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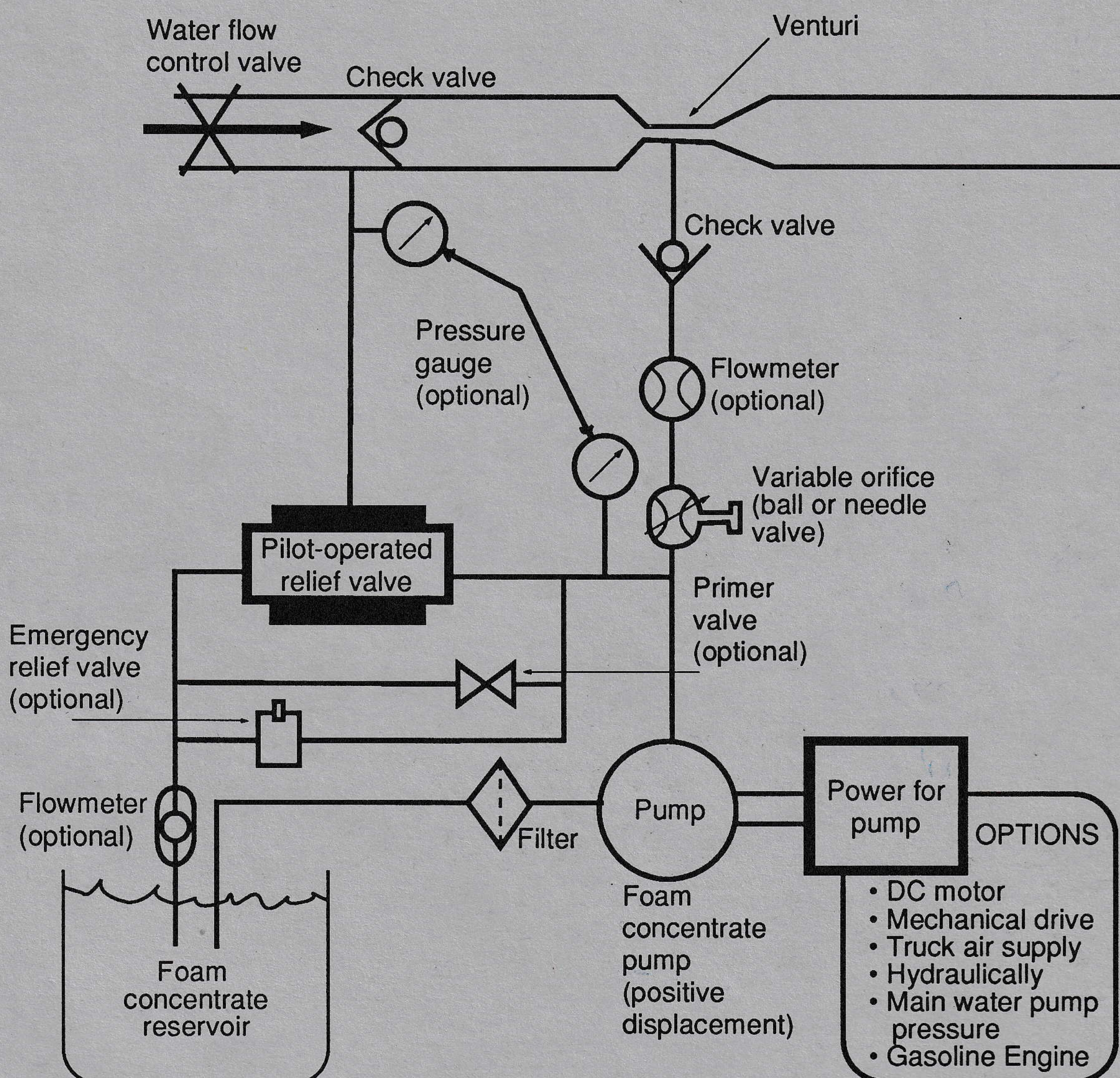
Proportioners for Use in Wildland Fire Applications

Technology and Development Center



Proportioners for Use in Wildland Fire Applications

Technology & Development Center

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Foam Application

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Scope and Abstract

This report covers methods of proportioning foam concentrate into water to make foam solution that can be used with standard nozzles, aspirating nozzles, or in a compressed air foam system (CAFS) for use in fighting wildland fires. There are two basic types of foam concentrate proportioning systems:

1. Manually regulated proportioning systems
2. Automatic regulating proportioning systems.

Manually regulated proportioning systems include:

Batch mixing
Suction-side proportioner
In-line eductor
Bypass eductor
Around-the-pump proportioner
Direct injection manually regulated

Automatic regulating proportioning systems include:

Balanced pressure venturi systems
    Pump systems
    Bladder tank systems
Water-motor meter proportioner
Direct injection automatic regulating proportioner

All manually regulated proportioning systems have significant disadvantages when used in wildland fire applications. In general, manually regulated proportioning systems do have one desirable advantage — low initial cost. However, manually regulated proportioning systems (other than batch mixing) have the potential of using much more foam concentrate than necessary, negating their initial low cost advantage. In reality, they could become the most costly proportioning system. Thus, manually regulated proportioning systems should be avoided, or when used; utilized with caution in wildfire suppression operations.

Because of the many shortcomings of the manually regulated proportioning systems, automatic regulating proportioning systems have been designed to reduce these limitations. Specifically, the automatic regulating proportioning systems are designed to remain proportional over a wide range of flows. They are not affected by changes in engine pressure, changes in hose length and size, or changes in nozzle adjustments, size, or elevation and generally inject the foam concentrate into the discharge side of the pump. The use of automatic regulating proportioning systems injection into the discharge side of the pump should be encouraged.

To encourage the use of automatic regulating proportioning systems injecting into the discharge side of the pump, automatic regulating proportioning systems should be formally tested and test results appropriately disseminated.

INTRODUCTION

During the last decade the improved fire extinguishing properties of class "A" foam have become increasingly recognized, resulting in a marked increased use of class "A" foam. Using class "A" foam to protect natural resources and improvements is becoming routine. When using foam it is desirable, for a number of reasons, to inject the foam concentrate at a set proportion (regardless of water flow or pressure) directly into the discharge or high-pressure side of the water pump. There are a number of proportioning systems used to proportion foam concentrate into water streams for use with standard nozzles, aspirating nozzles, or in compressed air foam systems (CAFS). There are two basic types of foam concentrate proportioning systems—manually regulated and automatic regulating. The proportioning systems that give the most desirable results are automatic regulating proportioning systems that inject directly into the discharge side of the water pump.

Ideally a foam concentrate proportioner should:

1. Be proportional over the entire range of the water pump's flow capacity and pressure. Once foam concentrate percent is set, it should not change over the range of the water pump's flow (be automatic regulating). The percent should be proportional down to near zero flow (near zero flow is considered to be 1 to 5 gpm) and stop flowing when the water is completely shut off. The proportioner should maintain accurate foam concentrate proportioning of ± 10 percent of the set proportion from full flow down to 10 percent of full flow and ± 25 percent of the set proportion from 10% of full flow down to near zero flow over the operating pressure and flow ranges of the water pump.

   In addition, the proportioner should not be affected by changes in engine pressure, changes in hose length and size, changes in water flow, or changes in nozzle adjustments, size, or elevation. For wildfire engines the proportioner should be able to handle the full flow of the pump of the apparatus it is installed on or used with. On wildland fire engines this may be as high as 200 gpm or more. It should be capable of operating up to 300 psi and is desirable that it operate up to 450 psi. It should be suitable for use with CAFS.

2. Not require that chemicals be added to the water tank, run through the pump, nor be recirculated back to the water tank or through the pump. This is important because most centrifugal fire pump installations have a continual small bleed back (if they do not; they should have) to the water tank or suction plumbing for pump cooling when water is not flowing into hose lines.

3. Inject foam concentrate directly into the water stream on the discharge side of the water pump in the correct proportion to make foam solution in the desired ratio of foam concentrate to water. Foam solution should flow directly from the engine piping system into the hose lines with no possibility of the foam solution recirculating and contaminating the water tank, plumbing, and pump.

4. Be low in cost and simple in design. Have both very high reliability (infrequent breakdowns) and very high availability (will work almost all the time when turned on). They must also have very high maintainability (if it does not work, can be repaired very quickly). Under normal use in wildfire suppression it should require servicing only once a year.

5. Be able to use different types of foam concentrates, either class "A" (USDA Forest Service approved) or class "B," at up to 1 percent concentration. Even higher percentages may be desirable for class "B" foam. Be able to change percentages while operating, both up and down, and be able to change from one type foam concentrate to another. Be able to proportion down to 0.1 percent or less.

6. Be able to provide, at a minimum, enough foam concentrate to treat a full water load from the apparatus on which it is installed.

7. Be able to indicate how much foam concentrate is left in the system for use.

8. Cause no or low water pressure loss as water flows through the proportioner.

9. It is advantageous that the proportioner not require any external power. If external power is required and the apparatus 12 volt electrical system is the power source, the proportioner should require less than 30 amperes to operate. If more power is needed than is desirable to be furnished by the apparatus 12 volt electrical system, the use of mechanical power from the apparatus should be considered and is desirable.

10. Be constructed of materials compatible for use with foams when routinely flushed.

FOAM PROPORTIONING SYSTEMS

The desirable features of a foam proportioning system for use with firefighting foam have been listed in the Introduction. There are a number of foam proportioners currently being used with firefighting foams. Many have shortcomings when compared to the desirable features listed earlier. To interpret the significance of these shortcomings, and for better selection and operation of firefighting foam proportioning systems, an understanding of the operation of proportioning systems is required.

There are two types of proportioning systems:

1. Manually regulated proportioning systems

2. Automatic regulating proportioning systems

Manually regulated proportioning systems are proportioners that require manual adjustment to maintain the mix ratio when there is a change of flow and/or pressure through the proportioner or require precalculation and measuring. Manually regulated proportioners include:

1. Batch mixing (batch mixing is really not a proportioner but is a very common proportioning method)

2. Suction-side proportioning systems

3. In-line eductor proportioning systems

4. Bypass eductor proportioning systems

5. Around-the-pump proportioning systems

6. Direct injection, manually regulated, proportioning systems.

Automatic regulating proportioning systems are proportioners that automatically adjust the flow of foam concentrate into the water stream to maintain the desired mix ratio. These automatic adjustments are made based on changes in water flow. Automatic regulating proportioning systems include:

1. Balanced pressure, venturi, proportioning systems
   A. Pump systems
   B. Pressure tank systems
2. Water-motor meter proportioning systems
3. Direct injection, automatic regulating, proportioning systems

When using a manually regulated proportioning system, the operator must monitor the operation of the proportioning system and manually make any adjustments required to keep the proportioner operating at the desired mix ratio. When using an automatic regulating proportioning system, (once the proportioning system has been placed in operation and mix ratio adjusted to the desired rate) no further adjustments are necessary with changes of flow and/or pressure.

Manually Regulated Proportioning Systems

Batch Mixing

Batch mixing is the simplest and lowest cost method of proportioning. When done with care, it is very accurate. Batch mixing is simply adding a measured amount of foam concentrate (generally by hand) to an engine's water tank, portable tank, or backpack pump tank and generally circulating to ensure the foam concentrate is well mixed with the water. The foam concentrate should be added to the water. Adding water to the foam concentrate can cause excessive foaming. For optimum performance, the foam solution should be used within 24 hours. Batch mixing can also be considered as the backup proportioning system when another type of proportioning system fails or the method to use when no other proportioning system is available.

Suction-side Proportioning System

The suction-side proportioning system is another manually regulated proportioning system. See figure 1. It consists of an in-line tee in the suction hose of the pump with a smaller hose containing a metering valve running to a foam concentrate supply. The suction-side proportioner is dependent on the pump drawing a vacuum to pull the foam concentrate from the supply container into the pump suction hose.

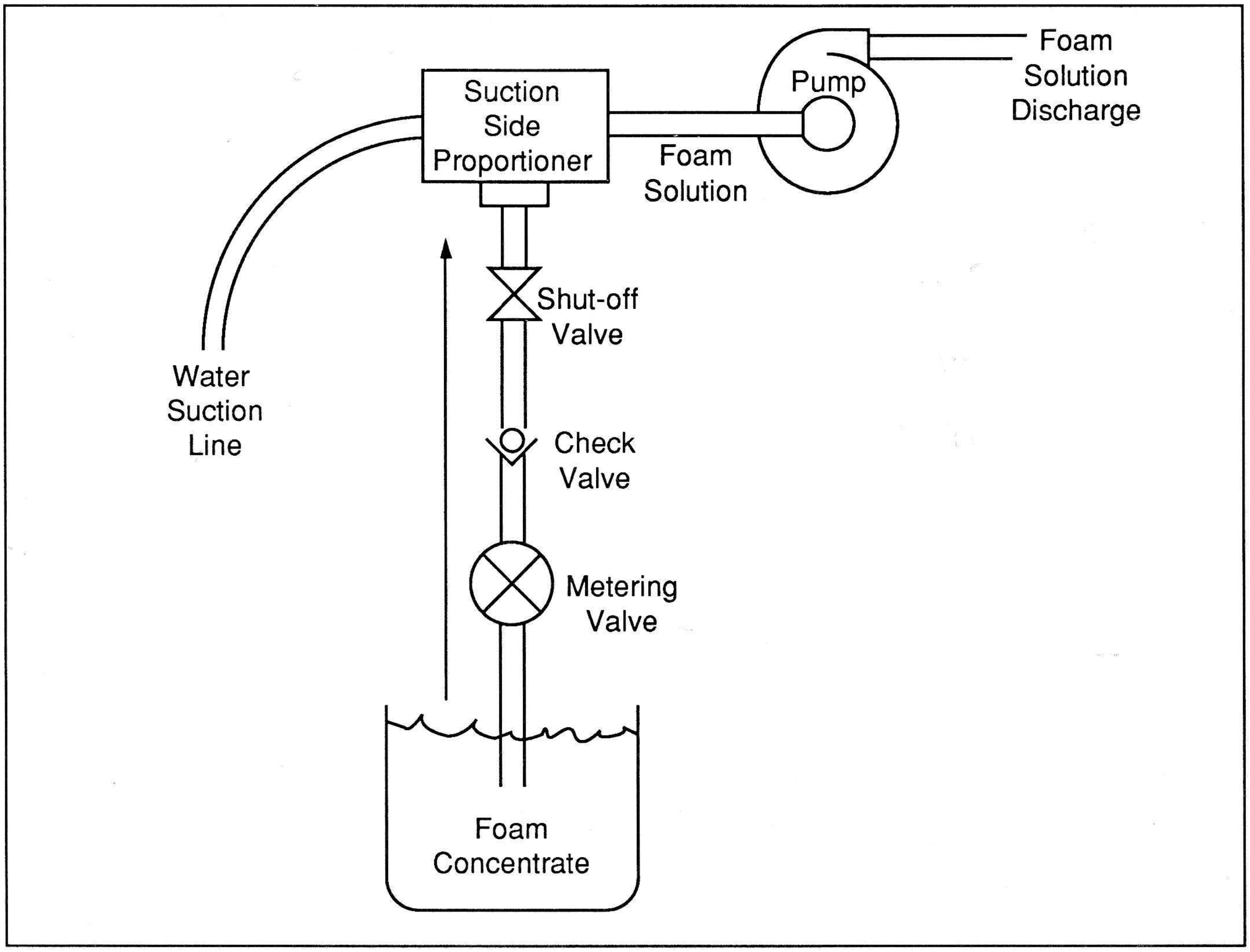

Figure 1. —Suction-side proportioning system.

Since pump vacuum is dependent on pump lift, pump flow, and suction hose size, the suction-side proportioner must be manually regulated. The suction-side proportioner is an inexpensive device with few parts or controls. It is best suited for portable pump operations because of the steady flows generally used with these pumps. If a portable pump is used without a foot valve and the portable pump is shut down, the foam concentrate can be sucked out of the supply container and flow into the water supply. Limitations of the suction-side proportioner are similar to batch mixing because concentrate is passed through the pump and, with recirculation, into the water tank. Also, the pump will lose its prime if the foam concentrate is exhausted (an attachment may soon be available to prevent this) or the foam concentrate pickup line comes out of the supply container.

In-line Eductor Proportioning Systems

The in-line eductor proportioner is also a manually regulated proportioning device. In-line eductor foam concentrate proportioning systems have been used by municipal fire service for many years. However, their operation has limitations and the principle of operation is not well understood. While it is true that an in-line eductor proportioning system can be made to work well in a given situation, any change in the operating conditions can result in a change in the proportioning (percent of foam concentrate in the foam solution) or the system not working at all. These changes include variations in engine pressure, reduced flow, added hose, nozzle elevation, or nozzle orifice changes. For these reasons, it can be said that an in-line eductor is very "situation sensitive." To explain why an in-line eductor proportioning system is so situation sensitive, an understanding of how it works is required.

An in-line eductor proportioning system is made up of (1) an eductor (or venturi), (2) a reservoir, (3) a check valve, and (4) a foam concentrate flow control device (a needle valve or an orifice). See figure 2.

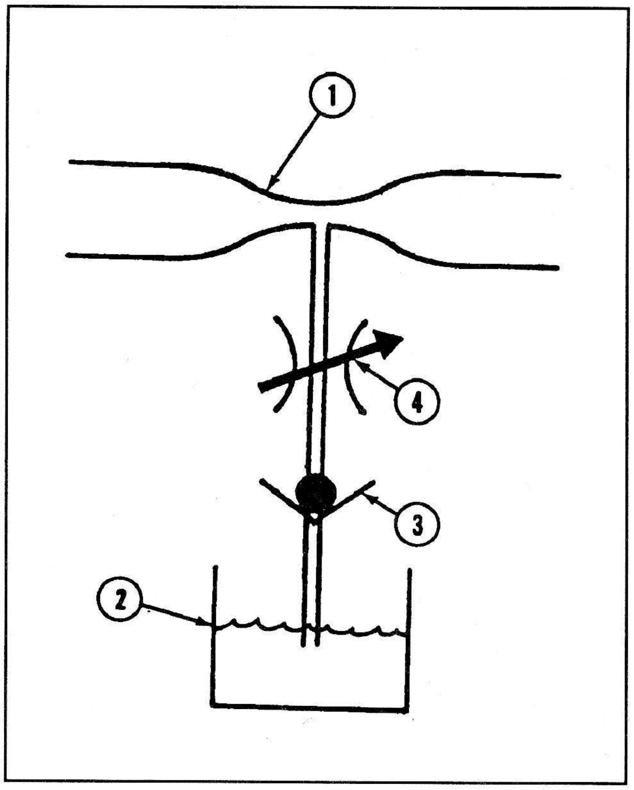

Figure 2. —In-line eductor proportioning system.

The eductor (figure 3) is made up of (1) the convergent cone, (2) throat, and (3) the divergent cone or diffuser. The eductor also must have an eductor metering orifice (4).

As water flows through the eductor, the water velocity is increased at the throat, resulting in reduced static pressure. As water leaves the throat, the water velocity is decreased, resulting in increased static pressure. For an eductor to work properly, the velocity through the throat must be increased until a negative pressure is created in the throat (figure 4).

A negative pressure up to 14.7 psi can be created depending on elevation (14.7 psi at sea level, less at higher elevations).

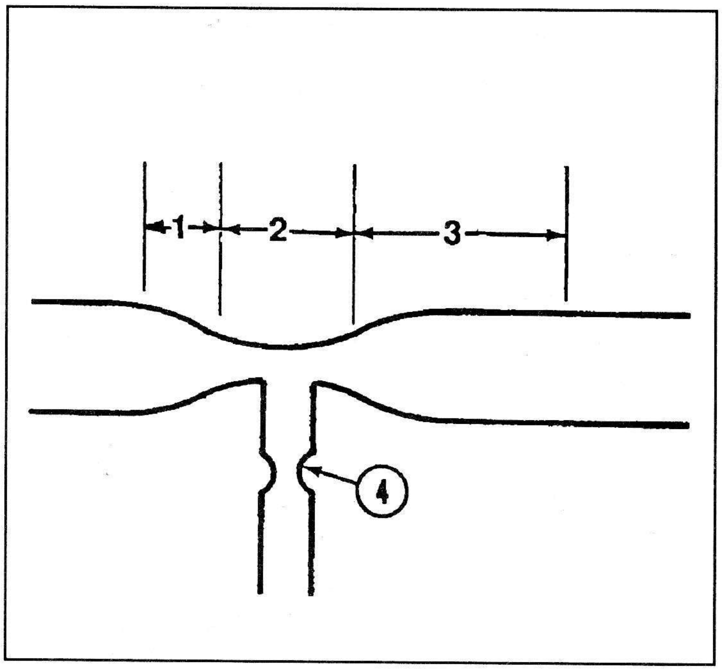

Figure 3. —An eductor.

When a fluid (such as water) is under pressure, the total pressure is made up of two parts—static and dynamic pressure. The static pressure is the pressure that shows on a pressure gauge. The dynamic pressure is the pressure of the moving fluid and the pressure that would be produced if the fluid were brought to a halt. The dynamic pressure is proportional to the velocity squared. If the velocity is doubled, the dynamic pressure is increased four times.

Static pressure and dynamic pressure can be interchanged. When a fluid is flowing in a large diameter pipe, static pressure can be high, but the fluid will not have a very high dynamic pressure because the fluid is moving at a very low velocity. If the pipe diameter is decreased, the fluid velocity will be increased, increasing the dynamic pressure and decreasing the static pressure. If the pipe diameter is now increased, the dynamic pressure will decrease and the static pressure will increase and this increase in static pressure will show on a pressure gauge.

These pressure changes, from static to dynamic and then back to static, are not without cost. There is an overall decrease in total pressure. Since dynamic pressure is fixed for a given fluid velocity (a given amount of flow in a given size pipe), the pressure loss shows up in the static pressure. It is possible to push the velocity so high that the static pressure goes to zero gauge pressure, and then even push velocity still higher so that the static pressure goes to a negative gauge pressure or vacuum. Almost absolute zero pressure, which is -14.7 psig (or 30 in Hg vacuum) at sea level, can be reached. This is what is achieved in an eductor. A pressure gauge pressure reading is correctly referred to as psi gauge or psig. A pressure gauge shows the pressure above or below atmospheric pressure (which is 14.7 psi at sea level). Total static pressure is psig plus atmospheric pressure.

The negative gauge pressure that can be created in an eductor is what causes the foam concentrate to flow from the reservoir to the eductor throat and into the water stream to make foam solution. As the water and foam concentrate move through the eductor, out of the throat into the diffuser, static pressure is regained. However, for an eductor operating near absolute zero pressure, only about 40 percent to a maximum of 75 percent of the inlet static pressure can be regained, depending on the design of the eductor.

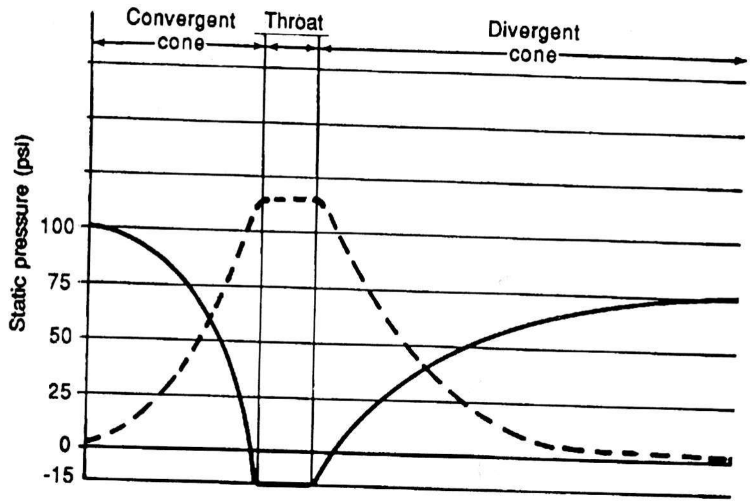

Figure 4. —Static and dynamic pressure as water flows through an eductor. Static pressure is solid line and dynamic pressure is represented by the broken line.

In a venturi, where static pressure does not change as much as in an eductor (where the static pressure may approach very close to absolute zero pressure), 80 to 90 percent of the static differential pressure can be regained.

As shown in figure 3, an eductor is made up of three sections—convergent cone, throat, and divergent cone. The convergent cone section is basically a nozzle. Fire nozzle tables (see table 1) can be used to predict the convergent cone section performance, however, total pressure must be used.

If you have a static pressure of 100 psig at the entrance of the convergent cone section, the total pressure change from this entrance to the throat section can be up to 114.7 psi (100 psig plus 14.7 psi of atmospheric pressure) - see figure 4. As an example, if we have an eductor with a 3/8-inch throat diameter and 100 psig static pressure at the entrance to the eductor, we can have up to 114.7 psi pressure driving water through the eductor which will force up to 45.1 gpm through the eductor (see table 1).

Theoretical Discharge Of Nozzles In U.S. Gallons Per Minute

HEAD		Velocity of Discharge Feet Per Second	DIAMETER OF NOZZLE IN INCHES								
Pounds	Feet		1/16	1/8	3/16	1/4	3/8	1/2	5/8	3/4	7/8
10	23.1	38.6	0.37	1.48	3.32	5.91	13.3	23.6	36.9	53.1	72.4
15	34.6	47.25	0.45	1.81	4.06	7.24	16.3	28.9	45.2	65.0	88.5
20	46.2	54.55	0.52	2.09	4.69	8.35	18.8	33.4	52.2	75.1	102.
25	57.7	61.0	0.58	2.34	5.25	9.34	21.0	37.3	58.3	84.0	114.
30	69.3	66.85	0.64	2.56	5.75	10.2	23.0	40.9	63.9	92.0	125.
35	80.8	72.2	0.69	2.77	6.21	11.1	24.8	44.2	69.0	99.5	135.
40	92.4	77.2	0.74	2.96	6.64	11.8	26.6	47.3	73.8	106.	145.
45	103.9	81.8	0.78	3.13	7.03	12.5	28.2	50.1	78.2	113.	153.
50	115.5	86.25	0.83	3.30	7.41	13.2	29.7	52.8	82.5	119.	162.
55	127.0	90.4	0.87	3.46	7.77	13.8	31.1	55.3	86.4	125.	169.
60	138.6	94.5	0.90	3.62	8.12	14.5	32.5	57.8	90.4	130.	177.
65	150.1	98.3	0.94	3.77	8.45	15.1	33.8	60.2	94.0	136.	184.
70	161.7	102.1	0.98	3.91	8.78	15.7	35.2	62.5	97.7	141.	191.
75	173.2	105.7	1.01	4.05	9.08	16.2	36.4	64.7	101.	146.	198.
80	184.8	109.1	1.05	4.18	9.39	16.7	37.6	66.8	104.	150.	205.
85	196.3	112.5	1.08	4.31	9.67	17.3	38.8	68.9	108.	155.	211.
90	207.9	115.8	1.11	4.43	9.95	17.7	39.9	70.8	111.	160.	217.
95	219.4	119.0	1.14	4.56	10.2	18.2	41.0	72.8	114.	164.	223.
100	230.9	122.0	1.17	4.67	10.5	18.7	42.1	74.7	117.	168.	229.
105	242.4	125.0	1.20	4.79	10.8	19.2	43.1	76.5	120.	172.	234.
110	254.0	128.0	1.23	4.90	11.0	19.6	44.1	78.4	122.	176.	240.
115	265.5	130.9	1.25	5.01	11.2	20.0	45.1	80.1	125.	180.	245.
120	277.1	133.7	1.28	5.12	11.5	20.5	46.0	81.8	128.	184.	251.
125	288.6	136.4	1.31	5.22	11.7	20.9	47.0	83.5	130.	188.	256.
130	300.2	139.1	1.33	5.33	12.0	21.3	48.0	85.2	133.	192.	261.
135	311.7	141.8	1.36	5.43	12.2	21.7	48.9	86.7	136.	195.	266.
140	323.3	144.3	1.38	5.53	12.4	22.1	49.8	88.4	138.	199.	271.
145	334.8	146.9	1.41	5.62	12.6	22.5	50.6	89.9	140.	202.	275.
150	346.4	149.5	1.43	5.72	12.9	22.9	51.5	91.5	143.	206.	280.
175	404.1	161.4	1.55	6.18	13.9	24.7	55.6	98.8	154.	222.	302.
200	461.9	172.6	1.65	6.61	14.8	26.4	59.5	106.	165.	238.	323.

Table 1.--Theoretical discharge of smooth taper nozzles in U.S. gpm.

The throat section is the reduced pressure area where the foam concentrate is injected at up to 14.7 psi pressure. We can control the foam concentrate injection rate by placing a flow resistance (a needle valve or orifice) in the foam concentrate line from the reservoir to the throat of the eductor. We can change the foam concentrate flow rate by changing the amount of resistance in the flow line. One reason why in-line eductor proportioning systems are so situation sensitive is that if static pressure to the inlet of the eductor is increased, water flow will be increased. However, there can be no increase in the pressure causing the foam concentrate to flow into the throat of the eductor because this pressure is already at absolute zero pressure and can go no lower. Thus, there can be no change in the flow rate of the foam concentrate—resulting in a decrease in the percentage of foam concentrate in the foam solution coming out of the eductor. To keep the percentage of the foam concentrate in the foam solution the same as before the increase in eductor inlet pressure, the flow resistance in the foam concentrate line must be decreased. This must be done manually by the operator; hence, the in-line eductor is a manually regulated proportioning system.

If static pressure at the inlet of the eductor is lowered, resulting in reduced water flow, static pressure at the eductor throat will be increased. In fact, it can be increased more than 14.7 psi, resulting in positive static pressure at the eductor throat. When this occurs, no foam concentrate will flow into the throat, resulting in no foam concentrate being added to the water stream. The same thing can happen if, for some reason, the water flow is reduced, e.g., cutting back water flow at the nozzle. The inlet static pressure at the entrance to the eductor can be the same, but the water flow is decreased to where the velocity through the throat of the eductor is not enough to create a negative pressure. In our example (100 psig inlet and 3/8-inch throat diameter) this would be a cut back of flow from 45 to 42.2 gpm. At 45 gpm the system would be working well. At 42.2 gpm the system would not be working at all. This, too, is what is meant by situation sensitive.

Here is another example of the eductor being situation sensitive. When the inlet pressure to the eductor is 100 psig and there is a 75 percent regain of pressure, 71 psig ($114.7 \times 0.75 = 86$; $86 - 14.7 = 71$ psig) will be available to flow water through the hose and nozzle. A 75 percent regain of inlet pressure for a venturi when operating down to zero absolute pressure requires a well designed venturi. As indicated in table 1, this requires a 1/2-inch nozzle to pass the 45 gpm at less than 71 psig (62.5 gpm at 70 psi). A 1/2-inch nozzle with 45 gpm flow requires only 36 psi to flow the 45 gpm, leaving 35 psi for pressure loss in the hose lay. A 35 psi pressure loss at 45 gpm flow in a 1-1/2-inch hose would result from a hose lay almost 400 feet long. So, if four 100 foot lengths of 1-1/2-inch hose were used, the eductor would just work.

Now, if another length of hose were added and engine pressure were not raised, flow would be reduced resulting in no foam concentrate being injected into the hose lay. If engine pressure is raised to maintain the 45 gpm, still no foam concentrate would be injected into the hose lay because there would still be no negative pressure created at the eductor throat. For the system to work, both the engine pressure and flow must be raised to approximately 60 gpm and 200 psi engine pressure. Under these conditions, the system should just work. As you can see, adding hose after the eductor can cause the eductor proportioning system not to work. Again, an example of "situation sensitivity." Procedures to overcome this problem include:

- Operate at higher engine pressure (may be effective on short hose lays, may not be effective on long hose lays)

- Operate at higher flow rates (should be effective)

- Use larger flow nozzles (should be very effective)

- Move eductor system closer to the end of the hose lay or reduce the amount of hose after the eductor (should be very effective)

- Use larger diameter hose (should be very effective).

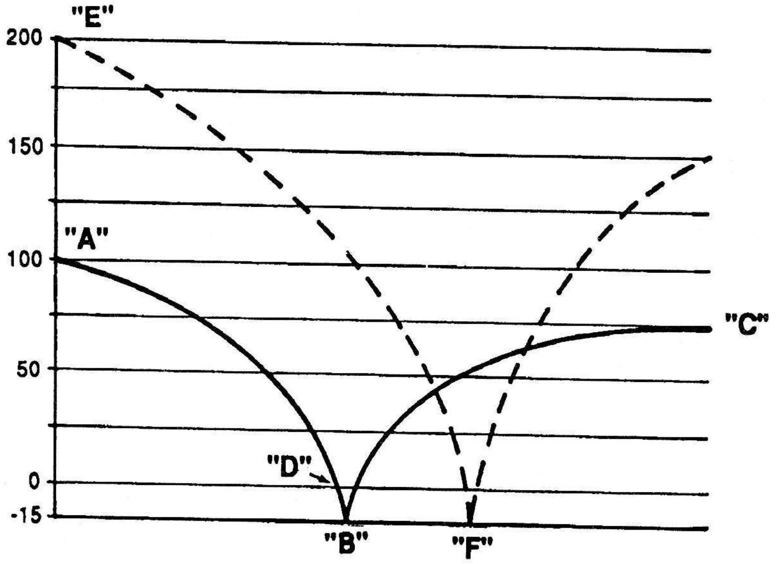

Figure 5. —Flow through an eductor.

Another explanation of why an eductor system is so very situation sensitive is the nature of eductor operations. At some pressure there is a maximum flow that can be forced through an eductor. This maximum flow is largely determined by the diameter of the throat of the eductor and also by the shape of the inlet to the throat. At 100 psig and a 3/8-inch throat diameter with a smooth inlet shape, only 45 gpm can be forced through the eductor. This 45 gpm flow will create a negative pressure of 14.7 psi at the throat. This negative 14.7 psi is what moves the foam concentrate into the water stream. A slight cut back in flow rate (45 to 42 gpm) will result in no negative pressure at the throat and thus no foam concentrate flow into the water stream.

This slight reduction in flow could be the result of added hose, reduced nozzle opening, or added elevation of the nozzle (figure 5). The solid line in figure 5 is the maximum flow at pressure "A" and this maximum flow will create the maximum possible negative pressure at "B." The maximum flow possible driven by 100 psig pressure is 45 gpm. The eductor has regained 75 percent of the inlet pressure at "C" or 71 psig.

When more resistance is added to the flow line, such as closing down a nozzle or adding hose, so that flow is reduced to 42 gpm at "D," no negative pressure is created and, therefore, no concentrate flows into the water stream. To make the system work, pressure must be raised to approximately 200 psi at "E." Flow is now 60 gpm at "F," and again a maximum negative pressure is created at "F," forcing foam concentrate to flow into the water stream.

In summary, in-line eductor proportioning systems can be set up and adjusted to function properly and will continue to work well as long as no changes are made. If changes are made such as reducing the size of the nozzle (like shutting down a nozzle when two are in use), adding hose, or adding elevation at the hose outlet, the proportion may change, or the system may not work at all. This results in the in-line eductor proportioning system being very situation sensitive. <u>Therefore, these systems should be avoided, or when used; utilized with caution in wildfire suppression conditions where low flows and long, small diameter hose lays are employed.</u>

Bypass Eductor Proportioning Systems

The bypass eductor proportioning system is a modification of the in-line eductor proportioning system. By adjustments, the system is able to operate over a much greater range of water flow than the standard in-line eductor. The bypass eductor proportioning system is a manually regulated proportioning system and has the same large pressure loss (25 to 60 percent) associated with the in-line eductor. It is also very situation sensitive like the in-line eductor. However, when a water flow change occurs, it is usually possible to adjust the system so it will continue to work.

The bypass eductor (figure 6) is made up of (1) a small eductor, (2) check valve, (3) foam concentrate metering valve, (4) reservoir, and (5) main-line water flow control valve. The system works by adjusting the main-line water flow control valve down until the pressure drop in the main line is enough to produce a water flow through the small eductor that will produce a vacuum. This vacuum will then move foam concentrate into the water stream. The pressure drop across the main-line flow control valve (bypass) and the pressure drop across the eductor are equal. The required pressure drop across the small eductor must be 25 to 60 percent of the total pressure to make the eductor work. Therefore, the pressure loss through a bypass eductor proportioning system is 25 to 60 percent, the same as the in-line eductor.

When the water flow control valve is completely shut off, all the water must pass through the small eductor. As the water flow valve is opened, water can also pass through this valve. Approximately twice as much water can be routed through the main-line water control valve as through the eductor. This results in a flow range of the eductor only to 3 times the flow of the eductor. However, the proportioner is very situation sensitive. When an operating change is made such as water flow, added hose length, or number or size of nozzles, usually both the main water control valve and the foam concentrate flow control valve must be adjusted in order to maintain the same foam concentrate ratio.

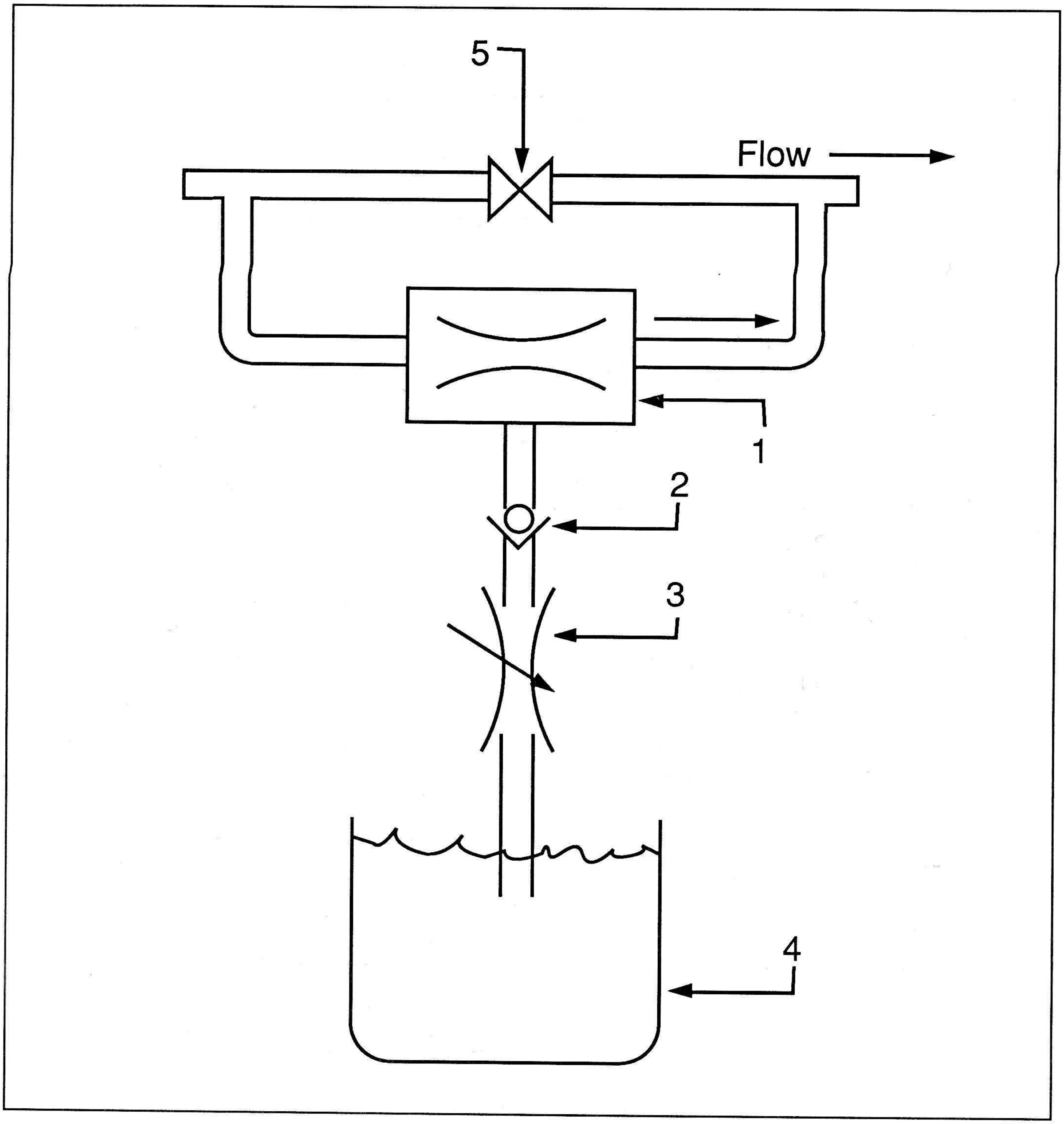

Figure 6. —Bypass eductor proportioning system.

Around-the-Pump Proportioning Systems

Another manually regulated system is the around-the-pump proportioner. This system diverts a small portion of the pump discharge through a small in-line eductor back to the suction side of the pump. This loop around the pump is used to draw foam concentrate into the main water stream by the use of an eductor. The foam solution created at the eductor is very rich, so the desired mix ratio is achieved when this rich foam solution combines with the main water stream just before entering the pump.

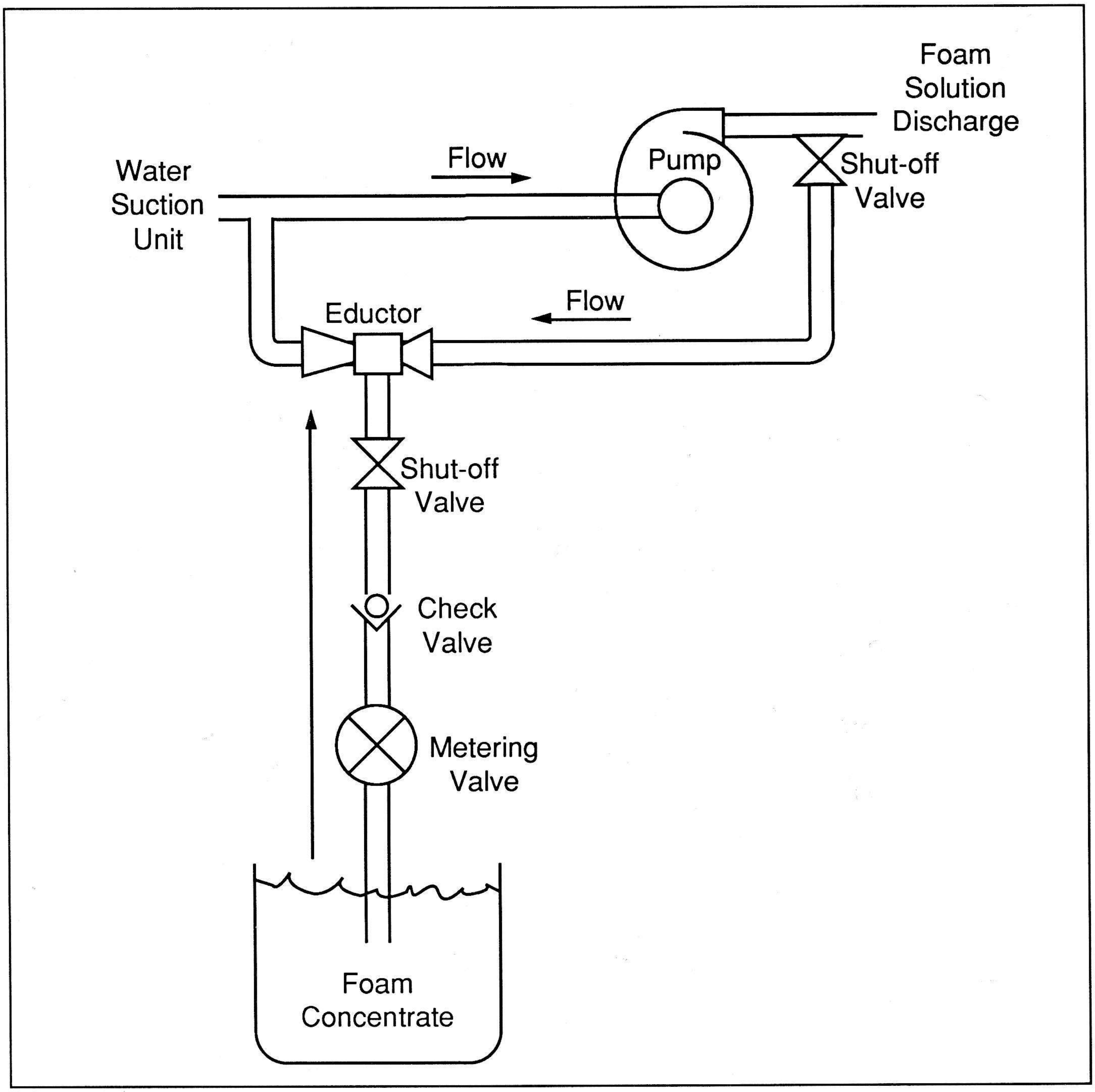

Figure 7. —Around-the-pump proportioning system.

The around-the-pump proportioning system (figure 7) is made up of a small eductor, check valve, foam concentrate metering valve, foam concentrate reservoir, and water loop shut-off valve. This proportioning system will work on pumps of any size and output, portable or built-in. With adjustments, it will operate at any water flow or pressure. A pump equipped with an around-the-pump proportioning system can draw water from a water tender without affecting the proportioning system. The system does not limit the number of nozzles or length of hose which can be used. Also foam concentrate metering valves have relative settings and need adjustment under different operating conditions.

The around-the-pump proportioning system must be manually regulated because the eductor does not automatically adjust the foam concentrate flow when a firefighter changes the water flow at the nozzle. To maintain the mix ratio, manual adjustment must be based on measured water flow. When water flow stops, either the shut-off valve in the around-the-pump loop must be shut off to stop water flow in the loop or the foam concentrate metering valve must be shut off to stop foam concentrate flow. This will prevent foam concentrate from being injected into the pump suction and then flowing into the engine water tank or water source if the pumper is not equipped with a foot or check valve in the suction line. If the pumper is equipped with a foot or check valve in the suction line, shutting off the water flow in the around-the-pump water loop or shutting off the foam concentrate metering valve will stop foam concentrate flow and prevent excessive pressure from building in the suction and discharge of the pump.

The around-the-pump proportioning system is more flexible than the in-line eductor, but it introduces foam concentrate into the water stream in the same manner as the suction-side proportioner. This means the around-the-pump proportioning system has the same disadvantages as batch mixing. Also, like the suction-side proportioner, if the pickup tube to the eductor separates from the foam concentrate, the pump will probably lose its prime. The around-the-pump proportioning system also has an undesirable characteristic. When using the proportioner with a foot or check valve in the suction line and the pump discharge is shut off and if the proportioner is not shut off, high pressure can build up in the discharge and suction sides of the pump until something breaks. This is not good.

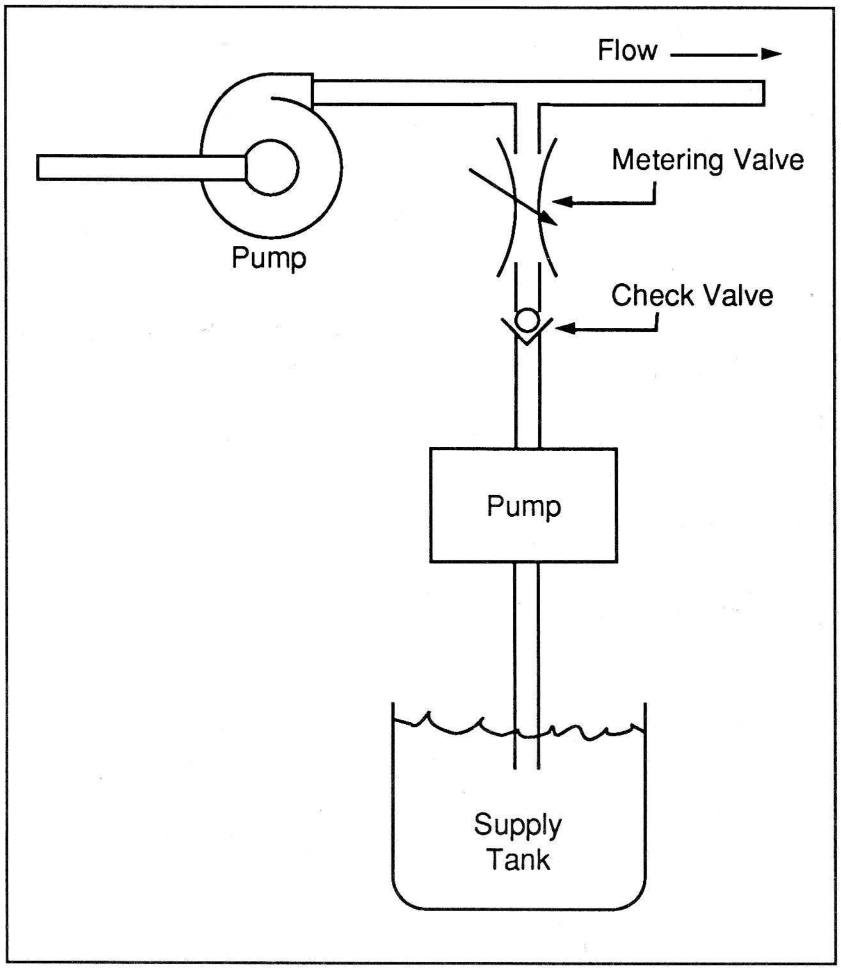

Figure 8. —Direct injection, manually regulated, proportioning system.

Direct Injection, Manually Regulated, Proportioning Systems

In a direct injection, manually regulated, proportioning system a small positive displacement metering pump injects foam concentrate directly into the water stream on the discharge side or suction side of the pump (see figure 8). The rate of foam concentrate injection can be adjusted to give the desired foam solution. However, when the water flow rate changes, the foam concentrate injection rate must be manually changed in order to keep the foam solution at the same desired percentage. These units usually have a low water flow cut-off switch to stop foam concentrate flow when water flow is stopped.

Problems of Manually Regulated Proportioning Systems

Manually regulated foam concentrate proportioning systems have a number of problems associated with them. They are:

For batch mixing:

- Foam proportion cannot be conveniently changed while operating. It can be increased by adding more foam concentrate to the water tank.
- When refilling a partially used pre-mixed tank of water, dip sticking or gauging is required to measure the volume of water left.
- The fire engine cannot draw water directly from a water tender or hydrant and make foam solution.
- Over time, foam solution degrades, tends to lose potency, and does not foam as well.
- Agitation of the foam solution, such as driving over rough terrain, water recirculation, or tank refill, produces a head of foam that can over-flow the tank.

For suction-side proportioners:

- Incoming water pressure to the pump must be kept below negative atmospheric pressure in order to move foam concentrate into the suction of the pump.
- To set proportion correctly, flow must be known.
- If the operating conditions change (e.g., flow rate of water or water level in the tank) proportioning rate may change.
- If the concentrate pickup line sucks air (such as running out of concentrate), the pump will lose its prime.

For pump discharge side in-line eductor and pump discharge side bypass eductor proportioners:

- Require specific operating conditions to work. Any change in operating conditions may result in large changes in foam concentrate ratio or may not work at all.
- Can expect high pressure loss through eductor (25 to 60 percent).
- Are sensitive to increased hose lengths and changes in nozzle sizes. Size and water flow of nozzle must match eductor or the proportioner may not work.

For around-the-pump proportioners:

- Flow must be known to set the proportion correctly.
- For the system to remain proportional without making adjustments, operating conditions must remain the same.

- If the concentrate pickup line sucks air, the water pump will lose its prime.
- Excessive pressure can be created on the suction and discharge sides of the pump, when the pump discharge is shut off, if a suction side foot or check valve is being used.

For batch mixing, suction side proportioners, and around-the-pump proportioners:

- Corrosion (results from the foam concentrate cleaning the tank, pump, and plumbing)
- Can cause pump priming difficulties
- Foaming in the tank can cause water level gauge to read incorrectly
- Foaming in the tank will over flow when refilling
- Use of more foam concentrate than required
- Problems with pump and valves caused by the foam concentrate washing out lubricants
- Contamination of the water tank makes water from the tank unusable for other purposes, such as transporting fish or potable water use.

These problems, associated with manually regulated proportioners, do not make them the most desirable proportioning systems for use in wildland fire fighting when using class "A" foam. Manually regulated proportioning systems are usually low in initial cost but may be the most expensive proportioning systems overall. They may proportion more foam concentrate than needed, increasing foam costs; may proportion less foam than needed, resulting in reduced effectiveness; or may not work at all.

Summary: Manually Regulated Proportioning Systems

In summary, manually regulated proportioning systems can be set up and adjusted to work very well and will continue to work well as long as no changes are made. If changes are made, such as reducing the size of the nozzle, shutting down a nozzle when two are in use, adding hose or adding elevation at the nozzle, the proportion may change or the system may not work at all. Also, as the name implies, manually regulated proportioning systems need to be adjusted to remain proportional when operating conditions change and, therefore, must be continually monitored. In order to monitor and accurately adjust manually regulated proportioning systems, flow meters must be used. In practice they seldom are. Manually regulated proportioning systems can be very situation sensitive—therefore, these systems should be avoided or when used; utilized with caution in wildfire suppression operations where low flows and long, small diameter hose lays are used.

Automatic Regulating Proportioners

Because of the significant shortcomings of the manually regulated proportioning systems, automatic regulating proportioning systems, which directly inject foam concentrate into the high pressure side of the water pump, have been developed. These automatic regulating proportioning systems address, or attempt to address, the significant shortcomings of the manually regulated proportioning systems.

Balanced Pressure, Venturi, Proportioning Systems

In a balanced pressure, venturi, proportioning system the foam concentrate is raised to the same pressure as the water pressure at the entrance to a venturi. As water passes through the venturi, the increased water velocity in the venturi throat results in increased dynamic pressure and decreased static pressure. The decreased static pressure is proportional to water flow squared, which results in the injection of foam concentrate into the water stream proportional to water flow. As the water flows into the divergent cone of the venturi, much of the static pressure is regained (80 to 90 % of the pressure differential). It is of interest to note that the operating principle of the balanced pressure, venturi, proportioning system is the same as a carburetor on a gasoline engine, which injects fuel into the air intake at a constant air/fuel ratio.

There are two general methods of raising and maintaining foam concentrate to the pressure at the entrance of the venturi. One is the use of a pump and pilot-operated relief valve. The other is a pressure tank containing a bladder with foam concentrate inside, which is pressurized from the water stream.

Balanced pressure, venturi, pump proportioning systems

To understand how the balanced pressure, venturi, pump proportioning system works, see the schematic of the essential elements (figure 9). These essential elements are (1) venturi, (2) check valve in the flow line in front of the venturi, (3) foam concentrate positive-displacement pump, (4) pilot-operated relief valve, (5) variable orifice (ball or needle valve), (6) check valve in the foam concentrate injection line, and (7) foam concentrate reservoir or tank. With these elements the system will work. Without any one of the essential parts, with the possible exception of the check valve (2) in the flow line in front of the venturi (1), the system will not work.

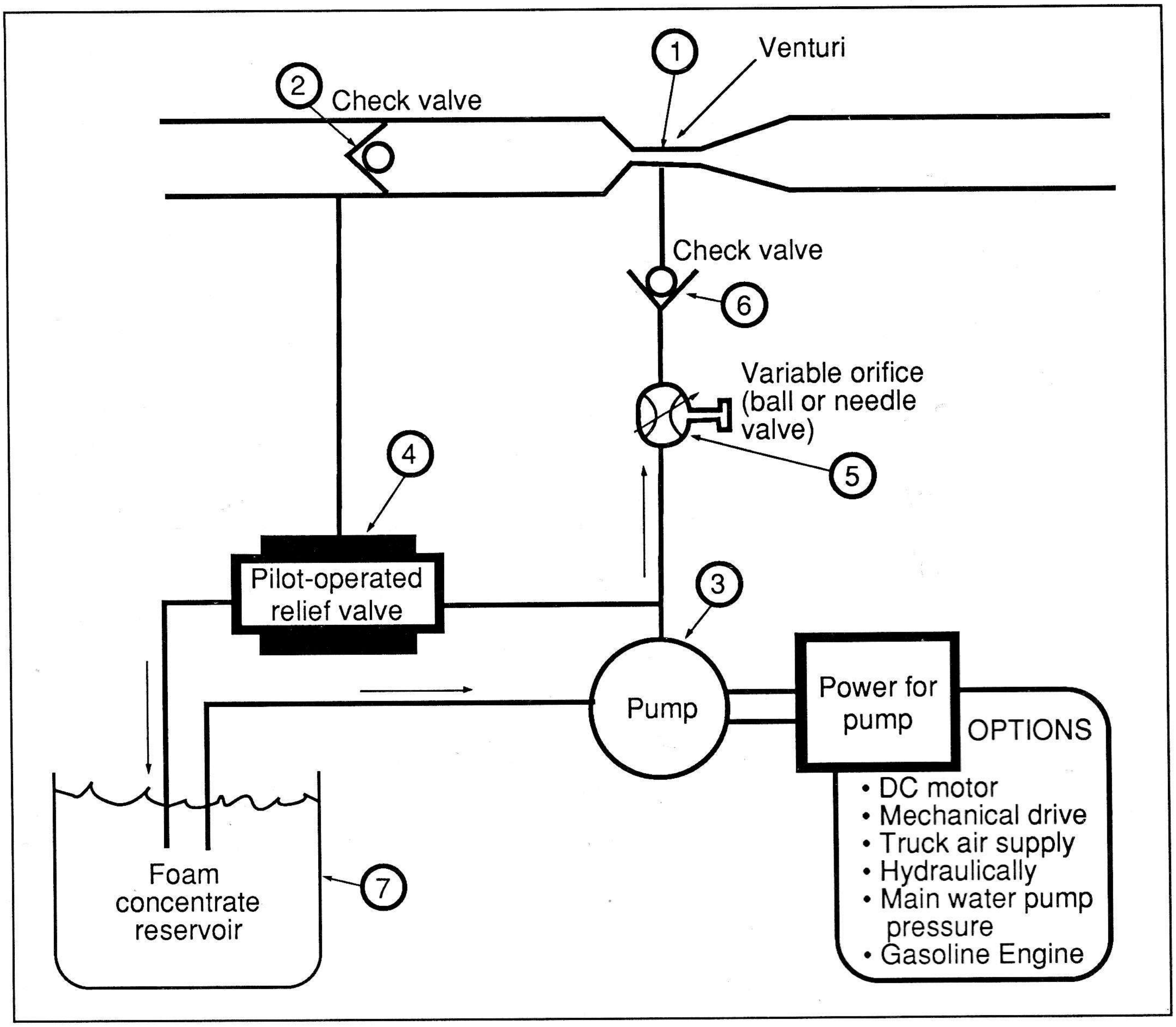

Figure 9. —Essential elements of balanced pressure, venturi, pump proportioning systems are (1) venturi, (2) check valve in the flow line in front of venturi, (3) foam concentrate positive-displacement pump, (4) pilot-operated relief valve, (5) variable orifice (ball or needle valve), (6) check valve in foam concentrate injection line, and (7) foam concentrate reservoir or tank.

Foam concentrate is drawn from the foam concentrate reservoir (7) by the small, positive displacement pump (3), which raises the pressure of the foam concentrate to the same pressure as main-line water pressure. Foam concentrate pressure is controlled by the pilot-operated relief valve (4), which maintains foam concentrate pressure at the same pressure as water pressure. In practice, when a check valve is used in front of the venturi, foam concentrate pressure may be set a little higher than water pressure. When a check valve is not used in front of the venturi, the foam concentrate pressure may be set a little lower than water pressure to insure foam concentrate will stop flowing when water stops flowing. With no water flowing, pressure is the same at the venturi inlet and at the venturi throat, resulting in no flow of foam concentrate into the water stream at the venturi throat.

When water is flowing, there is reduced static pressure at the venturi throat. Foam concentrate pressure, which is controlled by the pilot-operated relief valve (4), is the same as inlet water pressure to the check valve (2) and/or the venturi (1); therefore, foam concentrate flows from high pressure (pressure equal to the water pressure) into the throat of the venturi. The rate of flow of the foam concentrate into the throat of the venturi is controlled by the difference in pressure between the venturi inlet and venturi throat and by the setting on the variable orifice (5). The more the orifice is opened, the greater the foam concentrate flow. As the orifice is closed, the lower the foam concentrate flow. As water flow is increased, pressure at the venturi throat is decreased. As water flow is decreased, pressure at the venturi throat is increased. Therefore, foam concentrate flowing into the water stream is increased or decreased as water flow is increased or decreased. Thus, the injection of foam concentrate remains proportional to water flow, or the percent of foam concentrate in the water stream remains constant with varying flows.

Pressure decrease in the venturi throat is proportional to flow squared. If the water flow is doubled, pressure at the venturi will decrease by a factor of four. This results in excellent operation in the upper one-half of optimum design flow, and good operation in the upper two-thirds of optimum design flow. This means that, if the system was designed and sized for 50 gpm, it would work very well from 25 to 50 gpm and well from 16 to 50 gpm. The system could also be operated and work well at 100 percent over optimum design flow, and even up to 150 percent over optimum design flow. Optimum design flow is considered to be the flow when the venturi throat pressure is 20 psi below venturi inlet pressure.

In a well designed venturi, 80 to 90 percent of this differential pressure will be regained in the divergent cone or diffuser of the venturi, resulting in only a permanent pressure loss of 2 to 4 psi at optimum design flow. At 100 percent over optimum design flow, the differential pressure will be approximately 80 psi, resulting in a permanent pressure loss of 8 to 16 psi. At 150 percent over optimum design flow (which would not be considered as pushing the system too far), the differential pressure would be 125 psi, with a permanent pressure loss of somewhere on the order of 15 to 30 psi.

To make the balanced pressure, venturi, proportioning system work well down to near zero flow, a check valve can be placed in the flow line ahead of the venturi with a 1/2 psi cracking pressure. This results in the foam concentrate being injected into the water stream at near zero flow. We now have a system that will inject foam concentrate into a water stream from almost zero flow up to 250 percent of optimum design flow. The balanced pressure, venturi, proportioning system is:

1. Proportional from near zero to maximum flow (250 percent or more of optimum design flow) and is not affected by engine pressure, hose lengths and size, water flow, or nozzle adjustments, size, or elevation

2. Free of the requirement that chemicals be added to the main water tank or be run through the water pump

3. Capable of injection on the discharge side of the pump

4. Very reliable, when well designed and operated correctly

5. Able to draw foam concentrate from different tanks that can be easily gauged and the percent foam concentrate in the foam solution can be easily changed

6. A low pressure loss system at optimum design flow.

Elements that are absolutely essential for the balanced pressure, venturi, pump proportioning system to work from near zero flow to full flow are shown in figure 9. There are a few other items that should be included in the system. These items are identified in figure 10.

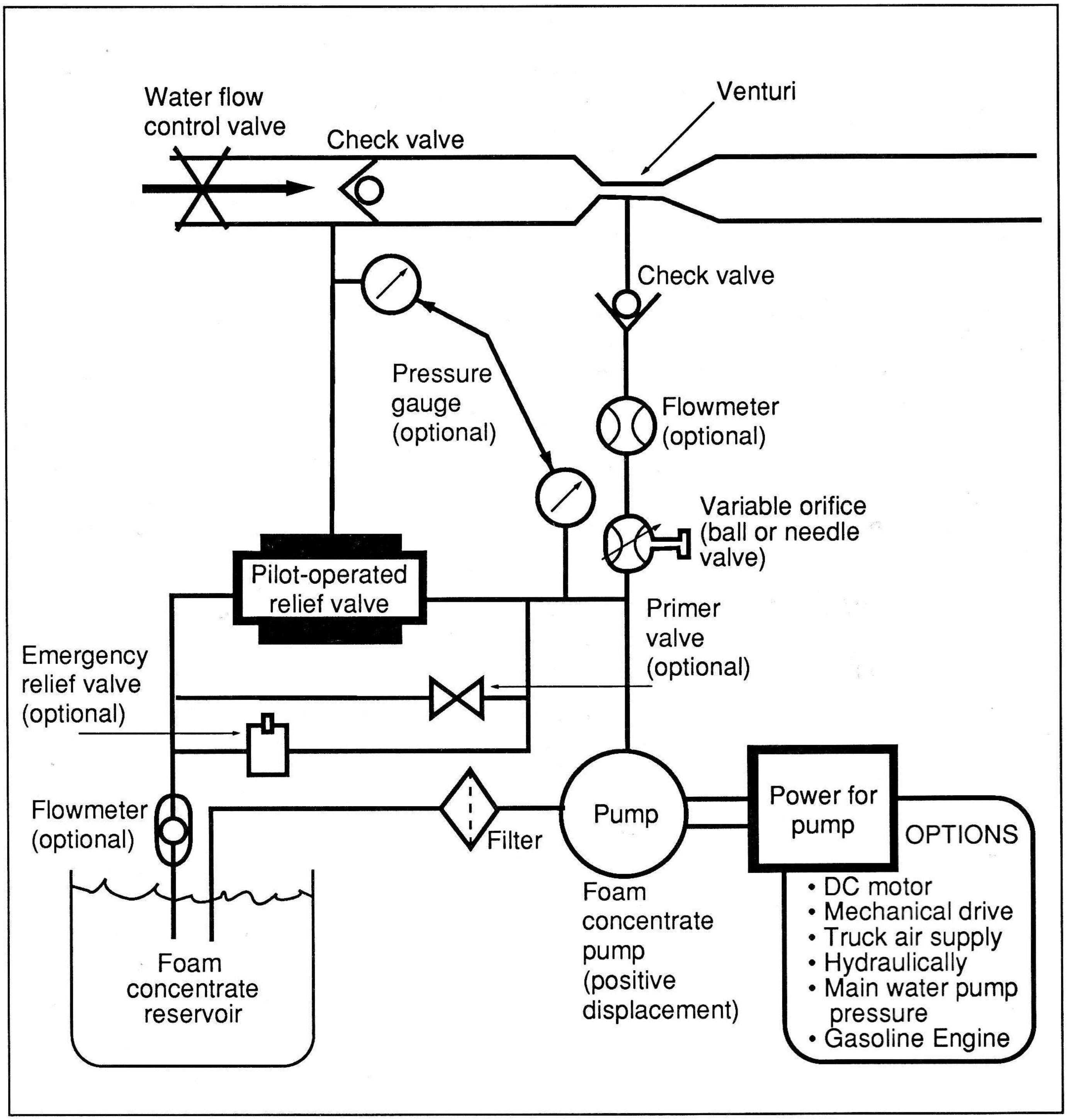

Figure 10. —Schematic of balanced pressure, venturi, pump proportioning system with suggested additional parts.

These additional parts will show foam concentrate usage rate by using a flowmeter in the foam injection line along with a flowmeter in the foam concentrate return line that will show that the foam concentrate pump is working. Also, pressure gauges may be installed to show water pressure and foam concentrate pressure and a suction filter installed to remove large particles from the foam concentrate suction line. Two other items probably should also be installed—an emergency relief valve for the foam concentrate and a primer valve.

The purpose of the emergency relief valve is to relieve foam concentrate pressure if, for some reason, it should become too high. This is considered good practice. The primer valve relieves foam concentrate pressure so that the foam concentrate pump is more easily primed. It can also be used to stop foam concentrate injection provided the primer valve outlet is returned to the foam concentrate reservoir or to the inlet of the foam concentrate pump. With the primer valve open, the foam concentrate will only be circulated and will not be injected into the water stream because the foam concentrate will be at near zero pressure.

Balanced pressure, venturi, bladder tank proportioning systems

Another way of providing the foam concentrate at line or water pressure is to replace the pilot-operated relief valve, foam concentrate positive-displacement pump, primer valve, pressure gauges, emergency relief valve, return flowmeter, and emergency relief valve with a bladder pressure tank. This system places water pressure on one side of the bladder and foam concentrate on the other side of the bladder (see figure 11 for schematic). With water pressure inside the tank, the foam concentrate is now at the same pressure as water pressure.

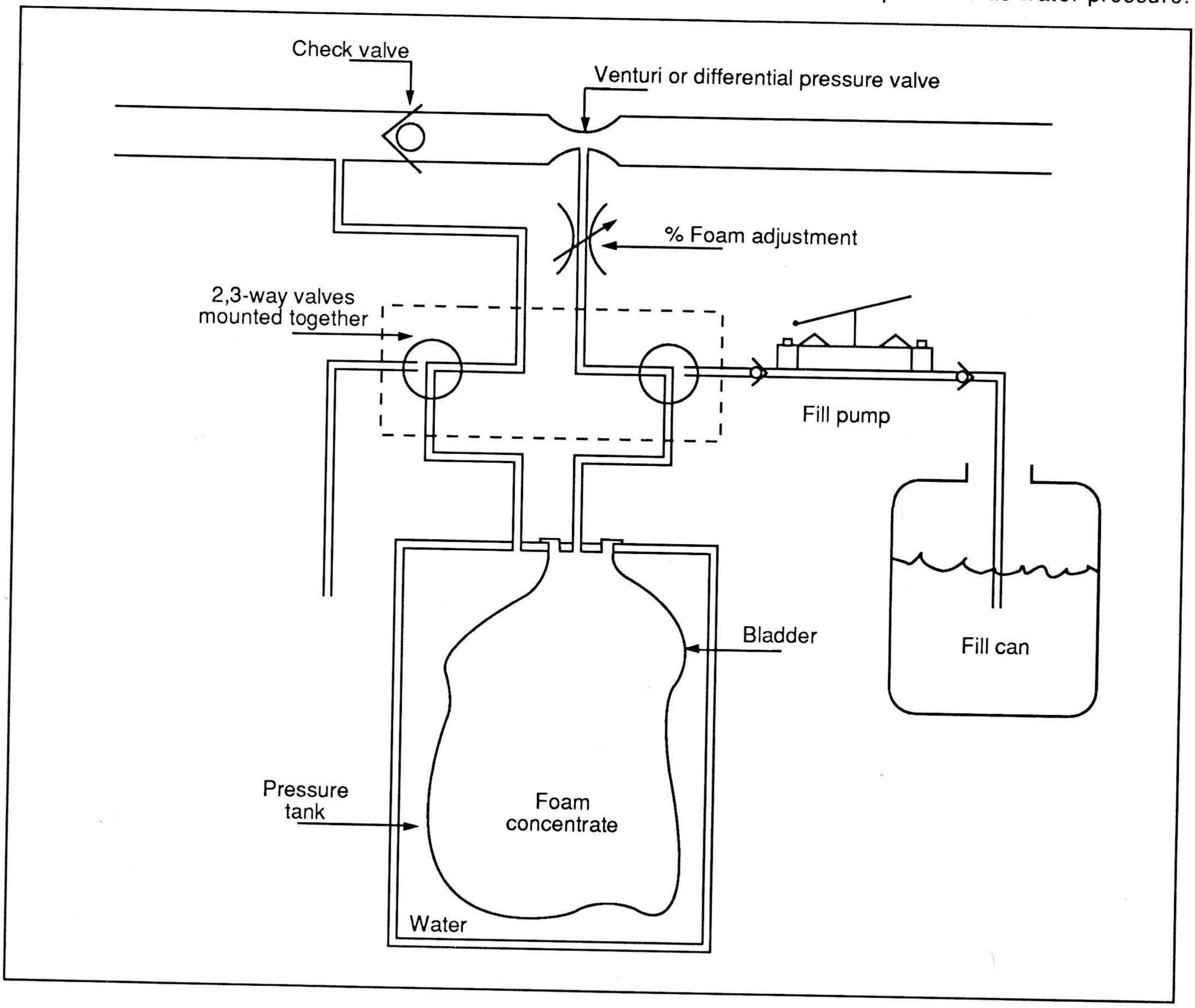

Figure 11. —Schematic of direct injection, balanced pressure, venturi, bladder tank proportioning system.

This system works just as the pump and pilot-operated relief valve system works. The balanced pressure, venturi, bladder tank proportioning system needs no external power. One manufacturer of a balanced pressure bladder tank proportioning system uses a differential pressure valve in place of the check valve and venturi. This differential pressure valve creates a pressure drop approximately proportional to water flow squared resulting in good proportioning just like a venturi.

Water-motor Meter Proportioning Systems

In a water-motor meter proportioning system a positive displacement water-motor drives a positive displacement foam concentrate metering pump (see figure 12). The ratio of the water motor displacement to the displacement of the metering pump is the ratio of the desired foam solution. Hence, the displacement of the metering pump will be one two-hundredths of the displacement of the water-motor when a .5 percent foam solution is desired. In practice, the displacement ratio will be higher to compensate for volumetric losses.

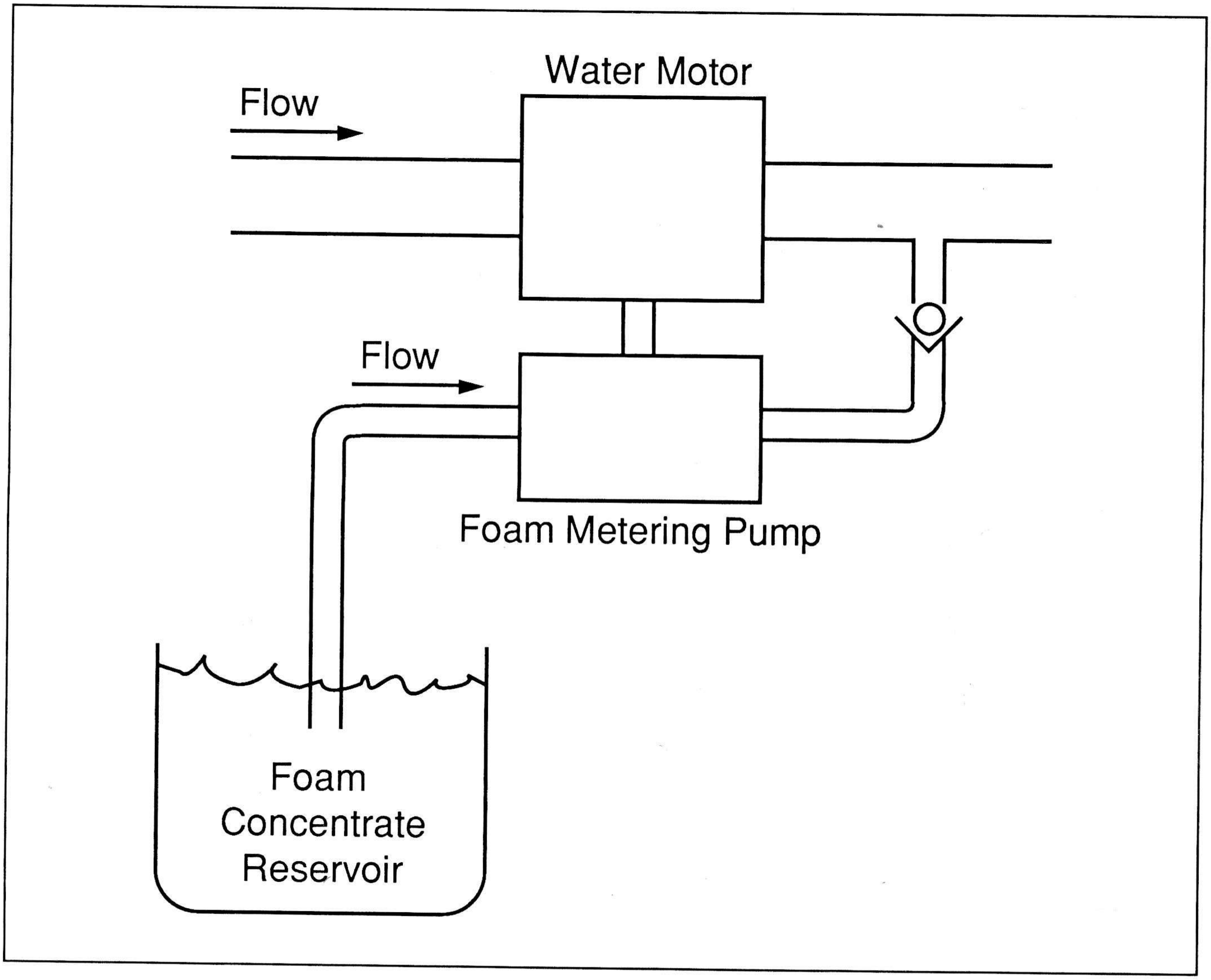

Figure 12. —Water-motor meter proportioning system.

The water-motor meter proportioning system requires no external power. However, when operating near zero flow the system tends not to run. Also in the design of the system, the water-motor must have an output shaft on each side to balance the side loading. If a water-motor is used with only a shaft coming out one side, the unit will start and run well when there is no downstream pressure. However, when there is downstream pressure (as is generally the case when firefighting) the unit tends not to start.

Direct Injection, Automatic Regulating, Proportioning System

In a direct injection, automatic regulating, proportioning system an electronically controlled positive displacement metering pump injects foam concentrate directly into the discharge side of the water pump (see figure 13). In normal operation of this type unit in the automatic mode, water flow is measured by a flowmeter which sends signals to the microprocessor, which controls the speed of the electric motor powering the foam concentrate metering pump. These systems can also generally be placed in a manual mode where the metering pump is pumping, for example, one-half gpm and injecting into the discharge side of the pump. Also, the system can give flow in gpm and the total amount of water pumped.

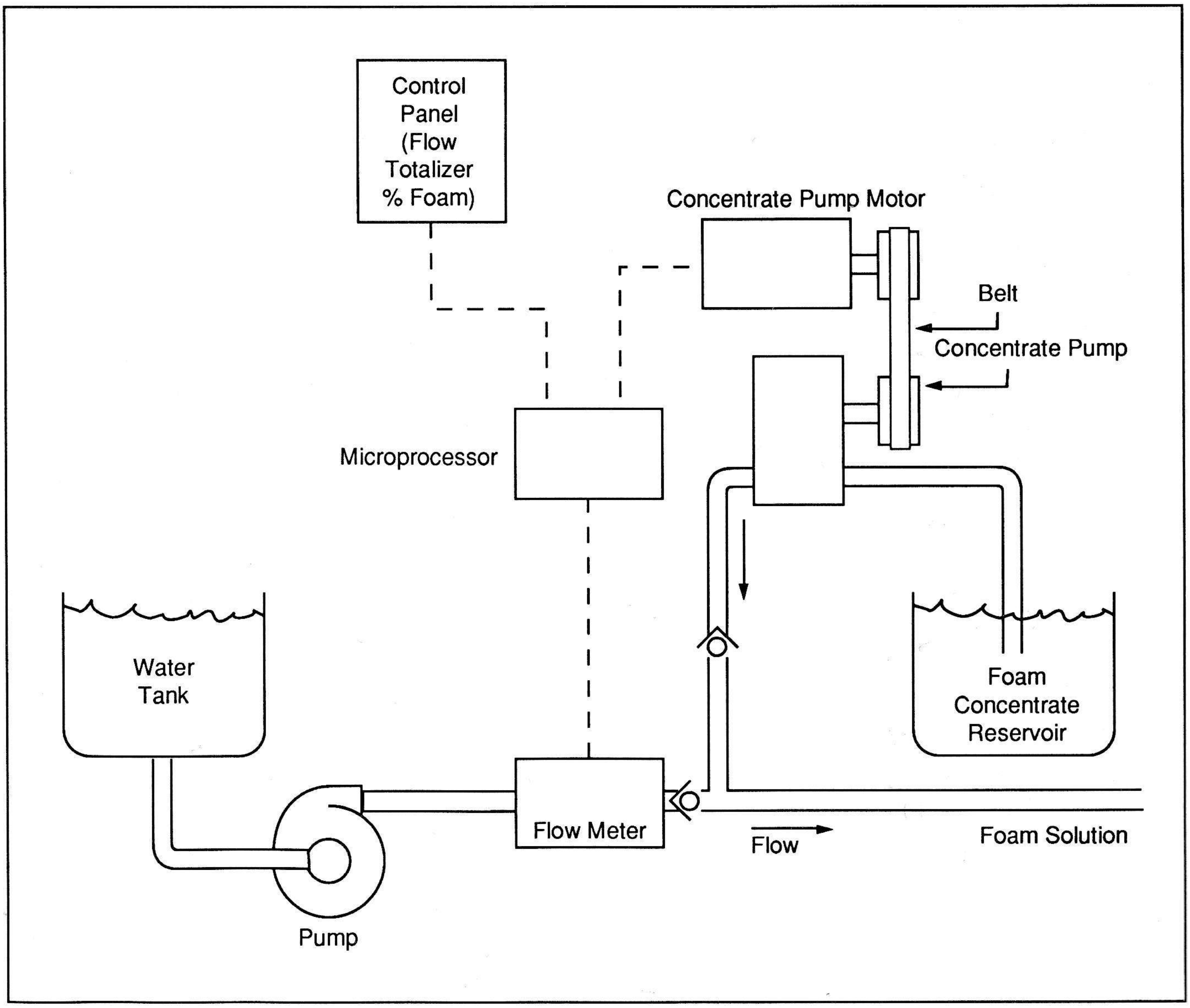

Figure 13. —Schematic of direct injection, automatic regulating, proportioning system.

Advantages and Disadvantages of Automatic Regulating Proportioning Systems

The major advantages of the automatic regulating direct injection proportioning systems are that no chemicals are added to the fire engine main water tank, the percentage of mix can be changed while operating, and an outside water source can be used. They are proportional over a wide range of flow, and are not affected by changes in engine pressure, changes in hose length and size, or changes in nozzle adjustments, size, or elevation.

Other advantages are:

- No external power required—
  Balanced pressure, venturi, pressure tank, proportioning systems
  Water-motor meter proportioning systems

- Refill while operating and indication of foam concentrate remaining—
  Balanced pressure, venturi, pump, proportioning systems
  Water-motor meter proportioning systems
  Direct injection, automatic regulating, proportioning systems

The major disadvantage of the automatic regulating proportioners is the generally high initial cost.

CONCLUSIONS AND RECOMMENDATIONS

1. Batch mixing should be considered as the backup proportioning system when another type of proportioning system fails or when no other proportioning system is available.

2. While manually regulated foam concentrate proportioning systems are generally the lowest initial cost, they may be in fact the highest cost systems overall, because they can proportion more foam concentrate than necessary or, worse yet, not proportion enough or none at all.

3. Because of the many shortcomings of the manually regulated proportioning systems, automatic regulating proportioning systems have been developed to reduce these limitations found in the manually regulated proportioning systems. Specifically, the automatic regulating proportioning systems are designed to remain proportional over a wide range of flows and are not affected by changes in engine pressure, changes in hose length and size, or changes in nozzle adjustments, size, or elevation.

4. The use of manually regulated proportioning systems should be avoided in wildfire suppression operations where low flows and long, small diameter hose lays are used and where frequent changes in water flow are necessary.

5. The use of automatic regulating proportioning systems injecting into the discharge side of the pump should be encouraged.

6. To help encourage the use of automatic regulating proportioning systems injecting directly into the discharge side of the pump, they should be formally tested and test results disseminated.

APPENDIX
Available Commercial Proportioners
Manually Regulated Proportioners

Suction-side proportioning systems
Fleck Bros.
4084 McConnell Court
Burnaby, British Columbia, Canada, V5A 3N7
(604) 420-3535

In-line eductor proportioning systems
Akron Brass
P. O. Box 86
Wooster, OH 44691
(216) 264-5678

Chemonics Industries, Inc.
P. O. Box 21568
Phoenix, AZ 85036
(602) 262-5401

Dema Engineering Co.
10020 Big Bend Blvd.
St. Louis, MO 63122
(314) 966-3533

Elkhart Brass Mfg. Co., Inc.
P. O. Box 1127
Elkhart, IN 46515
(219) 295-8330

Bypass eductor proportioning systems
Chemonics Industries, Inc.
P. O. Box 21568
Phoenix, AZ 85036
(602) 262-5401

Dema Engineering Co.
10020 Big Bend Blvd.
St Louis, Mo 63122
(314) 966-3533

Around-the-pump proportioning systems
CO-SON Industries
1493 Sieveright Ave.
Gloucester, Ontario, Canada, K1T-1M5
(613) 733-5348

Mulligan & Associates
P. O. Box 524
Gresham, OR 97030
(503) 239-2311

Direct injection, manually regulated proportioning systems
AccuFoam
P. O. Box 186
Benson, MN 56215
(612) 843-4932

Mulligan & Associates
P. O. Box 524
Gresham, OR 97030
(503) 239-2311

Automatic Regulating Proportioners

Balanced pressure venturi proportioning systems
<u>Pump proportioning systems</u>
KK Products
1004 Silhavy Rd.
Valparaiso, IN 46383
(219) 465-1266

<u>Bladder proportioning systems</u>
Robwen Inc.
1945 Blake Ave.
Los Angeles, CA 90039
(213) 665-5633

Water-motor proportioning systems
Hammonds Technical Services Inc.
P. O. Box 38114-373
Houston, TX 77238-8114
(713) 442-4074

Direct injection, automatic regulating proportioning systems
Hale Fire Pump Co.
700 Spring Mill Ave.
Conshohocken, PA 19428
(215) 825-6300