Module 5

Fire Fighting Foam Principles and Ethanol-Blended Fuel

Terminal Objective

Upon the successful completion of this module, participants will be able to develop foam use strategies for controlling/fighting fires associated with ethanol-blended fuels.

Enabling Objectives

1. Describe the manner in which foam applications can be used fight fuel fires.
2. List the ways in which foam applications suppress fire.
3. Predict when to fight fuel fires and when to simply protect surrounding areas.
4. State the generally accepted “rule of thumb” for the use of foam applications on ethanol-blended fuel fires.

Instructor Note:

Module Time: *1 hour*

Materials: Responding to Ethanol Incidents *video*

Introduction

As discussed previously, we have seen that the production of ethanol is quite large and likely to continue to increase. The predominate danger from ethanol emergencies is not from incidents involving cars and trucks running on ethanol-fuel blends, but instead from tanker trucks and rail cars carrying large amounts of ethanol, manufacturing facilities, and storage facilities. Responders need to be prepared for large-scale emergencies and prepared with the most effective techniques and extinguishing media. This module will focus on foam basics and then foam applied specifically to ethanol-related emergencies.

Basic Foam Principles

Instructor Note:

Tell participants that this section covers basic principles of foam use. It is put here because not all participants will have this basic knowledge of foam. It also provides a bridge to the next section on specific foam use with ethanol and helps to broaden their understanding of why most foams are ineffective when used on ethanol emergencies.

What is Foam?

As defined in National Fire Protection Association (NFPA) 11, low-expansion foam is:

"…an aggregate of air-filled bubbles formed from aqueous solutions which is lower in density than flammable liquids. It is used principally to form a cohesive floating blanket on flammable and combustible liquids, and prevents or extinguishes fire by excluding air and cooling the fuel. It also prevents reignition by suppressing formation of flammable vapors. It has the property of adhering to surfaces, which provides a degree of exposure protection from adjacent fires."

Why Use Foam?

Many extinguishing agents are effective on flammable liquids. However, foam is the only agent capable of suppressing vapors and providing visible proof of security. Reasons to use foam include:

- A foam blanket on an unignited spill can prevent a fire.
- The suppression of vapors prevents them from finding an ignition source.
- Foam can provide post-fire security by protecting the hazard until it can be secured or removed.
- Foam can provide protection from flammable liquids for fire and rescue personnel during emergency operations.

How Foam Works

Foam can control and extinguish flammable liquid fires in a number of ways. Foam can:

- exclude oxygen from the fuel vapors and thus prevent a flammable mixture,
- cool the fuel surface with the water content of the foam,
- prevent the release of flammable vapors from the fuel surface, and
- emulsify the fuel (some environmental foams).

Foam Tetrahedron

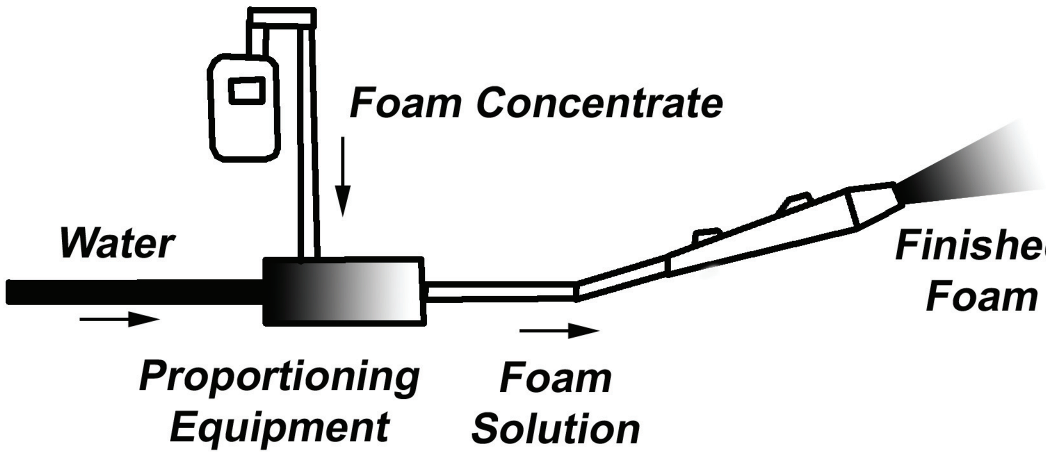
Foams used today are primarily of the mechanical type. This means that before being used, they must be proportioned (mixed with water) and aerated (mixed with air).

Four elements are necessary to produce a quality foam blanket. These elements include:

- foam concentrate,
- water,
- air, and
- aeration (mechanical agitation).

All of these elements must be combined properly to produce a quality foam blanket (see Figure 5.1).

Figure 5.1: Foam Production



If any of these elements are missing or are not properly proportioned, the result is a poor-quality foam or no foam at all.

What is Foam Not Effective On?

Foam is *not* effective on all types of fires. It is important to know the type of fire and the fuel involved. Foam is not effective on:

- Class C fires,
- three-dimensional fires,
- pressurized gases, and
- Class D fires.

Foam is Not Effective on Class C Electrical Fires

Class C fires involve energized electrical equipment; water conducts electricity. Since foam contains 94–97 percent water, it is not safe for use on this type of fire. In some cases, foam concentrate is even more conductive than water.

Class C fires can be extinguished using nonconductive extinguishing agents such as a dry chemical, carbon dioxide (CO_2), or halon. The safest procedure for this type of situation is to de-energize the equipment if possible and treat it as a Class A or Class B fire.

Foam is Not Effective on Three-Dimensional Fires

A three-dimensional fire is a liquid-fuel fire in which the fuel is being discharged from an elevated or pressurized source, creating a pool of fuel on a lower surface.

Foam is not effective at controlling three-dimensional flowing fires.

It is recommended that firefighters control a three-dimensional flowing fire by first controlling the spill fire; then they may extinguish the flowing fire using a dry chemical agent.

Foam is Not Effective on Pressurized Gases

Foam is not effective on fires involving pressurized gases. These materials are usually stored as liquids, but are normally vapor at ambient temperature. The vapor pressure of these types of fuels is too high for foam to be effective. To be effective, foam must set up as a two-dimensional blanket on top of a pooled liquid.

Examples of pressurized gases include:

- propane,
- butane,
- vinyl chloride, and
- butadiene.

Foam is Not Effective on Combustible Metals

Class D fires involve combustible metals such as aluminum, magnesium, titanium, sodium, and potassium. Combustible metals usually react with water; therefore, foam is not an effective extinguishing agent.

Fires involving combustible metals require specialized techniques and extinguishing agents that have been developed to deal with these types of fires. A Class D extinguisher or a Class D powder is the recommended choice for fires involving combustible metals.

What is Foam Effective On?

Foam is effective at suppressing vapors and extinguishing Class B fires. Class B fires are defined as fires involving flammable or combustible liquids. For the purposes of this discussion, Class B products are divided into two categories: hydrocarbons and polar solvents.

Hydrocarbons

Most hydrocarbons are byproducts of crude oil or have been extracted from vegetable fiber. Hydrocarbons have a specific gravity of less than 1.0 and therefore float on water.

Examples of hydrocarbon fuels include:

- gasoline,
- diesel,
- jet propellant (JP4),
- heptane,
- kerosene, and
- naptha.

Polar Solvents

Polar solvents are products of distillation or products that have been synthetically produced. Polar solvent fuels are miscible, that is they will mix with water. Polar fuels have a varying attraction for water. For example, acetone has a stronger affinity for water than does rubbing alcohol.

Polar solvent fuels are usually destructive to foams designed for use on hydrocarbons. Specially formulated foams have been developed for use on polar solvents.

Some examples of polar solvent fuels include:

- ketones,
- esters,
- alcohol including ethyl-alcohol (ethanol),
- amine,
- methyl tertiary-butyl ether (MTBE), and
- acetone.

Foam Terminology

Before discussing the types of foam and the foam making process, it is important to understand the following terms:

- *Foam concentrate* is the liquid substance purchased from a manufacturer in a container, pail, drum, or tote.

- *Foam solution* is the mixture obtained when foam concentrate is proportioned (mixed) with water prior to the addition of air.

- *Finished foam* is obtained by adding air to foam solution through either entrainment or mechanical agitation.

Types of Foam

Several foam types have been developed over the years, each with particular qualities:

- *Protein foam*, one of the earliest foams, is produced by the hydrolysis of protein material such as animal hoof and horn. Stabilizers and inhibitors are added to prevent corrosion, resist bacterial decomposition, and control viscosity.

- *Fluoroprotein foams* are formed by the addition to protein foam of special fluorochemical surfactants that reduce the surface tension of the protein-based concentrate and allow more fluid movement.

- *Aqueous Film-Forming Foam* (AFFF) replaces protein-based foamers with synthetic foaming agents added to fluorochemical surfactants. Designed for rapid knockdown, AFFFs sacrifice heat resistance and long-term stability.

- *Film-Forming Fluoroprotein Foam* (FFFP) is a protein-based foam with the more advanced fluorochemical surfactants of AFFF. FFFPs combine the burnback resistance of fluoroprotein foam with the knockdown power of AFFF.

- *Alcohol-Resistant (AR) foam* is a combination of synthetic stabilizers, foaming agents, fluorochemicals, and synthetic polymers designed for use on polar solvents. The chemical makeup of these foams prevents the polar solvents from destroying them. Today’s more modern AR foams can be used on both polar solvents and hydrocarbons.

Foam Characteristics

No single foam product performs the same for all classes of fires. Each foam type excels at different functions; however, performance in other areas is often diminished. Knockdown, heat resistance, fuel tolerance, vapor suppression, and alcohol tolerance are all characteristics of various foam types. Each property is explained in the text that follows.

Knockdown

Knockdown is the speed at which foam spreads across the surface of a fuel. Quick knockdown is achieved by allowing the solution contained in the bubbles to spread rapidly across the fuel surface. Extremely quick knockdown sacrifices good post-fire security, which is required for a stable, long-lasting foam blanket.

Heat Resistance

Heat resistance is the ability of a foam bubble to withstand direct flame impingement or contact with elevated temperature surfaces, with little or no destruction to the foam bubble. The heat resistance of a foam blanket is often called “burnback resistance.”

Fuel Tolerance

Fuel tolerance is the ability of the foam to enter the fuel and resurface with little or no pick up of fuel within the structure of the bubble. A foam bubble which picks up fuel while submerged would simply carry the fuel to the surface and feed the fire.

Vapor Suppression

Vapor suppression is the ability of the foam blanket to suppress flammable vapors and prevent their release. Vapor suppression is necessary to extinguish fires involving flammable liquids and to prevent ignition of unignited flammable liquid spills.

Alcohol Tolerance

Alcohol tolerance is the ability of the foam blanket to create a polymeric barrier between the fuel and the foam, thus preventing the absorption of the water from the foam bubbles. This absorption would result in the destruction of the foam blanket.

Table 5.1: Various Types of Foam Rated by Their Properties

Property	Protein	Fluoroprotein	AFFF	FFFP	AR-AFFF
Knockdown	Fair	Good	Excellent	Good	Excellent
Heat Resistance	Excellent	Excellent	Fair	Good	Good
Fuel Tolerance	Fair	Excellent	Moderate	Good	Good
Vapor Suppression	Excellent	Excellent	Good	Good	Good
Alcohol Tolerance	**None**	**None**	**None**	**None**	**Excellent**

Source: National Foam

Foam Proportioning and Delivery Systems

The effectiveness of foam depends on proper proportioning and the ability to deliver finished foam to the spill or fire.

Concentration Levels

Foams are applied at various concentration levels depending on the fuel involved and the concentrate being used.

Typically for *hydrocarbons*, foam is proportioned at 3 percent: that is three parts foam concentrate to ninety-seven parts water.

For *polar solvents*, foam is usually proportioned at 6 percent: that is six parts foam concentrate to ninety-four parts water.

Some concentrates allow for proportioning at 1 percent on hydrocarbons.

Foam Proportioning Systems

A number of ways exist to proportion foam. These include:

- line eductors,
- self-educting nozzles,
- pressure systems, and
- pump proportioning systems.

This section will discuss the most common proportioning systems: line eductors and foam nozzle proportioners (foam nozzles with pickup tubes).

Eductors

Eductors use the *venturi* principle to pull foam into the water stream. The flow of water past the venturi opening creates a vacuum that draws the concentrate through the metering valve.

The *metering valve* controls the amount of concentrate allowed to flow into the water stream.

The *ball check valve* prevents water from flowing back into the pickup tube and the concentrate container.

Major elements of the eductor setup include foam concentrate supply, water supply, eductor arrangement, metering valve, pickup tube, and foam solution discharge.

Two common types of eductors are *in-line eductors* and *bypass eductors*.

In-Line Eductors

In-line eductors are some of the least expensive and simplest pieces of proportioning equipment available (see Figures 5.2 and 5.3). For this reason, they are perhaps the most common type of foam proportioner used in the fire service. Some advantages include:

- low cost,
- minimal maintenance, and
- simple operation.

Figure 5.2: In-Line Eductor

Figure 5.3: In-Line Indicator

Bypass Eductors

Bypass eductors (see Figures 5.4 and 5.5) differ in that they have a ball valve to divert flow from foam to just water, allowing time for cooling without wasting foam and with less flow restriction.

Figure 5.4: Bypass Eductor

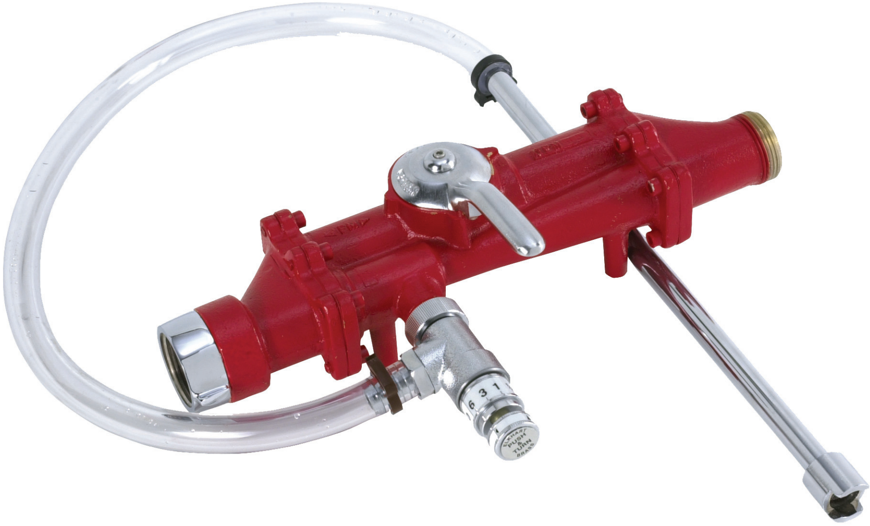
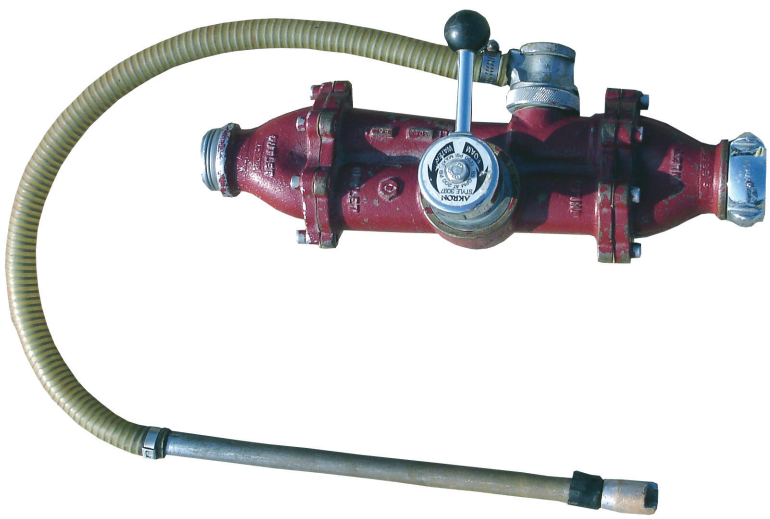


Figure 5.5: Bypass Indicator



Common Eductor Failures

The most common causes for eductor failure include:

- mismatched eductor and nozzle,
- air leaks in the pickup tube,
- improper flushing after use,
- kinked discharge hoseline,
- improper nozzle elevation,

- too much hose between eductor and nozzle, and
- incorrectly set nozzle flow.

These may be eliminated by careful preparation, inspection, and use of the eductor, nozzle, and hose.

Other eductor failures may be caused by:

- incorrect inlet pressure to eductor,
- partially closed nozzle shutoff,
- collapsed or obstructed pickup tube, and
- a pickup tube which is too long.

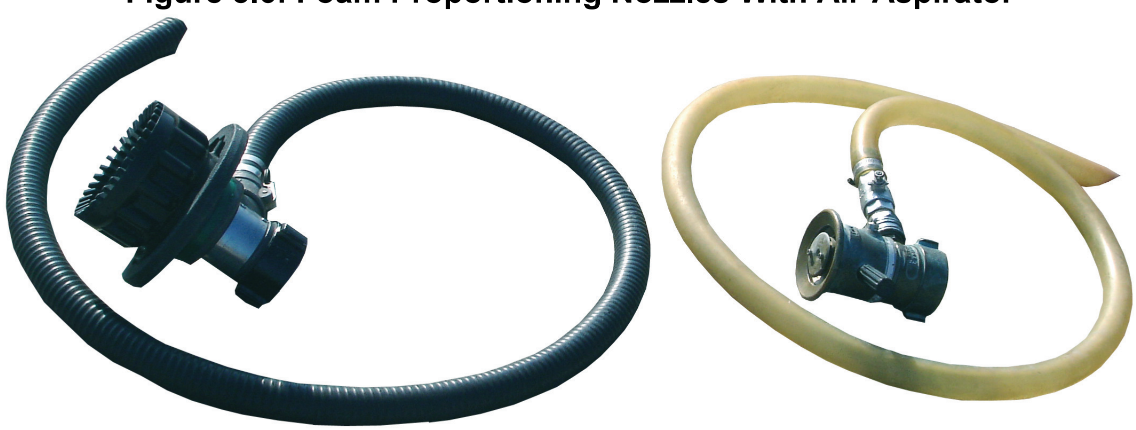
Foam Nozzles

Foam nozzles are either foam proportioning, air aspirating, or non-air aspirating.

Foam Proportioning Nozzles

Foam proportioning nozzles (see Figure 5.6) have built-in orifice plates and utilize the venturi principle of operation, producing a very effective foam. These monitor nozzles have the ability to deliver significant volumes of finished foam. Due to the insignificant pressure drop across the eductor, they are able to project foam over long distances.

Figure 5.6: Foam Proportioning Nozzles With Air-Aspirator



Advantages of foam proportioning nozzles include:

- they are easy to operate,
- they are easy to clean,

- there are no moving parts, and
- there is no additional foam equipment needed.

Air Aspirating Nozzles

Air aspirating nozzles are foam generating nozzles that mix air and atmospheric pressure with foam solution (see Figure 5.7). These nozzles produce an expansion ratio of between 8:1 and 10:1 and produce a good-quality, low-expansion foam.

Figure 5.7: Air Aspirating Nozzles

Non-Air Aspirating Nozzles

Fog nozzles are an example of non-air aspirating nozzles (see Figure 5.8). Non-air aspirating nozzles produce an expansion ratio of between 3:1 and 5:1. This expansion ratio is not as good as that of air aspirating nozzles, but these nozzles often add some versatility which can be beneficial in various fire attack situations. Versatility includes the ability to switch from a foam solution to water in order to protect personnel and provide area cooling. Air aspirating nozzles do not offer this advantage.

Figure 5.8: Non-Air Aspirating Nozzles

A disadvantage of aspirating and non-air aspirating nozzles is that you must have additional equipment in order to generate foam. In addition, the gallonage setting on the nozzle must match the set flow for the eductor. It is important to understand the benefits of both types of nozzles in order to select the most appropriate one.

Application Techniques

Proper application is critical for foam. The key to foam application is to apply the foam as gently as possible to minimize agitation of the fuel and creation of additional vapors.

The most important thing to remember is to *never plunge the foam directly into the fuel*. This will agitate the fuel and create additional vapors.

Bounce-Off

The bounce-off method is effective if there is an object in or behind the spill area. The foam stream can be directed at the object, which will break the force of the stream, allowing the foam to gently flow onto the fuel surface.

Bank-In

When no obstacles exist to bounce the foam off, firefighters should attempt to roll the foam onto the fire. By hitting the ground in front of the fire, the foam will pile up and roll into the spill area.

This technique is particularly effective with non-air aspirating fog nozzles. The mechanical agitation of the foam hitting the ground will help to aerate the foam.

Rain-Down

An alternative application technique is the rain-down method. The nozzle is elevated and the foam is allowed to fall over the spill as gently as possible.

Warning! *Never* plunge a stream of foam *directly* into fuel!

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Foam and Ethanol and Ethanol-Fuel Blends

Some of the foams mentioned in the previous sections have been around for over fifty years and have proven to be very effective on hydrocarbon fuels. However, these foams that were not developed for application on alcohol- or ethanol-blended fuels are simply ineffective on fuels containing alcohols or ethanol. This is because the alcohol or ethanol content of the blended fuel literally attacks the foam solution, absorbing the foam solution into the ethanol-blended fuel. Foam that is designed to be alcohol resistant forms a tough membrane between the foam blanket and the alcohol-type fuel. It is crucial that these AR foams are used in combating ethanol-blended fuel fires, including E-10. This is an important point. Additionally, to be effective, these foams must be applied gently to the surface of the alcohol- or ethanol-blended fuels. Otherwise, the foam is absorbed into the fuel and will not resurface to form an encapsulating blanket.

Extensive testing done at the Ansul Fire Technology Center indicated that even at low-level blends of ethanol with gasoline, as low as E-10, there is a major effect on foam performance. The testing also indicated that with high-level blends of ethanol with gasoline, even AR foams required careful application methodology and techniques to controls fires. AR-type foams must be applied to ethyl alcohol fires using Type II gentle application techniques. For responding emergency services, this will mean directing the foam stream onto a vertical surface and allowing it to run down onto the fuel. Direct application to the fuel surface will likely be ineffective unless the fuel depth is very shallow (i.e., 0.25 inches or less). Type III application (fixed and handline nozzle application) is prone to failure in ethanol-blended fuels of any substantial depth. The only time it is effective is when it is deflected off surfaces, such as tank walls, to create a gentle style application. It has also been found that even with indirect application off surfaces, it may require substantial increases in flow rate to accomplish extinguishments. Therefore, in situations where AR foam cannot be applied indirectly by deflection of the foam off tank walls or other surfaces or there is no built-in application device to provide gentle application, the best option may be to protect surrounding exposures.

Another property of alcohol- or ethanol-type fuel fires is that they require a higher flow rate (application rate) of foam to extinguish fires. AFFF-type foams require approximately 1 gallon per minute (gpm) foam solution flow for every 10 square feet of burning surface on a hydrocarbon-type fuel. Ethanol-blended fuels require approximately double that flow (2 gpm/10 square feet) of an AR-type foam solution. As with all types of foam, mixing percentage is dependent upon the type and design of the foam concentrate.

Foam Recommendations for Fire Departments

Departments that are subject to incidents involving the various blends of fuels found on highway incidents or at storage facilities should strongly consider converting to AR foam concentrates or develop a means of having a cache of AR foam readily available. If a department has a specific hazard that only involves nonalcohol or nonethanol blended fuels, they may want to consider non-AR foam for that specific hazard. However, for over-the-road incidents they should have AR foam readily available. Keep in mind that AR foams are effective on both alcohol fires and hydrocarbon fires. As a matter of fact, some of the AR foams have quicker knockdown abilities and longer foam retention times than some of the traditional protein-based hydrocarbon foams. It is also recommended that a thermal imaging camera be used to more accurately determine if a fire is completely extinguished, especially during sunlight hours.

With the present placarding and labeling of fuels in transport, it may not be easy to identify the various fuel blends when involved in an incident (see Figures 5.9–5.11).

Instructor Note:

Ask participants to offer a "rule of thumb" for foam use.

Answer: *Use AR foam at double the normal flow rate for all gasoline/gasoline-blend fires.*

Refer participants to Figures 5.9–5.11 for images of placards United Nations' (UN) 1203 (for E-10), UN 3475 (for E-85),and North American (NA) 1987 (for E-95).

Ask participants why current placarding policies can make identification of ethanol-blended fuels difficult.

Answer: *Most current placarding systems do not differentiate between gasoline and ethanol-blends. Also mention that a new placard was just adopted for ethanol-blends*

Figure 5.9: United Nations' (UN) 1203 Placard for E-10 or Gasoline

Figure 5.10: UN 3475 Placard for E-85

Figure 5.11: North American (NA) 1987 Placard for E-85, E-95, or E-100

Instructor Note:

Ask participants how multiple placards for fuels like E-85 can cause confusion and problems in mitigating emergencies.

UN 1993, which is for diesel, kerosene, and other similar fuels, has also been used (though not recommended) for ethanol-blended fuels. Responders should always use their judgment when responding based on placarded information.

Since AR foams are universally effective on both ethanol-blended fuels and nonethanol-blended fuels, they would be the foam of choice. When uncertain as to whether the fire encountered is an alcohol- or ethanol-blended fuel, fire departments may want to consider doubling their application rate (gpm) ability since ethanol-blended fuels require a higher rate of flow, keeping in mind that increasing the flow rate also increases water requirements.

Instructor Note:

To reinforce what was discussed in this module, show the segment from 6:12 to 10:45 from the video Responding to Ethanol Incidents*. This segment deals with the use of Type II and Type III foam application.*

Source: *Ethanol Emergency Response Coalition (EERC). (2007).* Responding to Ethanol Incidents *[Video].*

After the video ask and discuss the following:

- *What is the purpose of the burnback test?*
  - ***Answer:*** *To evaluate a foam's resistance to fire*
- *In Type II application with 95 percent ethanol, which foam was most effective?*
  - ***Answer:*** *AR-AFFF*
- *How did the AR-AFFF perform in the Type II test with 95 percent ethanol?*
  - ***Answer:*** *It extinguished the fire but failed the burnback test.*
- *Which was the only foam to pass the sprinkler test in a 95 percent ethanol fire?*
  - ***Answer:*** *AR-AFFF*
- *In the Type III test with 10 percent ethanol, did the AR-AFFF pass the test at the normal usage rate?*
  - ***Answer:*** *No, only at an increased usage rate*
- *Based on what we discussed in the module and what we saw in the video, what would be the best foam application method for Type III applications? Why?*
  - ***Answer:*** *Banking, because this method directs the foam stream toward a structure or object adjacent to the burning fuel to create a cascading effect that introduces the foam into the burning surface more gently then plunging or direct application.*
- *Why should direct application or plunging be avoided in ethanol or ethanol-fuel blend fires?*
  - ***Answer:*** *Plunging disturbs the polymers in the foam and prevents proper mixing with the polar solvent.*

Summary

Foam is accepted as the best fire suppression/fire fighting agent for use in incidents involving hydrocarbons and ethanol-blended fuels. Because of its ability to maintain a protective layer on ethanol-blended fuels, AR foam is the best choice for incidents involving these types of fuel. Because AR foam also works well on gasoline fires, it is the recommended choice for all fuel fires involving either gasoline- or ethanol-blended fuels.

AR foam does perform on hydrocarbon fires as well, so if it is unclear the nature of the burning fuel, AR is the preferred choice from a response standpoint.

References

NFPA. (2005). NFPA 11: *Standard for Low-, Medium-, and High-Expansion Foam*. Quincy, MA: NFPA.