



STORAGE TANKS

FIXED OR SEMI-FIXED SYSTEMS

Today, fires in storage tanks are rare events. During the development of the oil industry, however, tank fires were common occurrences. The design of the storage tanks often led to problems with fire, since the tanks were constructed using wood and tar coated paper. Tank fires were common, especially during a lightning storm. These experiences led to improvements in better codes and guidelines for handling storage tank fires. Floating roof tanks were adopted for petroleum products and proved to be a most reliable method of protection against losses due to fires. The less volatile products with higher flash points continue to be stored in welded steel fixed cone roof tanks.

As the frequency of fully involved storage tank fires decreases to a more acceptable level, the size of fire, when it happens, becomes larger due to the increase in tank size and capacity. It is quite common to see tanks with diameters in excess of 328 ft. (100 meters) capable of storing a million barrels of product.

One practical method to protect flammable liquid storage tanks from fire is with a fixed or a semi-fixed foam fire protection system. When engineered, installed and maintained correctly, these systems will give many years of reliable service. The foam system can be used for fire prevention, control or direct extinguishment of any flammable or combustible liquid fire within the tank.

In order to select the correct foam system, it is necessary to understand the following systems:

A Fixed System is a complete installation piped from a central foam station, discharging through fixed discharge devices on the hazard being protected. Foam proportioning components are permanently installed.

A Semi Fixed System is an installation where the hazard is equipped with fixed discharge device(s) which connect to piping that terminates a safe distance from the hazard. (Normally outside the dike wall). Foam producing materials are transported to the scene after the fire starts and are connected to the piping.

DEFINITIONS

There are three major types of tanks commonly used for the storage of combustible or flammable liquids.

- Cone roof tank
- Open top floating roof tank
- Internal floating roof tank/Covered Floating Roof

A Cone Roof Storage Tank has vertical sides and is equipped with a fixed cone-shaped roof that is welded to the sides of the tank. Tanks that have been designed in accordance with API standards have a weak seam at the joint where the roof and sides meet. In the event of an internal explosion, the roof separates and blows off leaving the tank shell intact. This system allows the tank to retain its contents and any resulting fire will involve the full surface of the exposed flammable liquid.

An Open Top Floating Roof Storage Tank is similar to the cone roof tank in construction but with the exception that it has no fixed roof. A pontoon type roof floats directly on the flammable liquid surface. This floating roof has a mechanical shoe or tube seal attached to its full perimeter. The rim seal covers the space between the floating roof and the tank shell (side wall.)

An Internal Floating Roof/Covered Floating Roof Storage Tank is a combination of both the cone roof and the open top floating roof tank. The tank has a cone roof but with the addition of an internal floating roof or pan that floats directly on the fuel surface. This type of tank can be identified by the open vents in the tank side walls just beneath the roof joint. If the internal floating roof is other than a steel double deck or pontoon type, the fire protection system should be designed for full surface fires (similar to cone roof tanks.) For the double deck or pontoon internal roofs of steel construction, a design for seal area protection shall be permitted (same as open floating roof tanks.)



Small quantities of flammable liquids are sometimes stored in horizontal style tanks which normally sit on saddles or in underground storage facilities. This section applies only to the three major types of tanks as listed above.

IDENTIFY THE FLAMMABLE LIQUID

There are two basic classifications of flammable and combustible liquids:

- Hydrocarbon (non water miscible) and
- Polar Solvent (water miscible)

The Hydrocarbon family typically consists of standard petroleum products such as - Gasoline, Kerosene, Diesel, Jet Fuel, Heptane, Crude Oil which are products that do not mix with water.

The Polar Solvent group typically consists of Ethanol, Methanol, Ketone, Acetone or products that will mix readily with water.

All Buckeye U.L. Listed Foam Concentrates are suitable for use on Hydrocarbon fuel fires or spills.

Only Buckeye U.L. Listed 3% and the 3%-6% (at 6% proportioning rate) Alcohol Resistant -Aqueous Film Forming Foam (AR-AFFF) concentrates are suitable for use on Polar Solvent Fuel fires or spills.

NOTE: Pure MTBE is only slightly water miscible (approx. 5% - 7%.)

FLAMMABLE AND COMBUSTIBLE LIQUIDS

PER NFPA 11

Flammable liquids mean any liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 psi (276 kpa)(absolute) at 100°F (37.8 C.).

Flammable Liquids are subdivided as follows:

Class I liquids include those having flash points below 100°F (37.8°C) and may be subdivided as follows:

- Class IA liquids include those having flash points below 73°F (22.8°C) and having a boiling point below 100°F (37.8°C.)
- Class IB liquids include those having flash points below 73°F (22.8°C) and having a boiling point above 100°F (37.8°C.)

- Class IC liquids include those having flash points at or above 73°F (22.8°C) and below 100°F (37.8°C.)

Combustible Liquids mean any liquid having a flash point at or above 100°F (37.8°C.) They may be sub-divided as follows:

- Class II liquids include those having flash points at or above 100°F (37.8°C) and below 140°F (60°C.)
- Class IIIA liquids include those having flash points at or above 140°F (60°C) and below 200°F (93.3°C.)
- Class IIIB liquids include those having flash points at or above 200°F (93.3°C.)

FIRE PROTECTION OF STORAGE TANKS

U.L. has established two different types of foam discharge outlets:

- Type II Discharge Outlet - A fixed device that delivers foam onto the burning liquid and partially submerges the foam and produces minimal agitation of the surface. Examples of this type of device are Foam Chambers and Foam Makers.
- Type III Discharge Outlet - A fixed or portable device that delivers foam in a manner that causes the foam to fall directly onto the surface of the burning liquid in such a manner that causes severe agitation. Examples of this type of device are Hose Stream Nozzles and Monitors.
- There are two basic methods of fire protection systems for storage tanks:
- Sub-surface Base Injection
- Over the Top - (Subdivided as follows)
 - Foam Chambers
 - Foam Makers
 - Portable Foam Monitor
 - Foam Tower

SUB-SURFACE BASE INJECTION

The sub-surface method of fire protection produces foam with a "High Back Pressure Foam Maker" located outside the storage tank. This system delivers the expanded foam mass through piping into the base of the tank. The pipe may be an existing product line or can be a dedicated fire protection foam line. The expanded foam entering the tank through a discharge outlet is injected into the flammable liquid. The discharge outlet must be a minimum of 1 ft. above any water that may be present at the base of the tank. The foam will be destroyed if injected into the water layer. When injected into the fuel, the foam will rise through



the fuel and form a vapor tight foam blanket on the fuel surface.

Advantages of Sub-surface

The rising foam can cause the fuel in the tank to circulate which can assist in cooling the fuel at the surface.

If there is an explosion and fire that may damage the top of the tank, the sub-surface injection system is not likely to suffer damage.

The discharging foam is more efficiently directed to the fuel surface without any interruption from the thermal updraft of the fire.

Disadvantages of Sub-surface

CANNOT be used in storage tanks containing polar solvent type fuels.

Not Recommended for use in either Open Top Floating Roof or Internal Floating Roof type tanks. Caution must be used so that the maximum foam inlet velocity is not exceeded; otherwise, excessive fuel pickup by the foam as it enters the tank will be experienced.

Not to be used for protection of Class 1A hydrocarbon liquids .

HIGH BACK PRESSURE FOAM MAKER

The HBPFM is mounted in the foam line used to aspirate the foam solution before it is dis-charged into the storage tank. It will typically give an expansion ratio of between 2 -1 and 4 - 1. The device is capable of discharging against considerable back pressure which can be as high as 40% of the operating pressure. The back pressure is an accumulation of the head pressure of the fuel inside the storage tank and any friction loss between the foam maker and the tank. A minimum of 100 psi inlet pressure into the HBPFM is normally required to ensure correct operation. The foam velocity through the piping to the tank from the HBPFM is very critical. With flammable liquids, the foam velocity entering the tank should NOT exceed 10 ft. per second and with combustible liquids the foam velocity should NOT exceed 20 ft. per second.

The following chart shows the minimum discharge times and application rates for Sub-surface application:

Hydrocarbon Type Fuel	Minimum Discharge Time	Minimum Application Rate
Flash point between 100°F and 140°F (37.8°C and 93.3°C)	30 min.	0.10 gpm/ft. 4.1 L/min./m ²
Flash point below 100°F (37.8°C) liquids heated above their flash points.	55 min.	0.10 gpm/ft. 4.1 L/min./m ²
Crude Petroleum	55 min.	0.10 gpm/ft. 4.1 L/min./m ²

NOTE: The maximum application rate shall be 0.20 gpm/ft. (8.1 L/min./m.)

FOAM CHAMBERS TYPE II DISCHARGE DEVICE

The Foam Chamber is normally used on cone roof storage tanks. The chamber is bolted or welded on the outside of the tank shell near the roof joint. A deflector is mounted on the inside of the tank so that the discharging foam from the foam chamber will be diverted back against the inside of the tank wall.

The foam chamber is mounted on the cone roof storage tank vertical shell wall in a position just below the roof joint, or approximately 8" to 12" down from the roof joint to the center point of the foam chamber outlet.

When the foam chamber is mounted correctly, the internal glass vapor seal of the foam chamber will be just slightly higher in elevation than the roof joint on the storage tank.

Each foam chamber mounted on a cone roof storage tank **SHOULD** have its own individually valved riser supplying the foam solution from outside the dike area. For correct operation, a minimum of 40 psi is required at the inlet to the foam chamber.



FOAM MAKERS

TYPE II DISCHARGE DEVICE

The foam maker is normally used to aspirate foam solution before being discharged inside a dike (bund) area or when used with external floating roof tanks to supply foam to the rim seal area.

The discharge pipe down stream of the foam maker is sized to slow the velocity of the expanded foam and shaped to deflect the foam back against the inside of the dike wall or onto a splash board or the tank shell wall when used for floating roof seal protection.

The splash board is to be mounted above the top of the floating roof tank. The correct size discharge pipe from the foam maker should be installed in accordance with the information supplied in the dike protection system design information.

When mounted on a storage tank or used in a dike protection system, the foam maker can be mounted in either a horizontal or vertical position without any detrimental effect on foam performance.

It is recommended that a minimum 12" length of straight pipe be installed upstream from the foam maker during the installation.

When using the Buckeye 1 1/2" (38 mm) Foam Maker for a dike fire protection system, a 3" diameter pipe with minimum length of 28" and a maximum of 100" must be connected to the foam maker outlet (down stream side.) This length of discharge pipe allows for the correct foam expansion to take place and slows the discharge velocity. The Buckeye 2 1/2" (63 mm) Foam Maker requires a length of 4" pipe to be connected to the discharge side of the maker. This length of pipe should also be a minimum of 28" but can have a maximum length of 120". The discharge pipe in both instances should be directed back against the inside wall of the dike. This installation allows a more gentle application to the flammable liquid within the dike and lessen the submergence of the foam.

CRITERIA FOR SIZING A FOAM SYSTEM FOR A CONE ROOF STORAGE TANK.

- Identify the fuel inside the tank.
- Type of foam concentrate to be used.
- Calculate the fuel surface area (r 2.)
- Application rate.
- Type of discharge device required and quantity (based

on fuel flash point and tank diameter.)

- Calculate discharge duration.
- Supplementary hose lines required and discharge duration.
- Quantity of foam concentrate required.
- Establish bill of materials.

NOTE: To determine the quantity of foam concentrate in a given quantity of foam solution, use the following formula:

Multiply the foam solution by:

- x 0.01 if using a 1% type of concentrate
- x 0.03 if using a 3% type of concentrate
- x 0.06 if using a 6% type of concentrate

EXAMPLE

Cone roof tank - 150 ft. diameter

Fuel - Gasoline

Foam Concentrate - 3% AFFF

Surface area - $75' \times 75' \times 3.1417 = 17,672$ sq. ft.

App. Rate @ 0.10 gpm per sq. ft. (Per NFPA 11) $0.10 \times 17,672$ sq. ft. = 1,767.2 gpm of foam solution required.

Discharge device - Foam Chamber, Qty. 4 required.

Discharge Duration - 55 min. $1,767.2 \times 55 = 97,196$ gallons of foam solution $\times 0.03 = 2,916$ gallons of 3% AFFF concentrate required.

Supplementary Hose Lines required (Per NFPA 11) - Qty. 3 required (each minimum 50 gpm) (Tank dia. over 120 ft.).

Hose Line discharge duration (Per NFPA 11) -30 min. (Tank dia. over 95 ft.) $3 \times 50 = 150 \times 30 = 4,500$ gallons of foam solution $\times 0.03 = 135$ gallons of 3% AFFF. $3,051 (135 + 2,916)$ gallons of foam concentrate required.

A suitable bill of materials of major components for the above system using a bladder tank could be.

- 1 x 3,200 Gallon horizontal style bladder tank.
- 1 x 6" Between flange style ratio controller.
- 4 x 6" foam chambers each with a flow rate of 442 gpm at appropriate incoming pressure that exceeds 40 psi.
- 1 x 2 1/2" Threaded type ratio controller (For supplementary system.)
- 3 x 50 gpm handline nozzles.
- foam concentrate.



NOTE:

This chart identifies the number of Foam Chambers required for the protection of a flammable liquid contained in a vertical cone roof atmospheric storage tank where the discharge device is attached to the tank. Where two or more outlets are required, the outlets are to be equally spaced around the tank periphery and each outlet is to be sized to deliver foam at approximately the same rate.

Tank Diameter (or equivalent area)	Meters	Minimum Number of discharge outlets
Up to 80 ft.	24	1
Over 80 to 120	24 to 36	2
Over 120 to 140	36 to 42	3
Over 140 to 160	42 to 48	4
Over 160 to 180	48 to 54	5
Over 180 to 200	54 to 60	6

It is suggested that for tanks above 200 ft. (60 m) in diameter at least one additional discharge outlet be added for each additional 5,000 sq. ft. (465 sq. m.) of liquid surface or fractional part.

This chart indicates the number of SUPPLEMENTARY hose streams required for various size tanks. Each hose stream must be capable of a minimum flow rate of 50 gpm of foam solution.

Diameter of Largest Tank	Minimum Number of Hose Streams Required
Up to 65 ft. (19.5 m)	1
65 to 120 ft. (19.5 to 36 m)	2
Over 120 ft. (36 m)	3

This chart shows the Minimum discharge time and application rate for Type II fixed foam discharge devices on Cone Roof storage tanks.

Hydrocarbon Type	Application Rate	Discharge Time
Flash point between 100°F and 140°F (37.8°C and 93.3°C)	0.10 gpm/ft. (4.1 L/min./m)	30 min.
Flash point below 100°F (37.8°C) or liquids heated above their flash points	0.10 gpm/ft. (4.1 L/min./m)	55 min.
Crude Petroleum	0.10 gpm/ft. (4.1 L/min./m)	55 min.

- Flammable liquids having a boiling point of less than 100°F might require higher rates of application. These should be determined by test.
- For high-viscosity liquids heated above 200°F, lower initial rates of application of foam may be desirable to minimize frothing and the subsequent expulsion of the stored liquid from the storage tank. Good judgment should be used in applying foams to tanks containing hot oils, burning asphalts or burning liquids that have boiling points above the boiling point of water.
- The above table includes Gasohols and unleaded gasolines containing no more than 10% oxygenated additives by volume. Where these additives exceed 10% by volume or where the flammable liquid is a polar solvent or water miscible product, fire protection is normally supplied by the AR-AFFF type foam concentrates. In those instances check with Buckeye to establish recommended application rates. The minimum discharge duration is 55 min.

The following chart indicates the minimum operating time of the supplementary hose stream(s) for various size tanks.

Diameter of Largest Tank	Minimum Operating Time
Up to 35 ft. (10.5 m)	10 min.
35 to 95 ft. (10.5 to 28.5 m)	20 min.
Over 95 ft. (28.5 m)	30 min.

Equipment List using a Foam Pump Skid Assy. for a 150 ft. dia. tank containing gasoline.

- 1 x Atmospheric Foam Concentrate Storage Tank 3,100 Gallons
- 1 x Electric powered Foam Pump Proportioning skid with prepiped 6" ratio controller (Foam Chambers) and prepiped 2 1/2" ratio controller (Supplementary Hose Lines)
- 4 x 6 inch Foam Chambers
- 3 x 50 gpm Hand Line nozzles
- 3,051 x Gallons 3% AFFF (plus any additional for testing of the system)

NOTE:

When protecting multiple storage tanks the foam system is to be sized to protect the single largest hazard.

Fig. 9 depicts a manual foam pump skid system showing all necessary piping, valves, discharge devices, ratio con-



troller, foam pump and foam storage tank for the above system.

Fig. 10 shows a Cone Roof Storage Tank with a Semi-Fixed Foam System.

The following example shows the foam system requirements for seal protection of a 150 ft. diameter open top floating roof tank.

Type of Tank - Open Top Floating Roof Tank

Diameter of Tank - 150 ft.

Type of Fuel - Gasoline

Foam Dam installed on roof - Yes - 2 ft. from tank wall and 2 ft. in height

Sq. ft. area of annular ring - 930 sq. ft.

Application Rate - 0.30 gpm per sq. ft. (Per NFPA 11)
 $0.30 \times 930 \text{ sq. ft.} = 279 \text{ gpm of foam solution required.}$

Type of Discharge Device - Foam Makers

Discharge Duration - 20 min. $279 \times 20 = 5,580$ gallons of foam solution - $\times 0.03$ (3% AFFF) = 167.4 gallons of foam concentrated

Quantity of Foam Makers Required (Per NFPA 11) 6 required.

Add supplementary hose lines per example for Cone Roof Tank with Foam Chambers.

NOTE:

The number of fixed foam discharge points on an open top floating roof tank is determined by the circumference of the tank.

The maximum spacing between discharge points is 40 ft. (12.2 m) of tank circumference when using a 12" (305 mm) high foam dam and every 80 ft. (24.4 m) of tank circumference when using a 24" (610 mm) high foam dam.

In accordance with NFPA 11

Foam Dam Design - The foam dam should be circular and constructed of at least No. 10 US Standard Gage Thickness (0.134 in.) (3.4 mm) steel plate. The dam is to

be welded or otherwise securely fastened to the floating roof. The foam dam is designed to retain foam at the seal area at a sufficient depth to cover the seal area while causing the foam to flow laterally to the point of seal rupture.

Dam height is to be at least 12" (305 mm) and should extend at least 2" (51 mm) above any metal secondary seal or a combustible secondary seal using a plastic foam log.

It is to be at least 2" (51 mm) higher than any burnout panels in metal secondary seals.

Foam dams are to be at least 1 ft. (0.3 m) but no more than 2 ft. (0.6 m) from the edge of the floating roof.

Foam solution & rain water is to be drained by, slotting the bottom of the dam on the basis of 0.04 sq. in. of slot area per sq. ft. (278 mm sq./sq. m) of diked area while restricting the slots to 3/8 in. (9.5 mm) in height. Excessive dam openings for drainage should be avoided to prevent loss of foam through the drainage slots.

SUB-SURFACE SYSTEM

Sub-surface injection of foam is generally not recommended for fuels that have a viscosity greater than 2,000 ssu (440 centistokes) at their minimum anticipated storage temperature.

Example of a Sub-Surface Base Injection System

Cone Roof Tank - 80 ft. diameter

Fuel - Gasoline

Foam Concentrate - 3%-6% AR-AFFF

Surface Area - =

$$40' \times 40' \times 3.1417 = 5,026.7 \text{ sq. ft.}$$

App. Rate - 0.10 gpm per sq. ft.

$0.10 \times 5,027 \text{ sq. ft.} = 503 \text{ gpm of foam solution}$

Discharge Duration - 55 min.

Quantity of Foam Concentrate required

$$-503 \times 55 \times 0.03 = 830 \text{ gallons}$$

Discharge Device - Qty. 1 High Back Pressure Foam Maker ("Foam generator")

Number of Discharge outlets inside tank

Qty. 1 (Tank 80 ft. or less) (Per NFPA 11)

Supplementary hose lines are the same as example for Cone Roof Tank.



The following chart shows the number of discharge outlets required inside the tank.

Tank Diameter	Number of Discharge Outlets Required	
	Flash Point below 100°F (38°C)	Flash Point 100°F (38°C) or Higher
Up to 80 ft. (24 m)	1	1
Over 80 to 120 ft. (24 - 36 m)	2	1
Over 120 to 140 ft. (36 - 42 m)	3	2
Over 140 to 160 ft. (42 - 48 m)	4	2
Over 160 to 180 ft. (48 - 54 m)	5	2
Over 180 to 200 ft. (54 - 60 m)	6	3
Over 200 ft. (60 m)	6	3
	Plus 1 outlet for each additional 5,000 sq. ft. (465 sq. m)	Plus 1 outlet for each additional 7,500 sq. ft. (697 sq. m)

Equipment list for the above example using a bladder tank foam supplied foam system.

- 1 x 900 Gallon vertical style bladder tank.
- 1 x 4" Wafer style ratio controller.
- 1 x 2 1/2" Threaded type ratio controller (for supplementary hose lines.)
- 1 x 500 gpm High Back Pressure Foam Maker (HBPFM.)
- Supplementary hand line nozzles and foam concentrate.

Determining Number of Discharge Outlets for Subsurface Base Injection.

The number of discharge outlets required is based on the tank diameter and the flash point of the fuel as shown in the above chart.

FOAM MONITORS AND HANDLINES

NFPA II states that monitors are not to be considered as the primary means of protection for fixed roof tanks over 60 ft. in diameter. Foam handlines are not to be considered as the primary means of protection for tanks over 30 ft. in diameter or those over 20 ft. in height.

APPLICATION RATES USING MONITORS OR HANDLINES

The minimum foam solution application rate is based on the assumption that all discharging foam will reach the area being protected. In considering actual solution flow requirements, consideration should be given to potential foam losses from such as climatic conditions and thermal updraft of the fire.

The following chart shows application density and duration for monitors and handlines on tanks containing hydrocarbons.

Hydrocarbon Type	Minimum Application Rate gpm/ft ² (L/min.)/m ² (min.)	Minimum Discharge Time
Flash point between 100°F and 140°F (37.8°C and 93.3°C)	0.16	6.5
Flash point below 100°F (37.8°C) or liquids heated above their flash points	0.16	6.5
Crude Petroleum	0.16	6.5

Included in the above table are gasohols and unleaded gasolines containing no more than 10 percent of an oxygenated additive by volume.

On tanks containing water miscible/polar solvent flammable liquids the recommended foam application duration is 65 minutes.

Flammable liquids having a boiling point less than 100°F and products that have been burning for some time can develop a heat layer which might require foam solution application rates as high as 0.2 or 0.25 gpm per sq. ft.

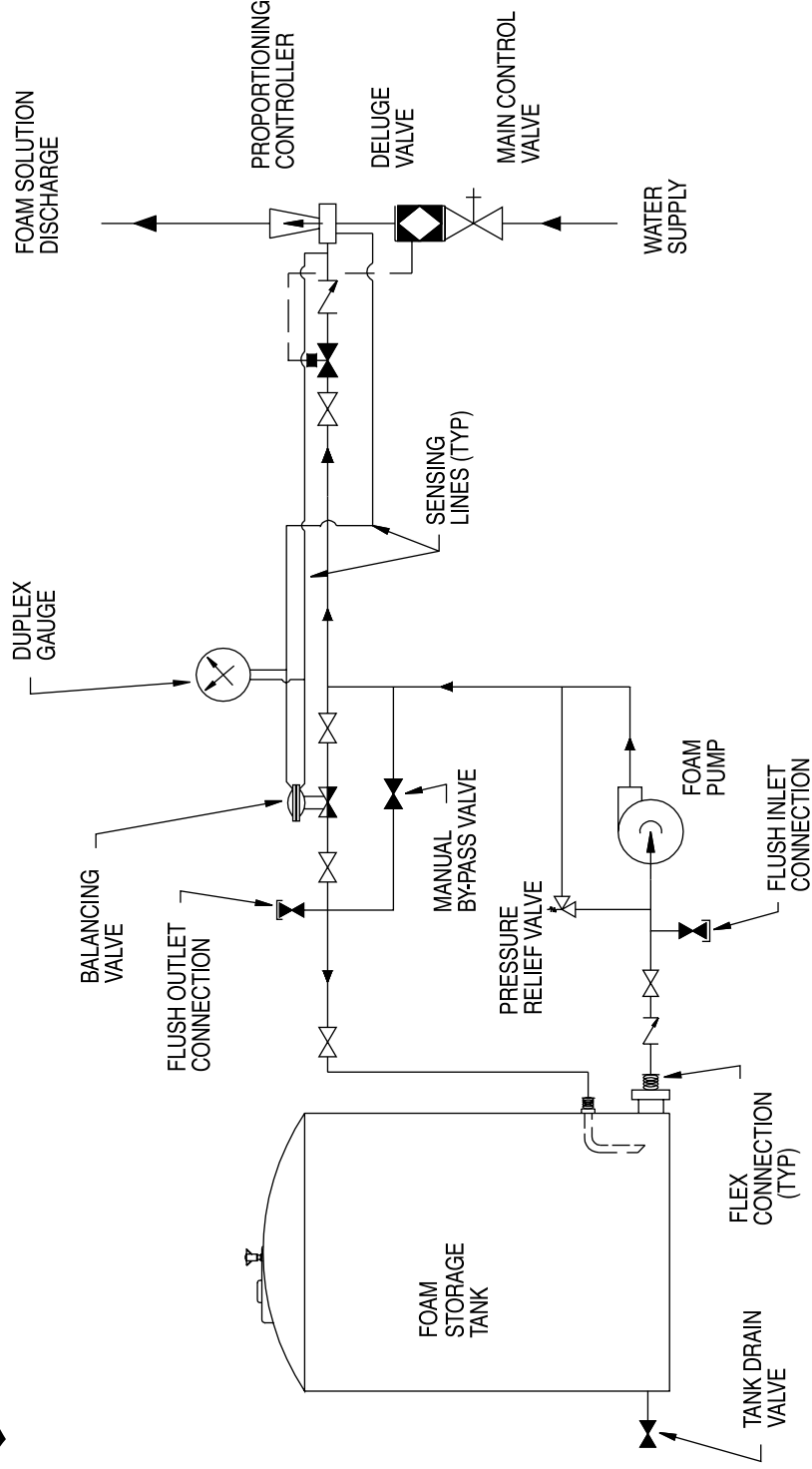
Where monitors or handlines are used to protect storage tanks containing polar solvent or water miscible liquids the discharge duration shall be a minimum of 65 minutes at the recommended application rate.



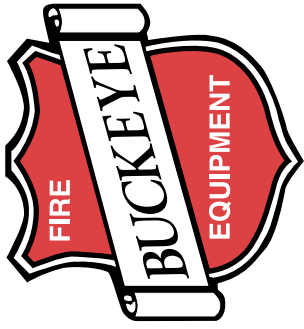


STORAGE TANKS

BALANCED PRESSURE PUMP SKID - FIG 9

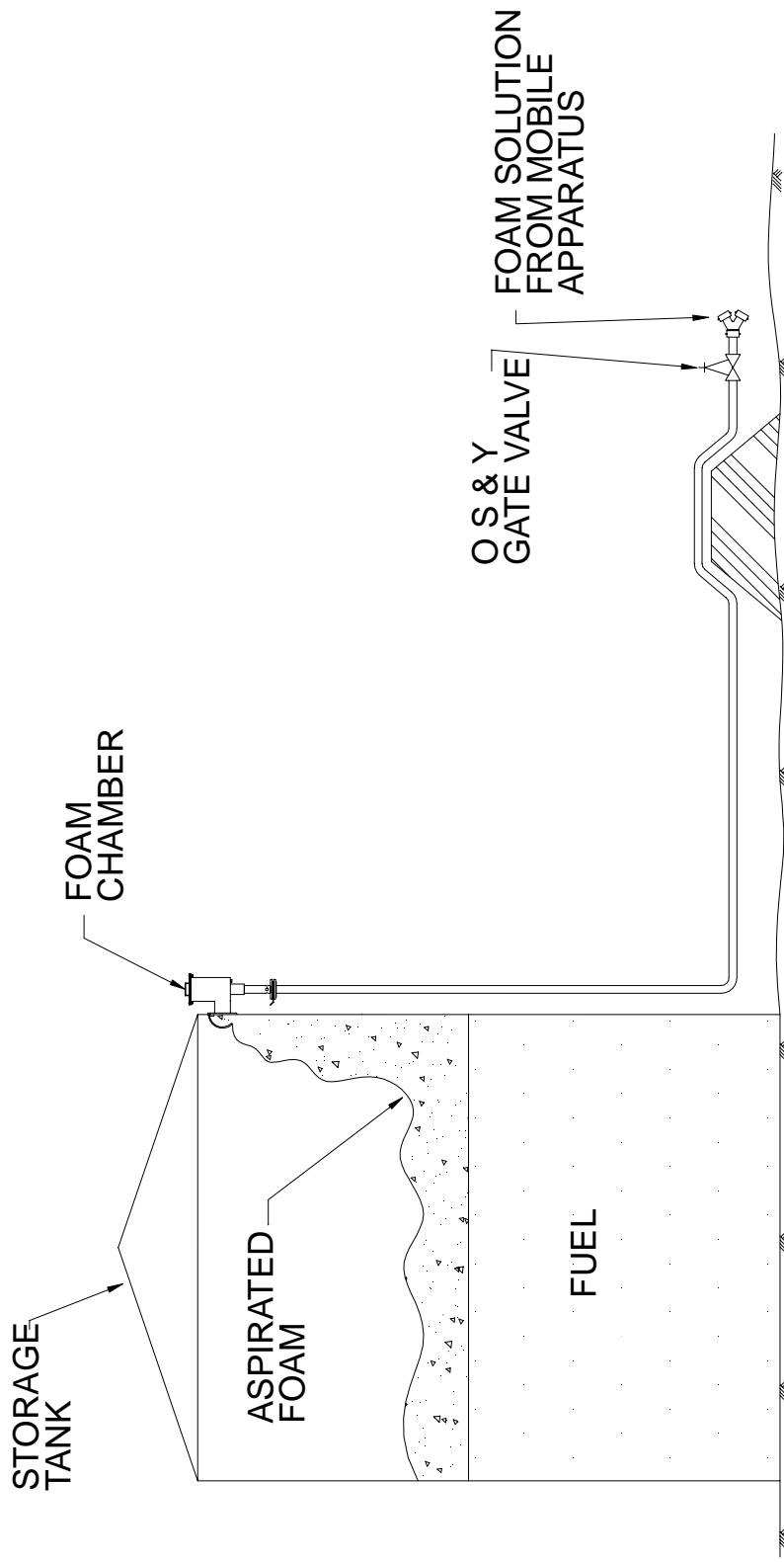


EXAMPLE OF BALANCED PRESSURE PUMP SKID WITH ONE PROPORTIONER



STORAGE TANKS

TOPSIDE APPLICATION - FIG 10



SEMI-FIXED FOAM SYSTEM with MOBILE APPARATUS SUPPLYING THE FOAM SOLUTION

