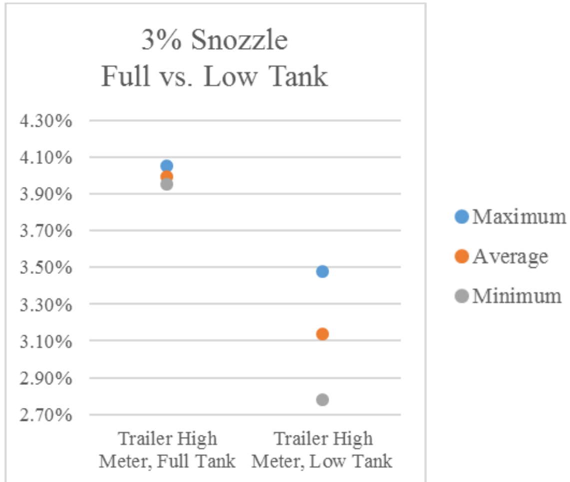


Figure 32. NoFoam Full Tank vs Low Tank

Electronic systems, such as the Foam Boss system on Crash 5, used in these tests are able to adjust to changes in supply. Because the system measures both the input flow rate and the total solution flow, if a change in head pressure causes a lower input flow rate, the system can open the proportioning valve more to compensate.

6.3.6 Effect of Calculation Method

Calculating foam proportioning percent using total foam substitute volume rather than flow rate had a small effect on the recorded percentage. In the case of Crash 9, the average difference in foam proportioning percentage between the two calculation methods was 0.1% or less, as shown in figure 33.

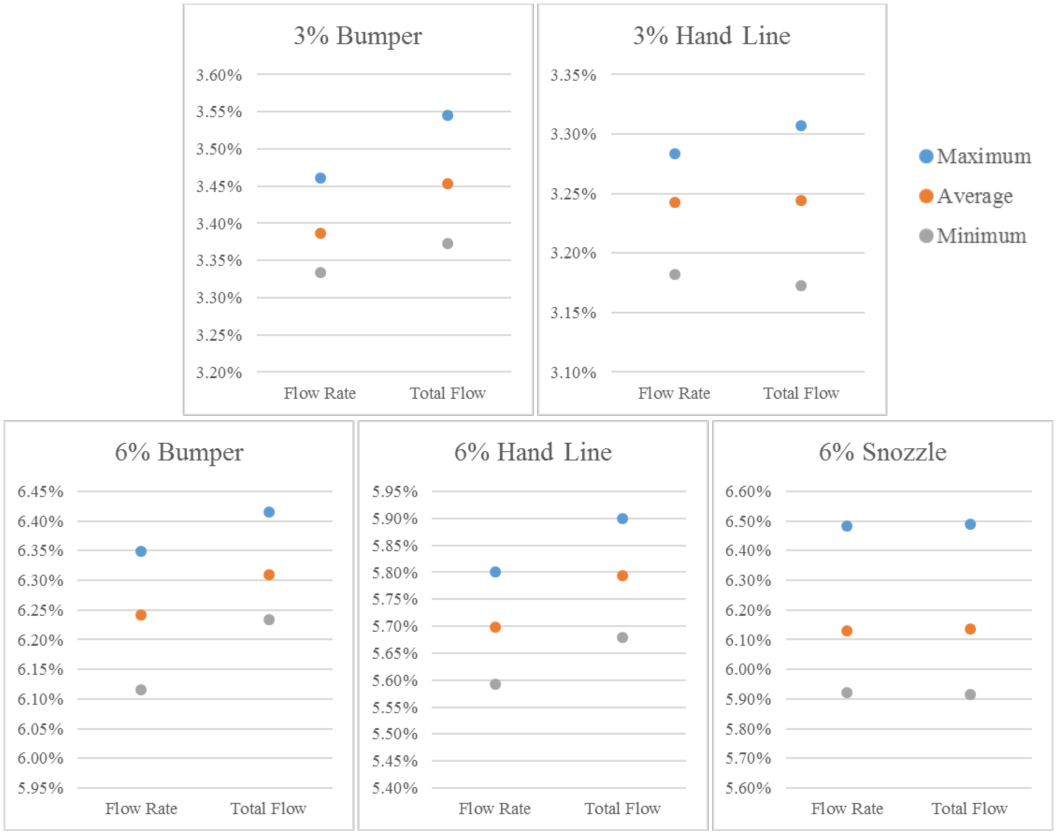


Figure 33. Crash 9 NoFoam Calculation Method Comparison

The 3% Snozzle discharges showed a similar trend, except for the readings on a low tank, which showed a larger difference of between 0.2% and 0.5%, as shown in figure 34.

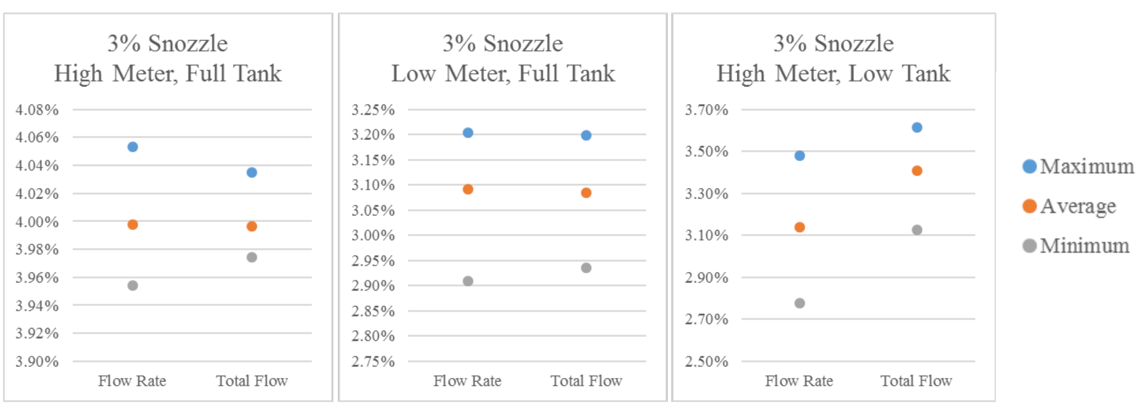


Figure 34. Crash 9 NoFoam Calculation Method Comparison for 3% Snozzle

On Crash 5, the difference between calculation methods decreased with increasing flow rate. On the Bumper High discharges, the difference in measured foam proportioning percent was approximately 0.2%, while on the Bumper Low discharges the difference was closer to 0.4%. In all cases, the calculation using total foam volume was closer to the recorded Foam Boss than the calculation using the foam flow rates. These results are shown in figure 35.

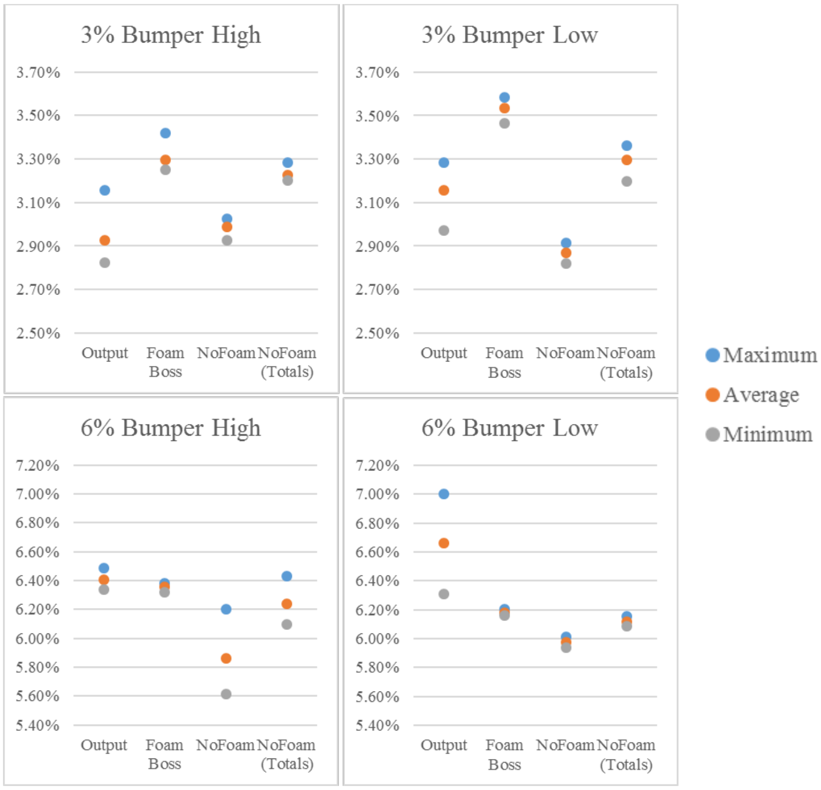


Figure 35. Crash 5 NoFoam Calculation Method Comparison

In general, calculations using total foam flow showed a higher foam proportioning percentage than the calculations using the foam flow rate. In some cases, this brought the measured percentage closer to the output results; but in other cases it either did not increase the measured percentage enough, or increased it too much, such as that observed in Crash 5's 3% Bumper Low results.

6.4 EFFECT OF INSTRUMENTATION ACCURACY

Based on the observable changes using the measurement equipment (0.0001 nD, 0.1 Brix, and 0.001 mS/cm for the refractometer and conductivity meters, respectively) and correlating these graduations to observed measurements of the sample standards, the smallest observable change in proportioning percentage was approximately 0.3% to 0.5% for readings from the refractometer (this includes both refractive index and Brix) and 0.01% for readings from the conductivity meter.

The lower error range on the conductivity meter readings may not mean that it was the most accurate, however. Even on compensated meters, temperature can heavily affect measurements, and the probe can be difficult to clean between samples, making the possibility of human error higher than with the refractometer. This error can be mitigated through improved measurement procedure, such as by ensuring all samples are at the same temperature. However, improved procedure may be difficult for testing performed in the field.

Considering the error range for refractometer readings of proportioning rate as ±0.426% for 3% proportioning rates and ±0.529% for 6% proportioning rates (as the meter can only be accurate to its smallest graduation), the inconsistency observed in the results from Crash 9 fell within the error range. This means that it is possible that the results from Crash 9 were more consistent than observed, but the equipment was not sensitive enough to accurately record it.

The accuracy of the MISCO PA202 is typical of handheld digital refractometers. Manual refractometers are prone to human error due to the complex methods for reading them. Depending on the specific model, they can have a less granular measurement scale [9 and 10]. However, NFPA 412 does not currently make a distinction between analog and digital refractometers. Both are acceptable to use for measurements. Due to this, results that are within the error range of the measurement equipment are considered to correlate to output results for the purposes of this research effort.

Except for 3% and 6% Bumper discharges on Crash 9 and the 6% Bumper High discharge on Crash 5, ECOLOGIC readings came within the error range of the output tests in every case, as shown in appendix D. Two examples of the error range graphs compared to testing results are shown in figure 36. The graph on the left shows 3% Hand Line results from Crash 9, while the graph on the right shows 3% Bumper Low results from Crash 5. The yellow bars show the error range for the output results from the highest measured and lowest measured values, and the dashed lines show the overall error range. It is thought that the exceptionally low readings of the Bumper discharges on Crash 9 are a result of a flow restriction caused by some aspect of the system itself. It is possible that Crash 5 experienced the same restriction, but the exact cause could not be found through this research effort.

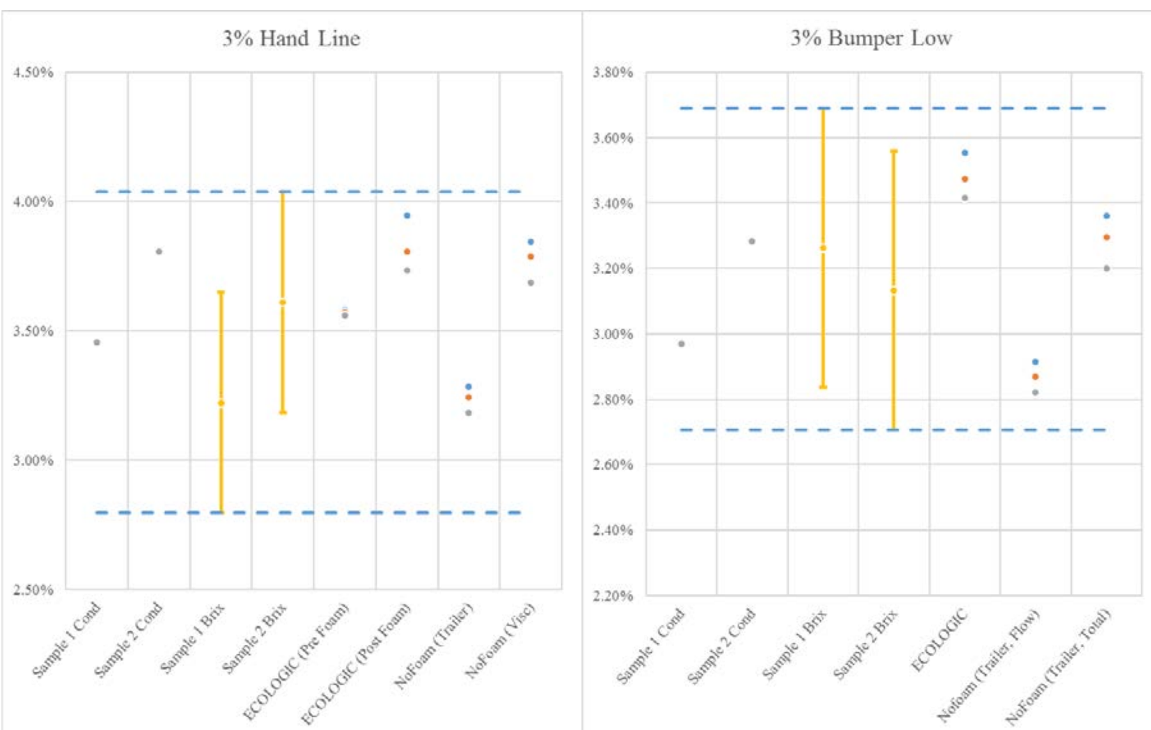


Figure 36. ECOLOGIC Error Range Examples

The NoFoam system readings using typical configurations fell within the output tests error range on all 3% discharges and the 6% hand line discharge on Crash 9. On the 6% Snozzle and Bumper discharges on Crash 9, the NoFoam system showed a reading lower than the error range. The 3% Bumper discharge, while within the error range, was at the very edge of that range. As these discharges had the highest flow rates (with the 3% Bumper discharge and 6% Snozzle discharge having similar foam concentrate flow rates), it is possible that the system was restricted in some way at these higher flow rates.

On Crash 5, the NoFoam system readings fell within the error range on all 3% discharges when calculated either using instantaneous flow rates or total flow volume. On the 6% discharges on Crash 5, the NoFoam system was within the error range on the 6% Bumper Low discharge when calculated using the total flow volume. Results using instantaneous flow were outside the error range, but were still close, the average being within 0.1% of the lower bound. In the case of the 6% Bumper High discharge, both methods exhibited a lower proportioning rate compared to the baseline tests. While the results were noticeably lower than the baseline tests, they were at the low end of the error range.

6.5 OSHKOSH ECOEFP

Based on the limited amount of data available from these tests, the EcoEFP system appeared to accurately report proportioning percentages of the Oshkosh Striker's electronic proportioning system. For testing at the Oshkosh facility, all three discharges showed a proportioning rate of 3%, both during the output-based tests and the EcoEFP tests. Results from the refractometer measurements showed variation from these results. The Hand Line results were 0.33% higher than the refractometer results, the Bumper results were 0.1% higher, and the Roof High results were 0.27% lower.

The type of foam (UL 162 compliant Buckeye Platinum AFFF) used by Oshkosh had a lower measured Brix value than the Mil-Spec foam used in testing at the WJHTC, and thus the potential error from the electronic meter was greater. The variation between the electronically recorded results and the output-based results is possibly caused by measurement error rather than actual differences in proportioning rate.

Testing at the Port Authority Fire Training Facility showed similar results, with the Snozzle and Bumper discharges being within 0.1% to 0.2% of the output results. However, hand line results showed a larger discrepancy with a difference of 1.5% from the output results. It is unknown if the cause of this is a result of the system itself or the hand line on the specific vehicle. Additional testing would have to be performed to determine the root cause.

With the exception of the hand line results from testing at the Port Authority Fire Training Facility, the difference from EcoEFP system output-based test results is comparable to the observed difference from output-based tests of other input-based testing systems at a 3% proportioning rate.

7. CONCLUSIONS

To determine correlation between results of input- and output-based test methods, an error range was established based on the accuracy of currently accepted output-based test methods. The results of input-based proportioning test methods were found to correlate with output-based results if they were within the established error range. The correlation rate only considered the standard methods and configuration of each input-based system at the time of this research effort. Overall, input-based test results correlated to output-based results in 64% of tests. The correlation rate of input-based test results to output-based test results was primarily affected by the proportioning rate and the type of proportioning system.

Input-based tests had a greater correlation at a 3% proportioning rate than a 6% proportioning rate. For tests conducted at a 3% proportioning rate, input-based results correlated in 83% of cases. At a 6% proportioning rate, only 48% of input-based tests correlated to output-based results. The proportioning rate was found to have the greatest effect on the correlation of results.

Input-based test results were also affected by the type of proportioning system. Input-based results with an electronic proportioning system showed correlation in 76% of tests. Results using an orifice plate proportioning system only showed correlation in 61% of tests. At both proportioning rates, the input-based results of the electronic proportioning system exhibited a correlation in 12% more tests than the orifice plate system. At a 3% proportioning rate, electronic foam proportioning systems had a correlation rate of 91% compared to 79% for an orifice plate proportioner system. At a 6% proportioning rate, electronic proportioning systems had a correlation rate of 58% compared to 46% for an orifice plate proportioner system. The input-based systems in all cases demonstrated significant repeatability, even if they did not always correlate to output based tests. Confirmation testing performed at the time of delivery and installation that compares input and output based tests may help offset this difference by establishing reference values representing the current state of the vehicle. With this approach, substantial deviations from the reference value in future measurements can indicate changes in the operating condition of the vehicle. It is highly recommended that airports utilizing the 6% foam proportioning rate have the vendor perform the confirmation testing at the time of delivery.

The use of input-based test systems allows operators to test the functionality of an ARFF vehicle's foam system and can aid in diagnosing related problems without the need to discharge AFFF. According to domestic ARFF vehicle manufacturers, ARFF vehicles are seldom ordered with a proportioning system configured at a 6% proportioning rate. This is to say that the majority of ARFF vehicles ordered are using systems configured at a 3% proportioning rate which was shown to have an overall correlation rate of 83%. Additionally, when using input-based systems testing can be conducted without the costs of collection, clean up, disposal, and replacement of AFFF. This also reduces the firefighters' risk of exposure to AFFF as there is no need to create and collect samples or refill the ARFF vehicle with foam concentrate.

8. REFERENCES

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APPENDIX A—ECOLOGIC WORKSHEET

This appendix provides a sample of the test results worksheet (shown in figure A-1) provided with the E-ONE ECOLOGIC system. The worksheet allows the user to record the test data and provides the relevant formulas to determine the results of the test. The worksheet also provides spaces for recording descriptions of what discharge was tested, who conducted the test, when the test was conducted, the operating conditions of the test, and any comments about the test.

E-ONE

E-ONE ECO-LOGIC FOAM TEST WORKSHEET

SO Number: ____________________ Date: ____________________

Discharge Tested: __________________________ Test Number: ________

Ambient Air Temp.: ___________ Water Temp.: ___________

DISCHARGE FLOW RATE TEST

Discharge Nominal Flow Rate: ___________ (P) - Truck Water Pressure: ___________

<u>**Enter the values in the boxes in the formula below:**</u>

($W1$) = Water Meter Reading Before, in units
($W2$) = Water Meter Reading After, in units
(t_Q) = Time of <u>Discharge</u> Test, in decimal minutes
(Q_D) = Discharge Flow Rate, units/minute

$$\frac{[W2 \text{ - after}] - [W1 \text{ - before}]}{[t_Q \text{ - time}]} = [Q_D \text{ - flow rate}]$$

FOAM PERCENTAGE TEST

Nominal Foam %: ___________ (P) - Truck Water Pressure: ___________

<u>**Enter the values in the boxes in the formula below:**</u>

($F1$) = Foam Meter Reading Before, in units
($F2$) = Foam Meter Reading After, in units
(t_F) = Time of <u>Foam</u> Test, in decimal minutes
(Q_D) = Discharge Flow Rate, units/minute (from above)

$$\frac{([F2 \text{ - after}] - [F1 \text{ - before}])}{[Q_D \text{ - flow rate}] \times [t_F \text{ - time}]} \times 100 = [F\% \text{ - foam percent}]\%$$

Comments: ____

____

Test Conducted By: ____

1050226 Rev B - March 7, 2016 - 17 - E-ONE ECO-LOGIC Mobile Cart System Manual

Figure A-1. E-ONE ECOLOGIC Foam Test Worksheet

APPENDIX B—NOFOAM WORKSHEET

This appendix provides an example of the test worksheet provided with the NoFoam system. The worksheet shown in figure B-1 is formatted specifically for Crash 9, a 1992 E-ONE® Titan™ 4x4 equipped with a Snozzle 501 high-reach extendable turret (HRET) and Feecon® Around-the-Pump proportioning system with an orifice plate. The worksheet provides reference values for the range of acceptable test results for each listed discharge. The worksheet has boxes for recording each data point during the test and a section for notes about the test. The worksheet also provides instructions on how to conduct the test and calculate the proportioning rate to determine the results.

NoFoam Systems

HPRV 9

Titan Dual Tank

FAA - Atlantic City Int'l Airport

DATE & TESTED BY: ______________________

NOFOAM TEST SHEET	Theoretical AFFF flow rates		Water Pressure a.	Time Flowing b.	NoFoam Flowrate c1.	NoFoam Gallon count c2.	Water Refilled d.	Nozzle Gallon count e.	Nozzle Flowrate f.	Concentration Test Result g.	Call Sign: HPRV 9 VIN #: h.
Titan Dual Tank STATION (rated flow GPM)	THEORETICAL FLOW RATE 3% AFFF	NFPA 412 * ACCEPTABLE Range (GPM)	'Read meter' PSI	'Stopwatch' Seconds	'Read meter' GPM	'Read meter' Gallons	'Refill tank' Gallons	c2. + .d. Gallons	(e. / b.) x 60 GPM	100 x c2. / e. Percent	'PASS or FAIL' Notes and comments ↓
Bumper High (800 GPM)	24.0 GPM	22.4 - 28.0									*Straight stream*
Snozzle Low (400 GPM)	12.0 GPM	11.2 - 14.0									*Flat on roof*
Hand Line (60 GPM)	1.8 GPM	1.7 - 2.4									*Flow for 3 minutes*
Bumper High (800 GPM)	24.0 GPM	22.4 - 28.0									*Straight stream*
Snozzle Low (400 GPM)	12.0 GPM	11.2 - 14.0									*Flat on roof*
Hand Line (60 GPM)	1.8 GPM	1.7 - 2.4									*Flow for 3 minutes*

*) NPFA 412 (2014) section 5.2.2: For nominal 3 percent concentrates, the concentration shall be between 2.8 percent and 3.5 percent for turret and ground sweep nozzles and between 2.8 percent and 4.0 percent for hand line and undertruck nozzles.

*) NPFA 412 ACCEPTABLE Range (GPM): These flow rates are indicative only and based on your vehicle's total output according to specifications (STATION theoretical flow). Compliance with NFPA 412 requires you to use the measured flow (column g.).

NOTES:

Testing procedure checklist when using this test sheet:

Bumper High	Snozzle Low	Hand Line	Bumper High	Snozzle Low	Hand Line		Water refill work sheet matrix
							End gallons reading
							- Start gallons reading
							= Water Refilled (for column d.)

1. Shoot a bit of water to fill pipes and hoses.
2. Refill truck completely with water, notice the exact level.
3. Write down water pressure during test. [a.]
4. Use stopwatch to time the test exactly. [b.]
5. Test for 30 seconds or more, until flows are stable.
6. Write down NoFoam Trailer's flow meter reading when stable [c1.]
7. Write total gallons for this discharge [c2.] after flowing, then reset counter to zero.
8. Measure amount of water in gallons to refill truck to same level as before testing. [d.]
9. After all stations are tested, calculate nozzle flow rate (total gallons flowed divided by test time). [e.]
10. Calculate concentration of foam ([c2.] / [e.]). [g.]
11. Repeat steps 3 thru 10 for each station. Re-test any station as needed.
12. Determine PASS/FAIL based on NFPA 412 acceptable range (2.8%-3.5% Roof and bumper; 2.8%-4% hand line and under truck). [h.] Green shaded boxes are used for quick-tests (only using the NoFoam flow).

CAUTION: Always refer to the operations manual for detailed and additional instructions, including important safety precautions. Check the NoFoam System website for updated instructions and current manuals.

Figure B-1. NoFoam Systems Worksheet

APPENDIX C—SAMPLE OUTPUT DATA

This appendix provides a sample calculation sheet for the output tests. Values for refractive index, Brix, and conductivity were calculated using the method described in section 4.1. The average of the three readings taken was then used with the calibration curves described in section 4.5 to find the calculated proportioning rate based on each type of measurement. The calculation from NFPA 412 Method B [2] is labeled as “Meth. B” in the data.

The results shown in table C-1 include readings using refractive index (nD), Brix, conductivity (Cond.), an average of those three methods (Avg.), and a value from using NFPA 412 Method B (Method B). Figure C-1 shows calibration curves generated from output based testing data from table C-1.

Table C-1. Sample Data From Output-Based Testing Including Calculated Proportioning Percentage Values

2% Sample			
	nD	Brix	Cond.
1	1.3337	0.5	0.523
2	1.3337	0.5	0.527
3	1.3337	0.5	0.514
Avg.	1.3337	0.5	0.521

3% Sample			
	nD	Brix	Cond.
1	1.334	0.7	0.658
2	1.334	0.7	0.662
3	1.334	0.7	0.657
Avg.	1.334	0.7	0.659

4% Sample			
	nD	Brix	Cond.
1	1.3344	1	0.797
2	1.3344	1	0.801
3	1.3344	1	0.799
Avg.	1.3344	1	0.799

Discharge Time:	50		
Sample Time	40		

Bumper Discharge			
	nD	Brix	Cond.
1	1.3341	0.8	0.654
2	1.3341	0.8	0.656
3	1.3341	0.8	0.657
Avg.	1.3341	0.8	0.656

Water			
	nD	Brix	Cond.
1	1.333	0	0.183
2	1.333	0.1	0.182
3	1.3331	0	0.177
Avg.	1.3330	0.033	0.181

Foam			
	nD	Brix	Cond.
1	1.3663	21.6	4.55
2	1.3665	21.6	4.56
3	1.3665	21.6	4.58
Avg.	1.3664	21.6	4.56

	nD	Brix	Cond.
2%	1.3337	0.5	0.521
3%	1.334	0.7	0.659
4%	1.3344	1	0.799
Turret	1.3341	0.8	0.656

	nD	Brix	Cond.	Avg.	Meth. B
Linear Int.	3.19%	3.26%	2.97%	3.14%	3.19%

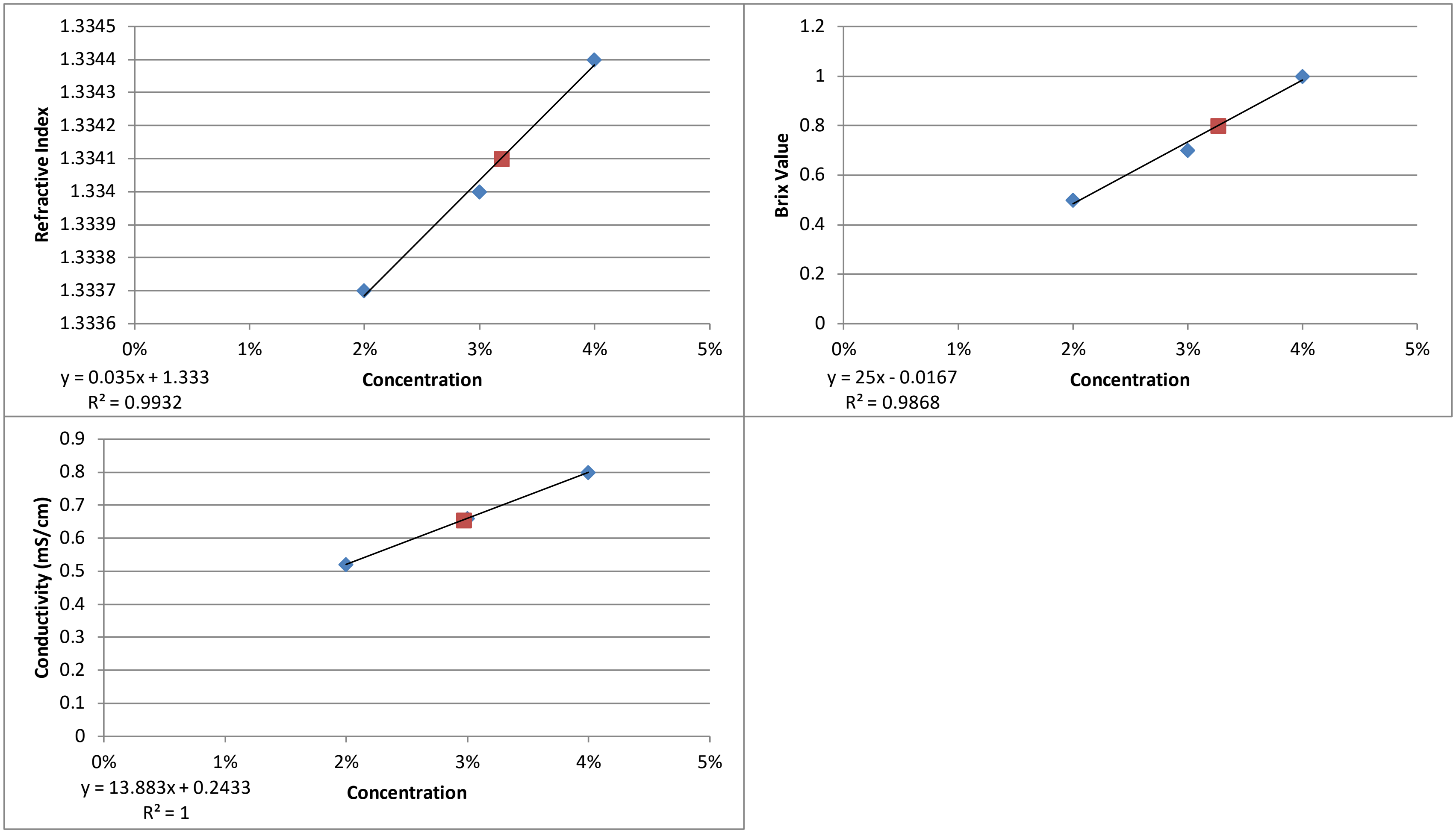

Figure C-1. Calibration Curves Generated From Output Based Testing Data From Table C-1

APPENDIX D—ERROR RANGE ANALYSIS

This appendix shows the error range analysis for Crash 9, a 1992 E-ONE® Titan™ 4x4 equipped with a Snozzle 501 high-reach extendable turret (HRET) and Feecon® Around-the-Pump proportioning system with an orifice plate (shown in figure D-1), and Crash 5, a 2005 Oshkosh Legacy Striker® 3000 equipped with a Snozzle® 651 HRET and Nordic Systems Corp. Foam Boss® electronic proportioning system (shown in figure D-2). Except for 3% and 6% Bumper discharges on Crash 9 and the 6% Bumper High discharge on Crash 5, ECOLOGIC readings came within the error range of the output tests in every case

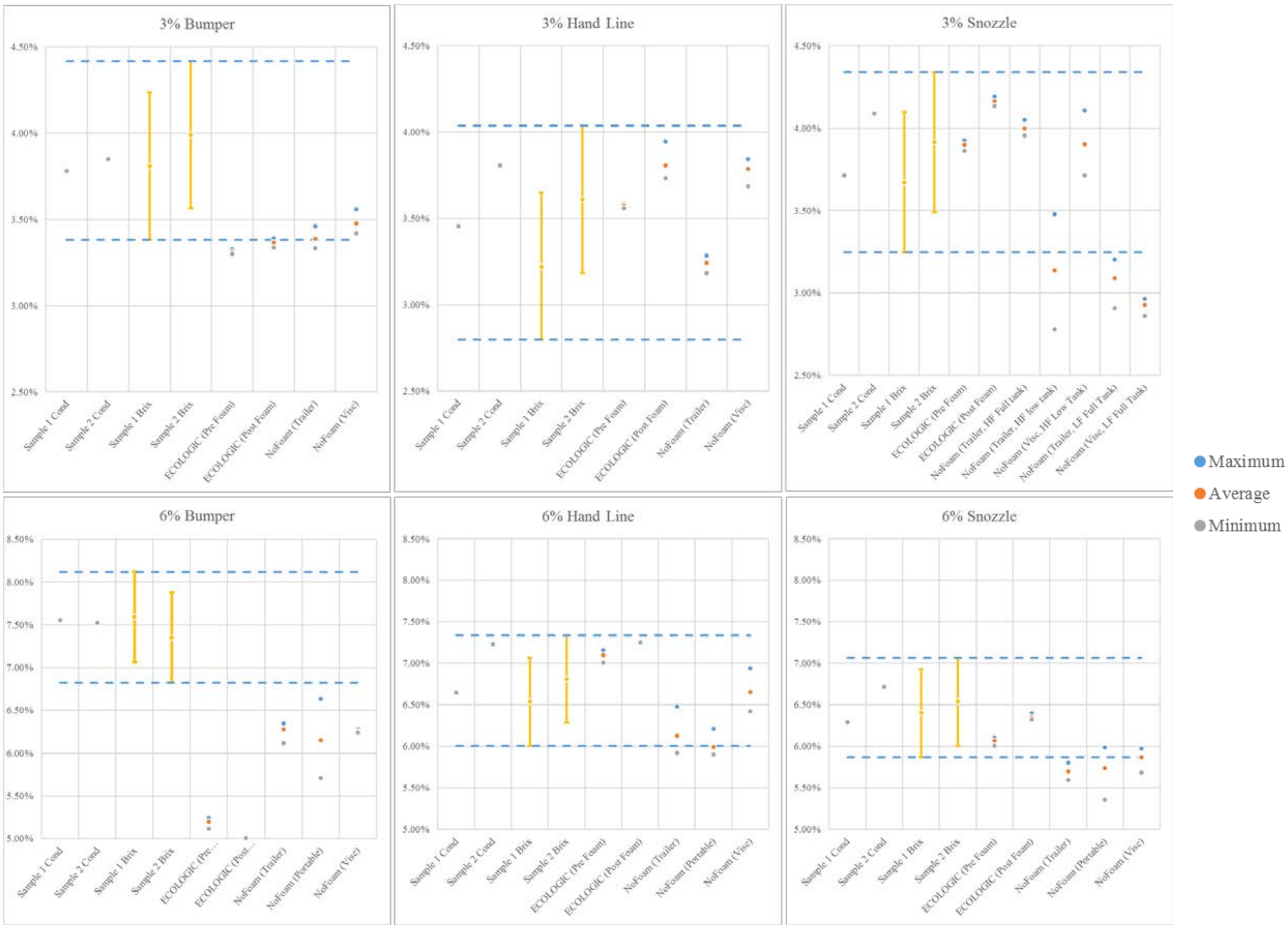

Figure D-1. Crash 9 Error Range Analysis

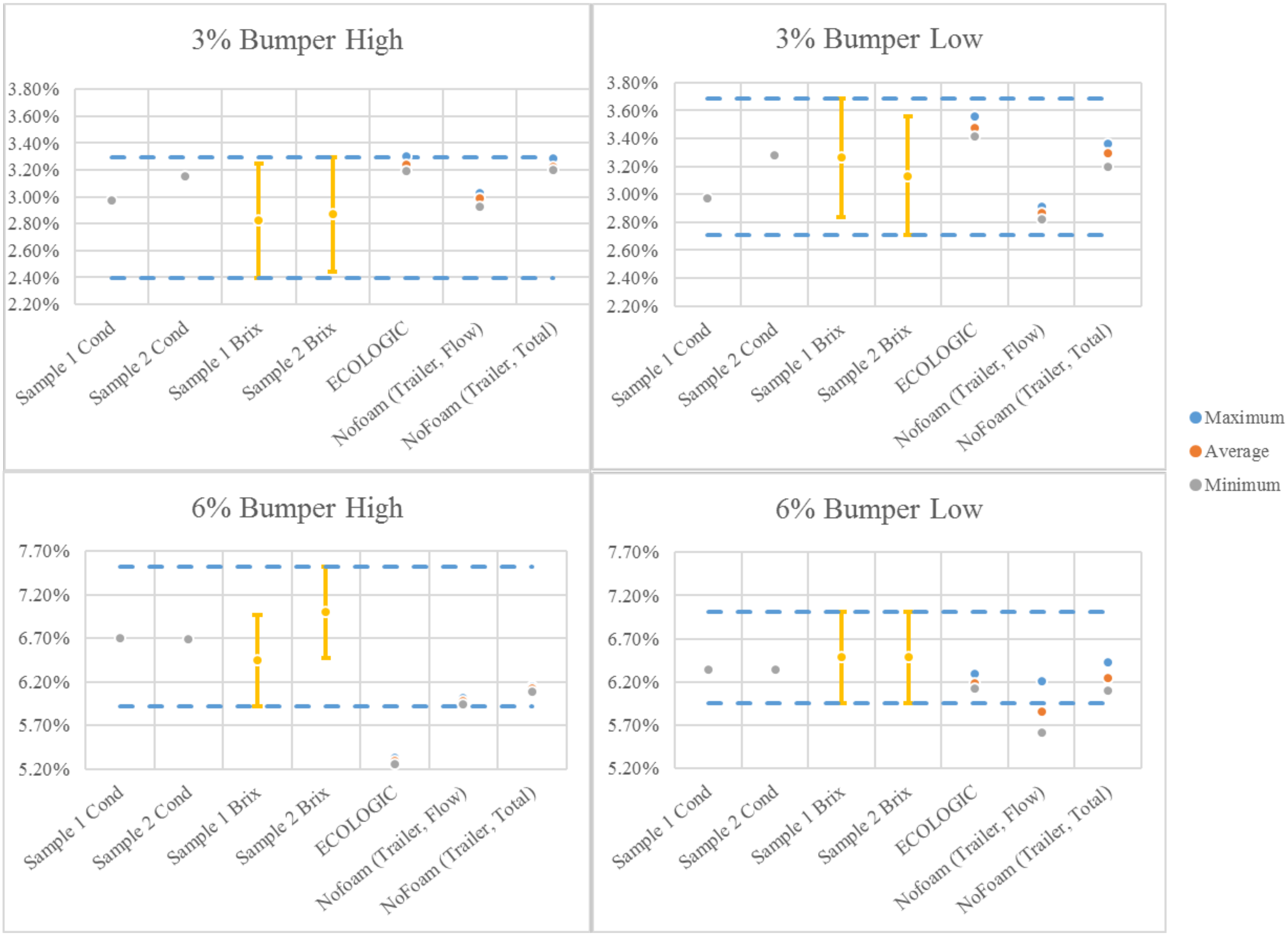

Figure D-2. Crash 5 Error Range Analysis