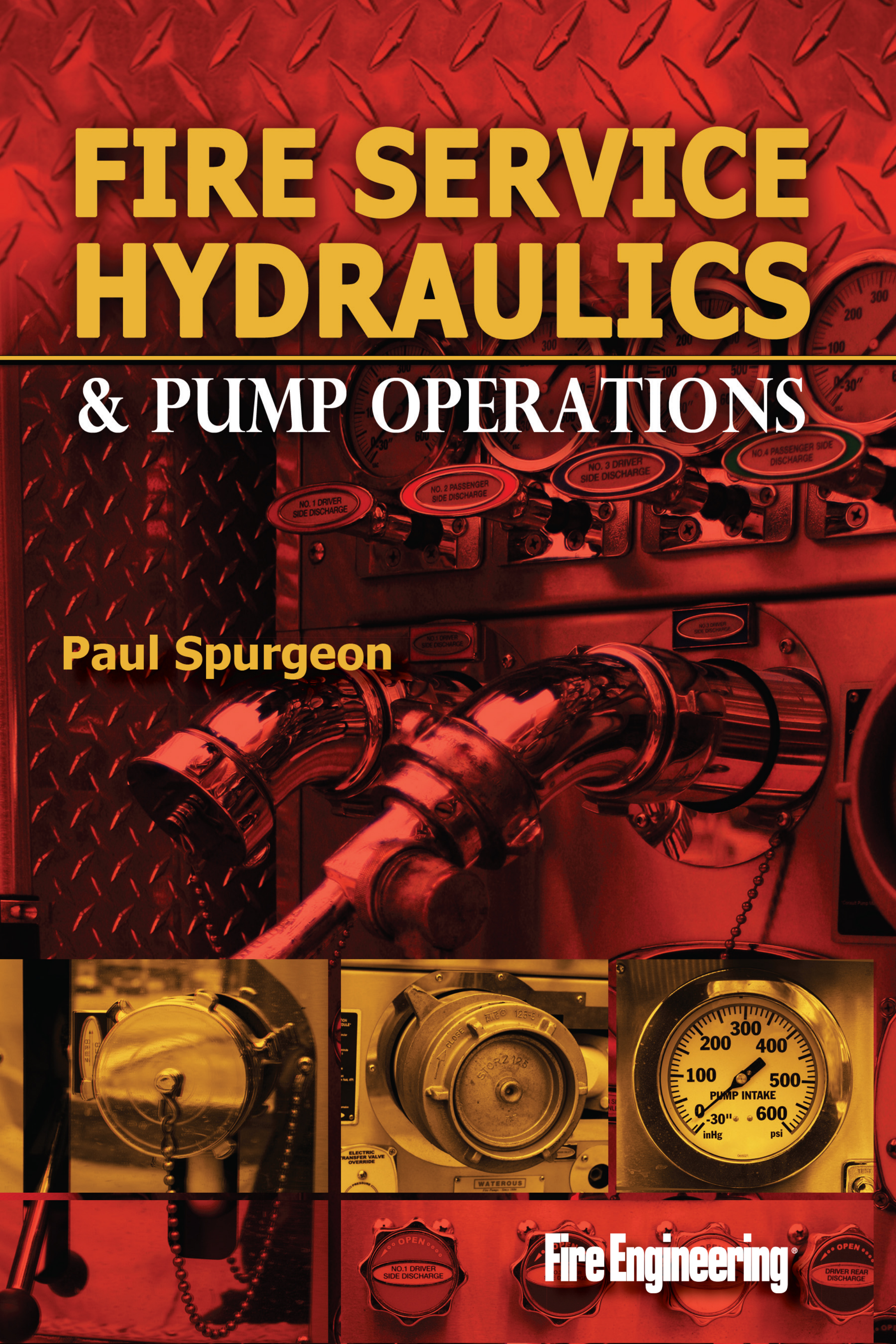
FIRE SERVICE HYDRAULICS
& PUMP OPERATIONS

Paul Spurgeon



Fire Engineering

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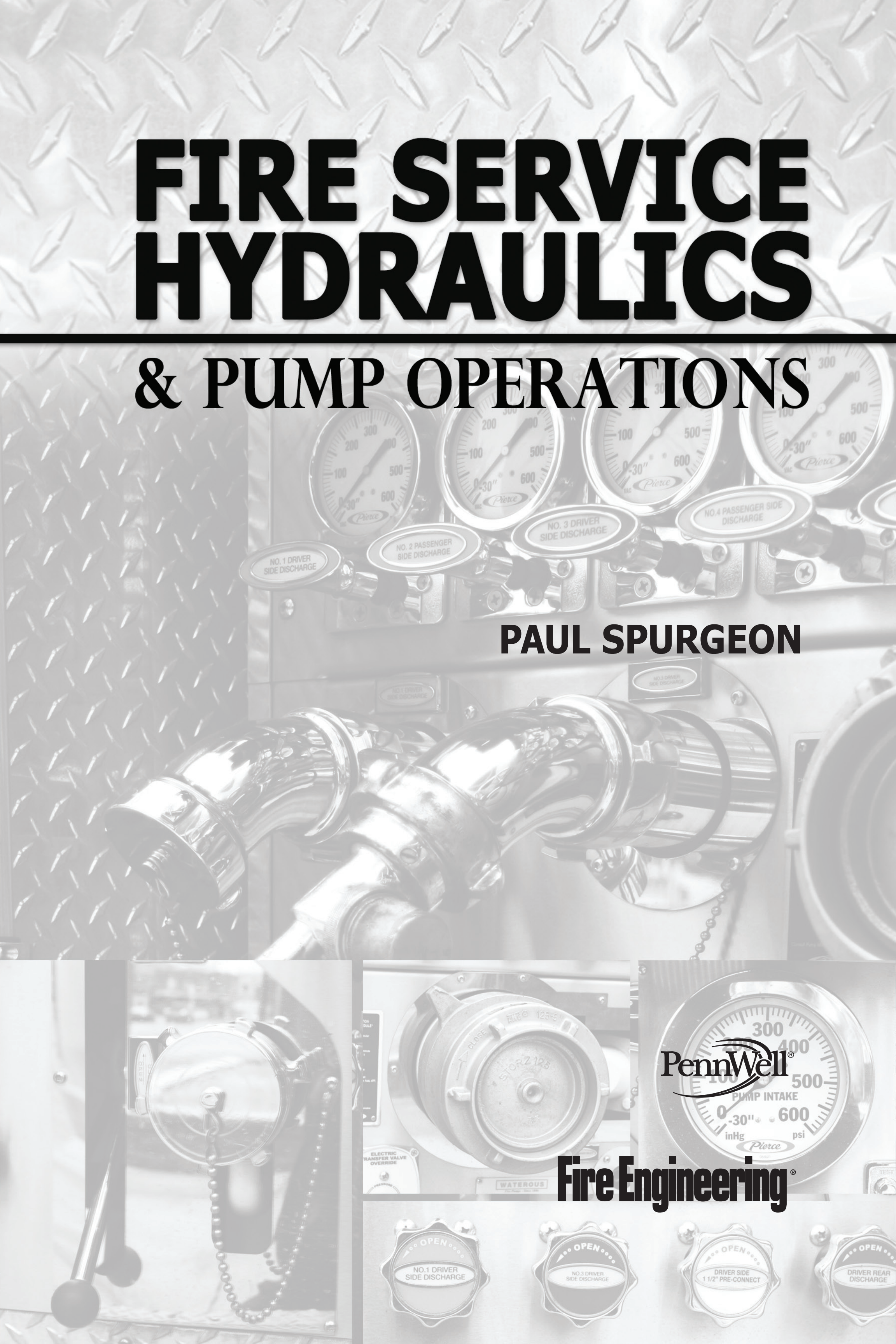

PAUL SPURGEON

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This book is first dedicated to my father, who introduced me to the world of firefighting. He also taught me the value of working hard and learning continuously. My wife and kids helped me immensely and put up with the hours it took to put this book together. Finally, this book is dedicated to the Denver Fire Department, whose members I respect and admire above all for their hard work and dedication.

CONTENTS

Section II

INTRODUCTION

Over the years, some highly respected people have studied, researched, and written about fire service hydraulics. Two books I have studied and learned from are *Fire Department Hydraulics* by Eugene F. Mahoney and *Fire Service Hydraulics* by numerous authors, edited by James F. Casey. These texts have provided much of my knowledge of the subject, but my approach to explaining this science is directed more toward the in-the-street, practical side of the field.

This book is broken down into two sections. The first section deals with the theory and practice of pencil-sharp hydraulics. The purpose of this section is to give you, the reader, the basic understanding of water usage in the fire service. These chapters break down the theories behind hydraulics and how the formulas are derived. A practical approach of getting water into the pump and then delivered to the fireground is explained in functional terms. The second chapter breaks down the equation that every pump operator needs to calculate at every fire. This is the formula that is at the heart of every pump operation. Special situations such as relay pumping and drafting are also covered. These situations are broken down into how and why they are applied. These situations may not occur every day, but when they do, you will be expected to know how to handle them. Not only will the hydraulic calculations be discussed, but why and how these special operations are needed is also addressed.

The math equations presented in the text are straightforward. It is basic addition, subtraction, multiplication, and order of operation. All decimals are rounded to the nearest hundredths place. Fire service hydraulics requires many math calculations. If you feel that math is not your strong suit, then it may be helpful to review a math book before you study this text.

Section II discusses the mechanics behind the equations. This section details how the pumps push the water through the hoses to the fire. In chapter 7, the reader will learn a basic approach to the types of pumps and how they are operated. In chapter 8, a pump panel is described so the reader will know what every knob and lever does. By the end of this section, you will know how to get water into the pump and out again and moved to the fire.

This text gives you a straightforward and clear understanding of fire service hydraulics by using a practical and realistic approach to the subject.

FESHE OBJECTIVES CORRELATION

This text is written to meet the course outcomes for the Fire Protection Hydraulics and Water Supply curriculum established in the FESHE Model Curriculum. Outcomes are met in the following chapters:

Objective	Chapter(s)	Page no(s).
1. Apply the application of mathematics and physics to the movement of water in fire suppression activities.	All	Found throughout
2. Identify the design principles of fire service pumping apparatus.	7	144–146
3. Analyze community fire flow demand criteria.	3, 4, 5	62–66, 71–81, 100, 103
4. Demonstrate through problem solving a thorough understanding of the principles of forces that affect water at rest and in motion.	1, 2, 4, 5	1–18, 25–54, 86, 88–94, 100–106
5. List and describe the various types of water distribution systems.	3	63–71
6. Discuss the various types of fire pumps.	7	63–71

1

WHY WE USE WATER

There are many reasons why water is used in fire service operations. Water acts in predictable and repeatable ways that allow firefighters to use it to extinguish fires. The actions of pump operators will have the same results each time, as long as they act in the same way every time. Over the years, methods have been developed to move water from point A to point B in a repeatable and predictable way.

Water as an Extinguishing Agent

Early on, humans discovered that if enough water was placed at the seat of a fire, the fire would disappear. Firefighting had begun. The same method is employed today using better equipment and technology. People over the years have studied water and its effects on fire, noticing certain characteristics. With a good understanding of those characteristics, it is possible to better handle fireground situations.

In its pure state, water is colorless, odorless, and tasteless. Its primary use to firefighters is to cool a burning material, preventing it from continuing to burn. Cool a burning material enough, and it will fail to produce enough vapors to burn. It is this vapor that ignites and causes so much trouble. If the temperature of an object is reduced to a point below its ignition temperature, it cannot produce enough vapors to burn, and the fire will be extinguished. The *law of latent heat of fusion* states that as a substance passes between solid and liquid states, it will absorb or release heat. When 1 pound (lb) of water turns to ice, it releases 143.4 British thermal units (Btus). As that same pound of ice turns back into a liquid, it will absorb the same amount of heat—143.4 Btus. Even more heat is given off or absorbed when a liquid changes into a gas, such as when water turns to steam. This is called the *latent heat of vaporization*. This heat is measured in Btus per unit weight. A *Btu* is defined as the amount of heat required to raise the temperature of 1 lb of water 1°F. To raise 1 lb of water from 60°F to 212°F, 162 Btus are needed. At 212°F, water turns to steam. As the liquid water turns into steam, that same pound of water will absorb 970.3 Btus. When all 970.3 Btus are absorbed, the entire pound of water will be converted to steam. Note that nearly six times more heat energy is absorbed converting the water to steam compared to what is required to raise the temperature from 60°F to 212°F. This is important because one of the basics of extinguishing fires is to cool a substance faster than it produces heat energy. The goal is to absorb more heat with water than is being produced by the burning process.

While water is mostly used for its cooling abilities, it can also extinguish fires by smothering or diluting. Smothering occurs when water is converted into steam and confined in an enclosed space. The steam produced will replace the air (oxygen) in the enclosed space. This is known as an *indirect attack*. This method of attack was first developed by Chief Lloyd Layman while he was in the Coast Guard. At the time, it was used primarily for ship fires, where areas of the ship could be sealed off from outside air. At 212°F, water vapor will expand approximately 1,700 times its original volume. At 500°F, water vapor will expand approximately 2,400 times. This steam expansion removes one side of the fire tetrahedron by reducing the amount of oxygen needed for combustion, as well as cooling the entire area (fig. 1–1).

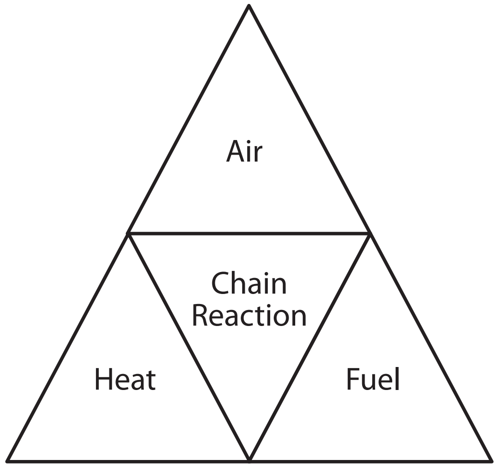

Fig. 1–1. The fire tetrahedron

Smothering can also occur when water is applied to the surface of a viscous flammable liquid. The water can sit on top of the liquid, separating the burning from the liquid material. The heat from the flames therefore cannot continue to heat the liquid, preventing it from producing vapors that will burn. However, using water itself is not the best way to smother a flammable liquid fire. More on this will be discussed in chapter 9, "Foam."

Properties of Water

As well as being a good extinguishing agent, water also has several characteristics that affect its use in fire protection:

1. **Water is nearly incompressible.** This allows water to be moved to where it is needed. Pressure applied to one end of a hose moves the water to the other end of the hose where the fire is located. (Only at extreme pressures can water be compressed. Since these types of pressure are not used in firefighting, water can be considered incompressible.)

2. **Water seeks its own level.** As water is poured into one side of a container, the surface will remain level. Figure 1–2 shows that as water is poured into side A, the level in side B will reach the same height. This also means that water will flow downhill or into lower levels of a structure.

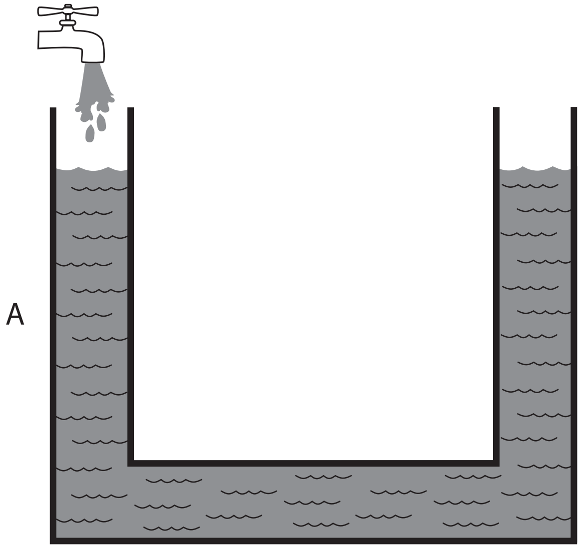

Fig. 1–2. Water seeks its own level.

3. **Water has weight.** The weight of water is generally considered to be 62.5 lb per cubic foot (ft^3) or 8.35 lb per gallon (gal). These figures vary with the temperature of the water, but the figures of 62.5 lb/ft^3 and 8.35 lb/gal are generally used. This is important when lifting water and storing it in tanks.

As good as water is as an extinguishing agent, it also has some disadvantages:

1. **Water has a relatively high surface tension.** This prevents it from penetrating some materials, such as baled cardboard. Most of the time, the baled material must be pulled apart in order to extinguish the fire. This is the case in places such as recycling plants that compact and bale materials for shipping.

2. **Water freezes.** As anyone who has fallen on ice knows, this can be dangerous. It can also prevent equipment from working properly.
3. **Water conducts electricity.** This prevents its use for electrical fires, since the electricity can travel through the water to the nozzle operator.
4. **Water reacts violently with some chemicals.** Magnesium, for example, burns at nearly explosive force.
5. **Water is not viscous.** This means that water doesn't do well at smothering fires.

Basic Fire Service Hydraulic Figures

A box that measures 1 ft × 1 ft × 1 ft has a volume of 1 ft^3 (fig. 1–3).

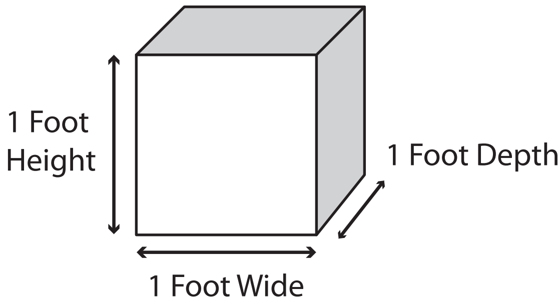

Fig. 1–3. One cubic foot

A cubic foot box filled with water weighs approximately 62.5 lb (fig. 1–4).

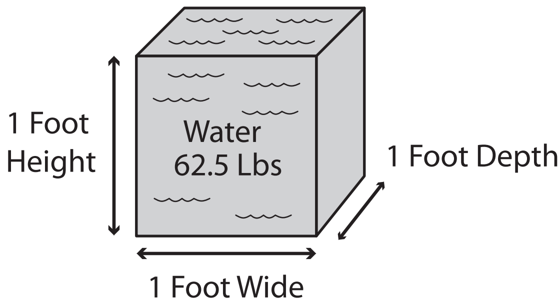

Fig. 1–4. One cubic foot = 62.5 lb of water.

One cubic foot of water is equal to 7.48 gal (fig. 1–5).

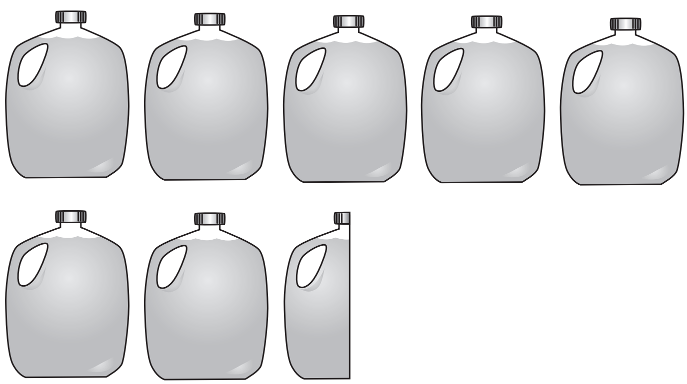

Fig. 1–5. One cubic foot of water = 7.48 gal.

One gallon of water weighs approximately 8.35 lb (fig. 1–6). This is found by dividing the number of pounds in a cubic foot (62.5) by the number of gallons in a cubic foot (7.48).

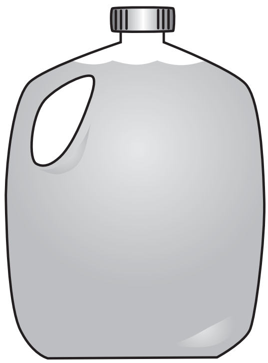

Fig. 1–6. One gallon of water = 8.35 lb.

One cubic foot contains 1,728 cubic inches (in^3) (fig. 1–7); 12″ × 12″ × 12″ = 1,728 in^3.

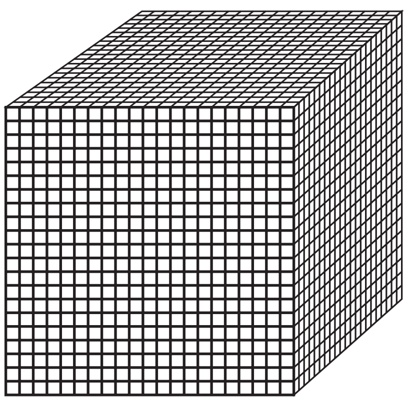

Fig. 1–7. One cubic foot = 1,728 in^3.

One gallon of water holds approximately 231 in^3 (fig. 1–8). This is determined by dividing the cubic inches in a cubic foot by 7.48, the number of gallons in a cubic foot (1,728 ÷ 7.48 = 231).

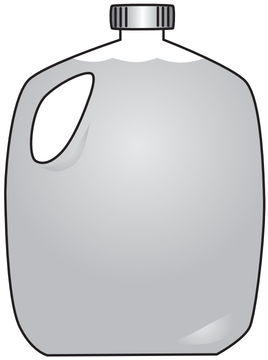

Fig. 1–8. One gallon = 231 in^3.

A column of water that measures 1″ × 1″ and is 1 ft tall will weigh 0.434 lb (fig. 1–9).

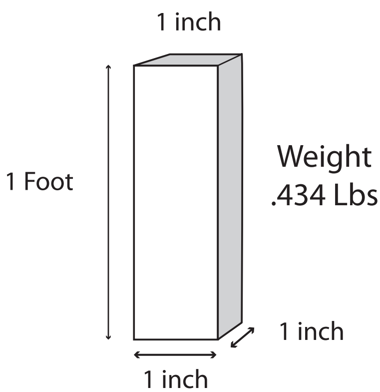

Fig. 1–9. A column of water 1 ft tall = 0.434 lb.

This is important to know when figuring how to overcome pressure created by elevation changes. A column of water 1″ × 1″ will need to be 2.304 ft tall in order to weigh 1 lb (fig. 1–10).

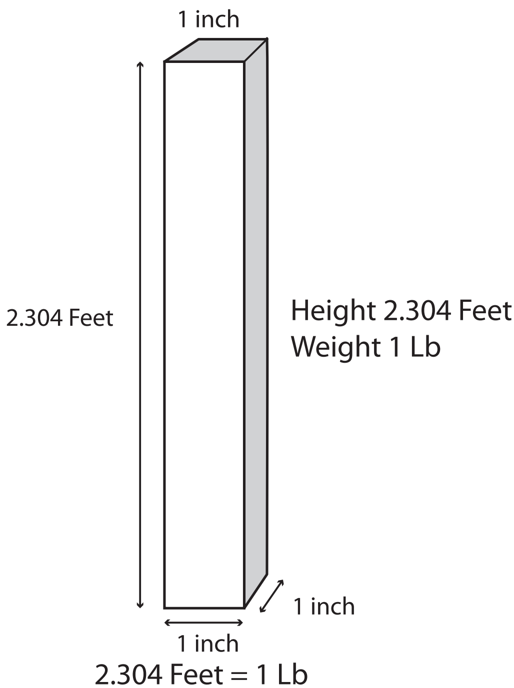

Fig. 1–10. A column of water that is 2.304 ft = 1 lb.

Force vs. Pressure

In many applications in life, the terms *pressure* and *force* are used interchangeably. In hydraulics, there needs to be a distinction. Pressure has some meaning to nearly everyone. It may be used in discussing how much air is in a tire or the amount of pressure needed to open a jar lid. In everyday life this term may be correct, but in fire service hydraulics, it is really the amount of force applied to the inside of the tire or the amount of force applied to open the jar.

Force is the amount of energy or weight applied at a given point. To illustrate the difference between force and pressure, place 10 blocks, each measuring 1 ft^3, side by side on a table. Assume each block weighs 10 lb. Since the blocks are side by side, the force on the table is 10 lb per square foot (lb/ft^2) or 100 lb per 10 ft^2. Now stack the blocks on top of each other. Since the total area on the table is covered by only 1 ft^2, the total force becomes 100 lb/ft^2.

Pressure is defined as force per unit area. If force (*F*) is applied to the surface area (*A*) of a fluid in a perpendicular manner, then the pressure (*P*) may be defined as follows:

$$P = F \div A$$

Pressure in the fire service is usually expressed in units of pounds per square inch. A column of water 1″ × 1″ and standing 2.304 ft high will create a pressure of 1 pound per square inch (psi) at the base. A container of water that has a 1 ft^2 base and is 2.304 ft tall will still have 1 lb of pressure per square inch, but it will have a force of 144 lb on the total area (144 total square inch columns that are 2.304 ft in height).

Types of pressure

Now to make things even more confusing, there are different types of pressures in the fire service.

Static pressure is simply the pressure of water when it is not moving. When a hoseline is charged but the nozzle is closed, the pressure is static. The pressure coming into the pump from a fire hydrant is considered static until it is allowed to flow out of the pump. Static pressure is shown on the main intake pressure gauge. The best way to determine initial static pressure in the fire pump is to take a reading after supply lines are attached but before the attack lines are charged and flowing. It is important to know what the intake static pressure is in order to be able to determine how much available water remains for future hoselines.

Flow pressure is the pressure of the water after the nozzle is opened and the water is moving. Flow pressure is less than static pressure due to the friction loss in the hose or other carrier, which will be discussed in a later chapter. Flow pressure is the amount the intake pressure gauge drops after the attack line is opened. For example, if the static pressure is 80 psi and the pressure drops to 60 psi when the hoseline is flowing, then the flow pressure is 20 psi. The flow pressure needs to be subtracted from the static pressure when figuring how much available water remains for future hoselines. This will be discussed in a later chapter.

Residual pressure is the remaining pressure in the distribution system after water is flowing. For example, if the static pressure is 80 psi and the flow pressure is 20 psi, the residual pressure is 60 psi. It is the pressure that is left over. This amount is used to determine the remaining volume of flow in gallons per minute (gpm) that can still be delivered.

Rules Governing Fluid Pressure

There are six basic rules that are used when talking about fluid pressure:

1. **Fluid pressure is perpendicular to any surface on which it acts.** Figure 1–11 shows a container with flat sides that is filled with water. The arrows represent the pressure caused by the weight of the water acting perpendicular to the side walls.

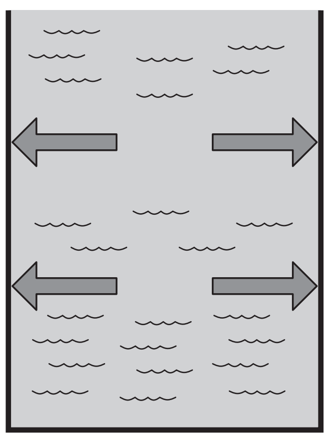

Fig. 1–11. Pressure is perpendicular to gravity.

2. **The pressure at any point in a fluid at rest is of the same intensity in all directions.** Figure 1–12 shows that gauges placed along a hoseline will read the same pressure at each gauge. This is static pressure.

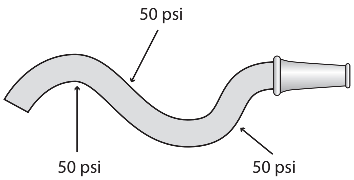

Fig. 1–12. Static pressure is equal in all directions.

3. **External pressure applied to a confined liquid is transmitted undiminished in all directions.** As the pressure is increased at the pump panel, the pressure will be the same in all directions inside the hoseline. If too much pressure is applied to a hoseline, it will burst.

4. **The downward pressure of a liquid in an open container is proportional to the depth of the liquid.** Figure 1–13 shows three containers. Container A is 1 ft tall and has a pressure at the base of 0.434 psi. Container B is 8 ft tall and has a pressure of 3.47 psi (8 × 0.434). Container C is 20 ft tall and has a pressure at the base of 8.68 psi (20 × 0.434).

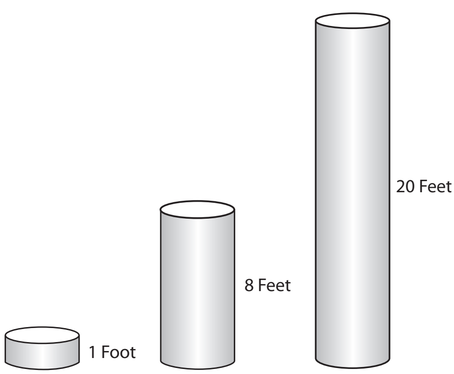

Fig. 1–13. Downward pressure is proportional to the depth.

5. **The downward pressure of a liquid in an open container is proportional to its density (fig. 1–14).** Mercury weighs 13.546 times more than water. Because mercury is denser than water, to create the same amount of downward pressure as a 1″ column of mercury, a column of water would have to be 13.546″ tall.

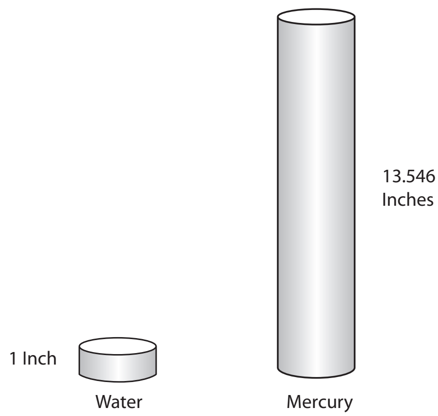

Fig. 1–14. Pressure is proportional to density.

6. **The downward pressure of a liquid on the bottom of an open container is independent of the shape or size of the container.** Figure 1–15 shows three different shaped containers, all 1 ft tall, having the same pressure of 0.434 lb at their base.

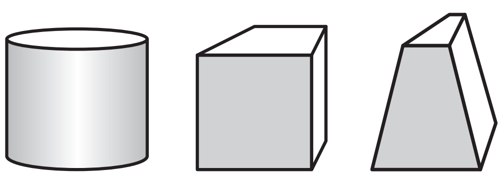

Fig. 1–15. Downward pressure is independent of shape.

Formulas

The capacity or volume of a water tank or hoseline is determined by figuring out the area of the base and multiplying it by the height. The formulas for rectangles or squares are different from a cylinder.

The volume of a rectangle or square can be figured by length (L) × width (W) × height (h) (fig. 1–16).

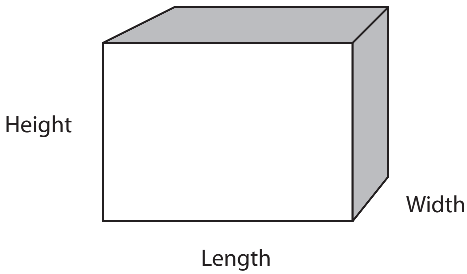

Fig. 1–16. Volume of a rectangle or square

The volume (V) of a cylinder can be figured by the following equation (fig. 1–17):

$$V = \pi R^2 h$$

where

R = radius of the cylinder and

h = height of the cylinder.

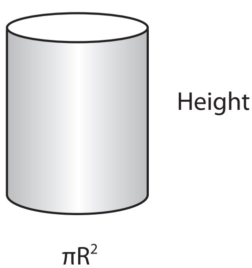

Fig. 1–17. Volume of a cylinder

To find the gallon capacity of these containers, multiply 7.48 (gallons in a cubic foot) by the volume (*V*) (fig. 1–18).

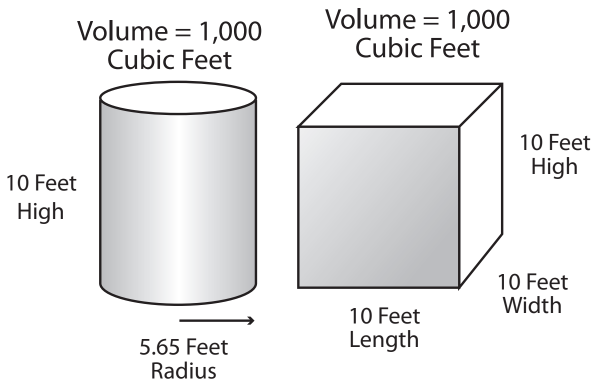

Fig. 1–18. Gallon capacity is 7.48 × volume.

The weight capacity of a container can be figured by multiplying the weight of 1 ft^3 of water by the volume (fig. 1–19).

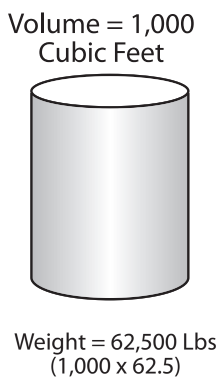

Fig. 1–19. Weight capacity = 62,500 lb.

Volume of a hoseline

A hoseline is simply a long cylinder. The difference between a water tank and hose is the unit of measurement. The water tank is expressed in cubic feet, and the hose is expressed in cubic inches. Thus, the length of hose needs to be converted into inches.

Example: Calculate the volume (*V*) of 50 ft of 2½″ hose, using the following equation:

$$V = \pi R^2 h$$

where

$R = 1\frac{1}{4}''$ and

$h = 600''$ (50 ft × 12″/ft).

$V = (3.14)(1.25)(1.25)(600)$

$V = 2{,}945.25 \text{ in}^3$

Gallon capacity of hoselines

The gallon capacity of hoselines can be found by dividing the volume in cubic inches by 231, the number of cubic inches in a gallon:

$$Gallon\ capacity = \frac{Volume\ in\ cubic\ inches}{231}$$

Example: Determine the gallon capacity of a 50-ft section of 2½″ hose:

$$Gallon\ capacity = \frac{2{,}945.25}{231}$$

$$Gallon\ capacity = 12.75 \text{ gal}$$

One instance in which it is important to know the gallon capacity of hoselines is when supplying lines directly from the water tank on the pumper. For instance, if the water tank has a capacity of 500 gal, and it is necessary to supply two lines, each 600 ft long of 2½″ hose, there could be a problem. If each 50-ft section holds 12.75 gal, and each line has 12 sections ($12 \times 50 = 600$ ft), then each line carries 153 gal of water. When both lines of 600 ft are filled, 306 gal are used just to fill the hoselines:

$$12.75 \text{ gal/sect.} \times 12 \text{ sect.} = 153 \text{ gal}$$

$$153 \text{ gal} \times 2 \text{ lines} = 306 \text{ gal}$$

This leaves less than 200 gal with which to extinguish the fire.

Weight of water

There are several figures used for the weight of water. Values ranging anywhere from 8 lb/gal up to 8.5 lb/gal are used. These differences are due to the temperature of the water. The most commonly used figure is 8.35 lb/gal, and that is what is used throughout this text.

Therefore, that same 50 ft section of 2½″ hose will weigh 106.46 lb:

$$12.75 \text{ gal} \times 8.35 \text{ lb/gal} = 106.46 \text{ lb}$$

One consideration when using 2½″ hose for attack lines is the weight of the line and how many people are available to move and advance the handline. It is a balancing act between getting enough gallons per minute to extinguish the fire and being able to handle a larger hose line. If a crew of three firefighters is first to arrive on scene, the officer might need to pull a smaller handline, such as a 1¾″ line, and try to hold the fire in place until more personnel arrive and can pull a larger handline.

Another thing to think about in regards to the weight of water is the strain the water is placing on a building. For example, for every 1,000 gal of water that is poured into a building, an extra 8,350 lb are placed in a building that is already compromised by the fire. The possibility of the building collapsing is greatly increased.

Consider a fire that the incident commander determines will need two handlines, each flowing 250 gallons per minute (gpm) in order to extinguish. If each hoseline flows for only two minutes, the total amount of water placed into the building is 1,000 gal. Even though most of the water will be used up extinguishing the fire, there is the potential of adding an extra 8,350 lb of weight to a fire-weakened structure. If firefighters are inside a building and see a lot of standing water, they need to be aware of the possibility of the building collapsing due to the extra weight. When a fire is being fought defensively, thousands of gallons are being poured into a structure. The weight of the water will cause the building to collapse more quickly, so the apparatus will need to be positioned outside of the collapse zone.

Because water is used so extensively, it is important to understand its properties and its effects on a fire. The officers in charge need to understand why water is used and also when using water may not be the best method to extinguish a fire. Firefighters battling the flames need to know how best to apply the water, as well as the hazards involved in applying the water. It is important to know what water can and cannot do on a fire scene.

Summary of Chapter Formulas

1. Water weighs approximately 62.5 lb/ft^3.
2. There are approximately 7.48 gal in 1 ft^3.
3. One gallon of water weighs approximately 8.35 lb.
4. There are 1,728 in^3 in 1 ft^3.
5. A gallon of water contains approximately 231 in^3.
6. A 1″ × 1″ column of water that is 1 ft tall weighs approximately 0.434 lb.
7. A column of water measuring 1″ × 1″ that is 2.304 ft tall weighs approximately 1 lb.

Test 1

1. Why is water primarily used to extinguish fires?
2. Define the law of latent heat of fusion.
3. Define the law of latent heat of vaporization.
4. Define Btu.
5. How many British thermal units are required to raise 1 lb of water from 60°F to 212°F?
6. How many British thermal units will 1 lb of water absorb as it turns into steam?
7. At 212°F, how much will water expand?
8. At 500°F, how much will water expand?
9. (T or F) Water is nearly incompressible.
10. (T or F) Water always seeks its own level.
11. How much does a cubic foot of water weigh?
12. List five disadvantages of water in firefighting.
13. Define a cubic foot.
14. How many gallons of water are in a cubic foot?
15. How much does a gallon of water weigh?
16. How many cubic inches are in a cubic foot?
17. How many cubic inches are in a gallon?
18. How much does a column of water weigh that is 1″ × 1″ and 1 ft tall?
19. How tall does a 1″ × 1″ column of water need to be to weigh 1 lb?
20. Define force.

21. Define pressure.
22. Define static pressure.
23. Define flow pressure.
24. Define residual pressure.
25. List the six rules governing fluid pressure.
26. How much more does mercury weigh than water?
27. What is the formula for determining the volume of a square or rectangle?
28. What is the formula for determining the volume of a cylinder?
29. What is the formula for finding the gallon capacity of a container?
30. What formula is used to find the weight of water in a container?

Test 1 Answers

1. Its cooling ability
2. As a substance passes between a solid and a liquid, it releases or absorbs heat.
3. The amount of heat absorbed or released as a liquid is changed into a gas
4. A British thermal unit is the amount of heat required to raise 1 lb of water 1ºF.
5. 162 Btus
6. 970.3 Btus
7. 1,700 times

8. 2,400 times
9. True
10. True
11. 62.5 lb
12. Disadvantages to using water in firefighting:
    - It has high surface tension.
    - It freezes.
    - It conducts electricity.
    - It reacts violently with some chemicals.
    - Its low viscosity limits its ability to smother most fires.
13. A box 1 ft wide × 1 ft deep × 1 ft high
14. 7.48 gal
15. 8.35 lb
16. 1,728 in^3
17. 231 in^3
18. 0.434 lb
19. 2.304 ft
20. The amount of energy or weight applied at a given point
21. Force per unit area
22. The pressure of water when it is not moving
23. The pressure of water after the nozzle is opened
24. The remaining pressure in a distribution system after water is flowing
25. Fluid pressure is perpendicular to any surface on which it acts.

The pressure at any point in a fluid at rest is the same intensity in all directions.

External pressure applied to a confined liquid is transmitted undiminished in all directions.

The downward pressure of a liquid in an open container is directly proportional to the depth of the liquid.

The downward pressure of a liquid in an open container is directly proportional to its density.

The downward pressure of a liquid on the bottom of an open container is independent of the shape or size of the container.

26. 13.546 times

27. Length × width × height

28. $\pi R^2 h$

29. Volume × 7.48 gal (number of gallons in a cubic foot)

30. Volume × 62.5 lb/ft^3 (weight of 1 ft^3)

2

THE EQUATION

There is a basic equation that every pump operator needs to calculate whenever he or she operates the fire pump:

$$EP = NP + FL + APP + ELEV$$

where

EP = engine pressure,

NP = nozzle pressure,

FL = friction loss,

APP = appliance friction loss, and

$ELEV$ = elevation loss or gain.

The engine pressure is calculated simply by plugging numbers into the equation and either adding or subtracting the numbers.

Some variables may be used more than once, while others may not be used at all. If more than one size of hose is used, friction loss for each size will need to be figured. This also applies if multiple appliances are used or if hoselines are laid both up and down a hill. The pump operator needs to account for each of these figures each time a hoseline is pulled from the apparatus.

Nozzle Pressure

To be called a fire stream, a hoseline needs to have a nozzle attached to the end. This nozzle gives the stream its shape, reach, and velocity. By definition, a *fire stream* is a stream of water after it leaves the nozzle until it reaches its final destination, which is usually the seat of the fire. As the streams are being produced, they are affected by the discharge pressure, nozzle design, and nozzle setting. A discharge pressure that is too strong not only will be very hard to handle, but will break up into smaller droplets that are not as effective extinguishing the fire. A discharge that is too weak may not be delivering enough gallons per minute to overcome the heat being produced by the fire. An adequate stream also needs to have the reach to be able to hit the seat of the fire. After the water leaves the nozzle, the stream is also affected by nature in the form of gravity and wind. The stream needs to be strong enough to overcome these factors. There needs to be enough reach so the firefighters do not need to be in the absolute hottest environment. If the stream falls short of the fire, it simply cannot extinguish the fire. Furthermore, if the stream is not capable of overcoming the wind, it may not be possible to place the water on the seat of the fire where it is needed.

The fire service has three standard nozzle pressures used today. These standards are derived from years of trial-and-error and experience. The nozzle pressure can be adjusted up to deliver more gallons per minute flow or down to make the line more maneuverable. Unfortunately, it is not possible to have both simultaneously. If the nozzle pressure is increased, a few more gallons per minute can be delivered, but the hoseline will become stiffer and harder to handle. There is even a point where the pressure becomes so great that the increased turbulence in the stream will fail to produce a working fire stream. If the nozzle pressure is decreased, the hoseline will be easier to handle, but at the expense of lower gallons per minute flow. The standards give a good compromise to deliver the best of both worlds. To extinguish the fire while being able to maneuver the hoseline, the following nozzle pressures have been adopted:

- Smooth bore handline—50 psi
- Fog nozzle handline—100 psi
- Smooth bore master stream—80 psi

These standards offer a good basic starting point in figuring the overall engine pressure.

Smooth bore nozzles

A smooth bore nozzle is simply a tube that narrows down to an opening with a specific inside diameter. As the water gets narrowed through the nozzle, it develops its smooth, solid stream. Note: Throughout this book the term *straight tip* and *smooth bore tip* are used. Both words are interchangeable in the fire service. In the late 1890s, John R. Freeman conducted experiments designed to define what characterizes a good solid stream. He came up with four requirements that are still used today:

1. A stream that has not lost its continuity by breaking into showers or spray
2. A stream that shoots 9⁄10 of the whole volume of water inside a 15″ diameter circle and ¾ of its volume into a 10″ diameter circle at its breakover point
3. A stream stiff enough to attain, under fair conditions, the named height or distance, even through a breeze
4. A stream that, with no wind blowing, will enter a room through a window and strike the ceiling with enough force to splatter well

These standards give a good foundation with which to build a good quality fire stream.

Discharge

Firefighters are aware that it is not the pressure of a stream that extinguishes a fire but the amount of water in gallons per minute that cools a fire. The officer in charge of a fire needs to determine the amount of water needed to extinguish the fire and choose the appropriate hoseline and nozzle that will deliver the correct gallons per minute. Large fires make for good news coverage, but in reality, they happen because the firefighters were unable to place enough water at the seat of the fire to overcome the amount of heat being produced. The officer as well as the pump operator need to know the gpm flow from different nozzle tips to know how much fire each can extinguish. As a general rule, the maximum nozzle diameter should not exceed one-half of the size of the hose to which it is attached. For example, a 2½″ handline should not have a smooth bore nozzle any larger than 1¼″. A 1¾″ handline should have a nozzle tip no larger than ⅞″.

The amount of water discharging from a smooth bore is determined by the nozzle pressure and the inside diameter of the opening. The formula for determining the gpm flow (*GPM*) from a smooth bore nozzle is as follows:

$$GPM = 29.72D^2\sqrt{P}$$

where

D = nozzle diameter and

$\sqrt{P}$ = square root of pressure.

Question: What is the gpm discharge from a handline with a 1″ smooth bore nozzle?

Answer: The gpm discharge is determined as follows:

$$GPM = 29.72D^2\sqrt{P}$$

$$GPM = (29.72)(1^2)(\sqrt{50})$$

$$GPM = (29.72)(1)(7.07)$$

$$GPM = 210.12$$

Question: What is the gpm discharge from a handline with a 1½″ smooth bore nozzle?

Answer: The gpm discharge is determined as follows:

$$GPM = 29.72\mathrm{D}^2\sqrt{P}$$

$$GPM = (29.72)(1.5^2)(7.07)$$

$$GPM = (29.72)(2.25)(7.07)$$

$$GPM = 472.77$$

Question: What is the gpm discharge from a master stream with a 2″ smooth bore nozzle?

Answer: The gpm discharge is determined as follows:

$$GPM = 29.72D^2\sqrt{P}$$

$$GPM = (29.72)(2^2)(8.94)$$

$$GPM = 1,062.79$$

Nozzle reaction

As mentioned before, the hoseline needs to be handled. It needs to be pulled into a building, up the stairs, around corners, and opened up so the stream can be sprayed onto the fire. One factor that plays into this is *nozzle reaction*, which is defined as the amount of force pushing back against the nozzle and ultimately the operator. If there is too much force, the nozzle will be hard to handle, and if there is not enough force, not enough water will be applied to extinguish the fire.

Years ago, tests by E. M. Byington of the Boston Fire Department resulted in a formula for determining the nozzle reaction (in pounds) (NR) of a hose stream:

$$NR = 1.5D^2P$$

where

D = nozzle diameter and

P = nozzle pressure.

Question: What is the nozzle reaction from a 1″ tip with a nozzle pressure of 50 psi?

Answer: Nozzle reaction is determined as follows:

$$NR = 1.5D^2P$$

$$NR = (1.5)(1^2)(50)$$

$$NR = (1.5)(1)(50)$$

$$NR = 75 \text{ lb}$$

Question: What is the nozzle reaction from a 1½″ tip with a nozzle pressure of 50 psi?

Answer: Nozzle reaction is determined as follows:

$$NR = 1.5D^2P$$

$$NR = (1.5)(1.5^2)(50)$$

$$NR = (1.5)(2.25)(50)$$

$$NR = 168.75 \text{ lb}$$

Clearly, operating a nozzle can be tiring work. If the nozzle pressure is increased, it will be able to produce more gallonage. However, it will also produce more nozzle reaction, necessitating more personnel to maneuver the hoseline. The appropriate-sized hoseline and nozzle need to be chosen to give the amount of water needed to extinguish the fire while being able to maneuver the line.

When a nozzle is first opened, there can be a sudden stronger nozzle reaction. This is defined as *momentary nozzle reaction* and is caused by the water in the line being static (there is no movement of the water). If the pump discharge pressure is 150 psi, the pressure at the nozzle is the same 150 psi while the nozzle remains closed. As the nozzle is opened fully, the pressure drops from the pump discharge pressure to the normal flow pressure. Until the pressure fully drops, a momentary nozzle reaction develops. It has been estimated that the momentary nozzle reaction is about 20% higher than the nozzle reaction from the flowing stream.

Fog nozzles

Many fire departments have chosen to place combination fog nozzles on their apparatus. They feel that it is important to have the option of delivering a stream that can be adjusted from a straight stream to a wide fog pattern. Many officers and nozzle operators like having the flexibility that a fog nozzle provides. A fog pattern can be shot out a window to help with ventilation. Air will get entrained with the outside of a fog pattern and move in the direction of the water. They are also good for auto fires and other outside fires, as well as liquid petroleum fires.

Note that the term *solid stream* is not used when referring to the pattern setting. At the narrowest pattern, a fog nozzle still produces a fog stream. It consists of tiny water droplets discharged in a uniform direction toward the fire. The small water droplets, if applied properly, will absorb the heat faster than a solid stream. This is because there is more surface area with all of the droplets compared with a solid stream. Another advantage of having tiny water droplets is that they quickly turn into steam. When a fire is in an enclosed space, a relatively small amount of fog stream can be shot into the area, and then the area is sealed up. The water will turn into steam, smothering the fire. This is called the *indirect attack method*. The advantage of this attack method is that it uses relatively small amounts of water. This helps to prevent water damage to the structure. This method of attacking fire was first developed by Chief Lloyd Layman while he was in the U.S. Coast Guard. As explained in chapter 1, when water turns to steam, it expands. The amount of expansion is determined by the amount of heat in the room. Table 2–1 shows the amount of expansion at various temperatures:

Table 2–1. Steam expansion ratios

Temperature (ºF)	Expansion ratio
212º	1,700 to 1
500º	2,400 to 1
1,200º	4,200 to 1

It should be noted that this indirect attack is used *only in enclosed spaces where there is no possibility of life in the room*. The steam will burn and kill anyone inside the environment. If there is a possibility of anyone in the room, including firefighters, then a fog pattern needs to be used in conjunction with proper ventilation. As the water is turned into steam, it will cool the burning material, but the steam has to be allowed to escape to the outside.

Fires in ordinary combustible materials are extinguished by cooling the materials, not by smothering. Therefore, after an indirect attack is performed, crews still need to enter the room and finish extinguishing the fire. The room needs to be ventilated in a coordinated fashion with the opening of the fog stream. Once the steam is allowed to escape, the room should be cool enough that firefighters can get close enough to finish extinguishing the seat of the fire.

Friction Loss

Friction is defined in the dictionary as the "rubbing of one object against another." In the fire service, *friction loss* is defined as the loss of energy, in pressure, whenever water runs through hoses, fittings, and appliances. As water runs through hose, it rubs against the linings of the hose, the couplings, and even itself. Each time this happens, friction causes the water to slow down. Pump operators need to compensate for this loss. For the purposes of this discussion, there are two different ways water flows through hoses. The first, laminar flow, happens with relatively low velocities. As shown in figure 2–1, the water flows in straight lines through the hose. There is nothing disturbing the direction of the flow.

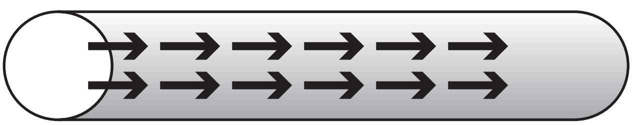

Fig. 2–1. Laminar flow

In a perfect world, the water would flow right through the hose and never encounter any obstacles that would slow it down. In laminar flow, the water flows in parallel lines, with the flow at the center moving at a greater velocity than the edges. It decreases further out toward the edges of the hose. Picture layers of water flowing on top of each other. In laminar flow, the layers move smoothly against each other, all in one direction.

Since this is not a perfect world, there is also turbulent flow. As stated before, as the water flows through the hoses and appliances, it rubs against the lining of the hose and appliances, causing friction. Even if the lining is in perfect condition, the water will rub against it, causing friction. As the velocity increases, so does the friction. It also flows over couplings and around bends in the hose, causing additional friction. Picture a single drop of water inside the hose. As it flows along, it contacts the lining, a coupling, or a bend in the hose. As it makes this contact, it changes direction (even slightly) and stops flowing in a nice straight line. This will slow down the forward velocity of the droplet. This is the simplest explanation of friction loss. Every time the water changes direction for any reason, friction is created. Friction is also caused by the water itself. All liquids have what is called *viscosity*, which, in general terms, is the thickness or stickiness of a liquid. The higher the viscosity, the slower the fluid will flow. Oil or syrup has a higher viscosity than water or vinegar. As a liquid flows past itself, it creates friction with the layers next to it. As each layer comes in contact with another layer, it will move and change direction. This causes the velocity to decrease. A good example of this is to pour very thick syrup down a gentle slope. The front end of the syrup will look like it is rolling down the slope. Each layer seems to grab the layer next to it, pulling it along. Water does the same thing. As it flows through the hose, it rubs and pulls and moves in directions other than the desired straight line. Figure 2–2 shows what this turbulence in a hoseline might look like.

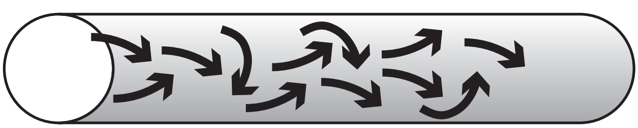

Fig. 2–2. Turbulent flow

A simple way of demonstrating this principle is to turn on a garden hose. Without connecting a nozzle to the end, the hose is placed in a straight line. The water coming out the end runs in a nice smooth stream. Immediately at the end of the hose, the water has a nice solid cylindrical shape. Next, kink the hose slightly about 12″ to 18″ behind the discharge opening. The stream not only loses its forward velocity, but the shape of the stream is not nearly as uniform as before. This is a very simplified version of what happens inside a fire hose.

Friction loss in fire hose is governed by the following rules:

1. **Friction loss varies with the quality of the hose.** The thickness of the inner lining, the age of the hose, and the weave of the jacket all affect the quality of the hose. Even with the advancement in the quality of the inner lining of the hose, some friction still exists. It is impossible to have a perfectly smooth inner lining. As the hose ages and gets used, the inner lining becomes worn or torn. It may develop cracks or gouges that will create turbulence. Every little imperfection in the lining will create friction. It is recommended that water be run through each section of hose regularly to prevent some of this happening. This will help to keep the lining fresh and pliable. After time, old sections of hose simply need to be replaced. If an old hose that has been condemned and taken out of service is cut open, the effects of age and usage are readily apparent.

2. **Friction loss varies directly with the length of the hose.** Friction loss is calculated in 100-ft lengths, and the total friction loss is figured when all lengths are added together. For example, if the friction loss in one length of 1¾″ hose is 15 psi, then four 100-ft lengths added together will have a total friction loss of 60 psi.

3. **Friction loss varies with the square of the velocity.** If the velocity is doubled, the friction loss is quadrupled. If the velocity is quadrupled, the friction loss will be increased 16 times.

4. **For a given flow, the friction loss varies inversely as the fifth power of the diameter of the hose.** This is the most important thing to understand when limiting the effects of friction loss. This rule shows why it is important to increase the diameter of the hose when trying to keep friction loss to a minimum. While keeping the flow the same, as the hose size is doubled, the friction loss is only $(\frac{1}{2})^5$, or 1/32 times the friction loss in the smaller

hose. This is the reason many fire departments switched from 1½″ hose to 1¾″ hose. This is illustrated as follows:

$$1.75^5 \div 1.5^5 = 1.167^5 = 2.16$$

This shows that the friction loss in 1¾″ hose is one-half that of a 1½″ hose. A 1¾″ hose is not any harder to handle than the smaller 1½″ hose. It has much less friction loss but can deliver a larger volume of water at the same pressure. This effect is even more dramatic when switching to even larger hose sizes. For example, when changing from a 1½″ hose to a 2½″ hose, there is 13 times less friction loss in the 2½″ hose.

$$2.5^5 \div 1.5^5 = 1.67^5 = 12.99$$

Question: If the friction loss in a 100-ft length of 1½″ hose is 50 psi, then what would be the total amount of friction loss in 400 ft of 2½″ hose if both are flowing 200 gpm?

Answer: As noted, there is 13 times less friction loss in 2½″ hose than 1½″ hose.

$$2.5^5 \div 1.5^5 = 1.67^5 = 12.99 \text{ (or 13)}$$

$$50 \text{ psi} \div 13 = 3.85 \text{ psi per 100 ft}$$

$$3.85 \text{ psi/100 ft} \times 4 \text{ lengths of 100 ft} = 15.4 \text{ psi}$$

Question: If the friction loss in a 100-ft length of 2½″ hose is 25 psi, then what would the friction loss be in a 100-ft length of 3″ hose if the flow per minute remains the same?

Answer: Friction loss may be determined as follows:

$$3^5 \div 2.5^5 = 2.49$$

$$243 \div 97.66 = 2.49 \text{ (2.5 times less friction loss)}$$

$$25 \text{ psi} \div 2.5 = 10 \text{ psi}$$

There is only 10 psi of friction loss in the 3″ hose compared to 25 psi in the 2½″ hose.

5. **For a given velocity, friction loss is independent of the pressure (fig. 2–3).** The amount of friction loss in a hose depends upon the amount of water flowing through the hose and the velocity with which it is moving. If the hoseline is laid up a hill, the pump will need to overcome the back pressure created by the elevation, but the friction loss would remain the same. If the friction loss in 100-ft of 2½″ hose is 15 psi, the friction loss pressure would decrease by 15 psi for every 100 ft length connected together as stated in rule 2, but the pump discharge pressure will need to be increased to compensate for the elevation loss.

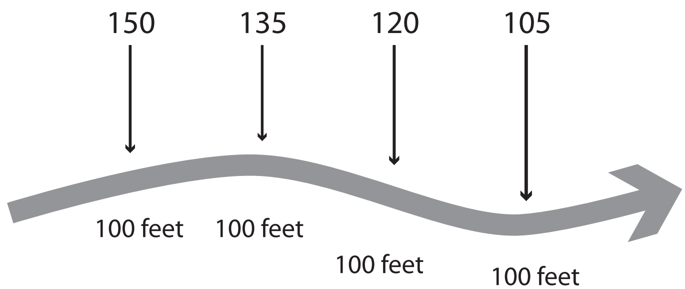

Fig. 2–3. Friction loss is independent of the pressure

The friction loss formula

As stated before, there are many factors that affect how much friction loss there might be in a given length of hose. It is nearly impossible to tell the condition of the lining, for example. The only true way to figure the amount of friction loss is to connect pressure gauges to each end of the hoseline, place the hoses in straight lines and on level ground, and subtract the difference. It is important to keep the hose and equipment in good working condition at all times to eliminate as much of the friction-causing problems as possible.

For many years, certain formulas have been used to get a fairly accurate measurement of the friction loss. While these formulas are not perfect, they are adequate for fire service purposes.

Underwriters formula. The most widely used formulas for determining friction loss in a single 2½″ hoseline are as follows:

$$FL = 2Q^2 + Q$$

and

$$FL = 2Q^2 + \tfrac{1}{2}Q$$

These are called the *Underwriters formulas*. The first is used when the flow is 100 gpm or higher. The second formula is used for flows under 100 gpm.

The use of these formulas starts with knowledge of gallons per minute of flow (*GPM*) based on the nozzle tip size. This gpm flow figure is then divided by 100 to give *Q*.

$$Q = GPM\ /100$$

Example: $Q = 400$ gpm $/100 = 4$

$$Q = 250 \text{ gpm } /100 = 2.5$$

Question: What is the friction loss in 100 ft of 2½″ hose using a 1″ straight tip? (*Hint:* Earlier in this chapter, it was determined that a 1″ tip will flow 210 gpm.)

Answer: Friction loss is determined by the equation for flow 100 gpm or higher.

$$Q = 210/100 = 2.1$$

$$FL = 2Q^2 + Q$$

$$FL = 2(2.1^2) + 2.1$$

$$FL = 2(4.41) + 2.1$$

$$FL = 10.92 \text{ psi}$$

Question: What is the friction loss in 100 ft of 2½″ hose using a ½″ straight tip flowing 50 gpm?

Answer: Friction loss is determined by the equation for flow under 100 gpm.

$$Q = 50/100 = 0.5$$

$$FL = 2Q^2 + \tfrac{1}{2}Q$$

$$FL = 2(0.5^2) + 0.25$$

$$FL = 2(0.25) + 0.25$$

$$FL = 0.75 \text{ psi}$$

When calculating friction loss for hose sizes other than 2½″, a conversion factor needs to be used. These factors are calculated using friction loss rule number 4. This states that if the flow stays the same, the friction loss varies inversely as the fifth power of the diameter of the hose. The following table shows the conversion factors for different hose sizes:

Hose Size	Conversion Factor
1½″	12.99, or 13
1¾″	5.98, or 6
2″	3.05, or 3
3″	2.49, or 2.5 **(divide)**

Simply multiply the formula by the conversion factor (or in the case of 3″ hose, divide) to get the correct friction loss.

Question: What is the friction loss in 100 ft of 1¾″ hose with a 200-gpm fog nozzle?

Answer: Friction loss is determined by the equation for flow of 100 gpm or more, multiplying by a conversion factor of 6 for a 1¾″ hose.

$$FL = (2Q^2 + Q) \times 6$$

$$FL = [2(2^2) + 2] \times 6$$

$$FL = [2(4) + 2] \times 6$$

$$FL = 10 \times 6$$

$$FL = 60 \text{ psi}$$

Question: What is the friction loss in 100 ft of 3″ hose using a 200-gpm fog nozzle?

Answer: Friction loss is determined by using the equation for flow of 100 gpm or more and dividing by 2.5, the conversion factor for 3″ hose.

$$FL = (2Q^2 + Q) \div 2.5$$

$$FL = [2(2^2) + 2] \div 2.5$$

$$FL = [2(4) + 2] \div 2.5$$

$$FL = 4 \text{ psi}$$

Coefficient formula. Another formula used by several fire departments is as follows:

$$CQ^2L$$

where

C = coefficient,

Q = gpm / 100, and

L = length in 100 ft.

Many feel this formula is quicker to use, but the operator needs to remember the coefficient for each different hose size.

A *coefficient* is simply a number used for different hose sizes. The following table shows the coefficients for different hose sizes:

Hose Size	Conversion Factor
1¾″	15.5
2½″	2.0
3″	0.80
4″	0.20

Question: What is the friction loss in 300 ft of 1¾″ hose using a 150-gpm straight tip nozzle?

Answer: The friction loss is determined as follows:

$$FL = CQ^2L$$

$$FL = 15.5(1.5^2)3$$

$$FL = 15.5(2.25)3$$

$$FL = 104.6 \text{ psi}$$

Question: What is the friction loss in 100 ft of 2½″ hose using a 200-gpm fog nozzle?

Answer: Friction loss is determined as follows:

$$FL = CQ^2L$$

$$FL = 2(2^2)1$$

$$FL = 2(4)1$$

$$FL = 8 \text{ psi}$$

When comparing the above answer with the same question using the Underwriters formula, it is apparent that the answers differ. Which formula is right? The answer is that both are correct. There is no right or wrong formula. Fire departments all over use either formula. As stated before, there are too many factors involved to accurately calculate a friction loss. The only way to accurately figure the friction loss in any length of hose is to place pressure gauges on each end of the line and subtract the difference. The important thing is to work with both formulas and see which seems to work better in the circumstances.

Until now, only single hoseline layouts have been discussed. Single lines are easy to figure, since only one friction loss needs to be determined and applied to the overall formula. But what happens when there is a combination layout?

A *combination layout* consists of multiple hoselines that join into one hoseline or one hoseline that divides into two or more lines. The most common combination layout consists of multiple lines that combine into one (see fig. 2–4).

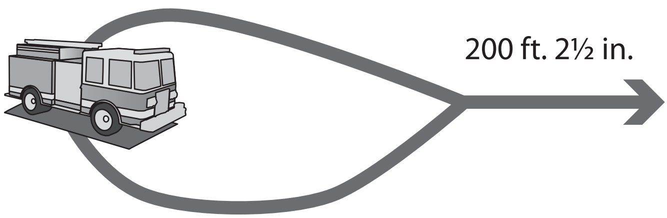

Fig. 2–4. Most combination layouts combine multiple hoselines into a single one.

These layouts are used any time more water is needed at the nozzle than can be easily delivered through any one hoseline. One such situation occurs when very long hose stretches are needed. There would be too much friction loss in a single hoseline, so it is divided between two or more lines and then coalesced into the attack line. For example, two 2½″ hoselines, each 400 ft long, are joined into a single 1¾″ attack line. The friction loss may be too much if the entire layout was all in 1¾″ hose. Another situation occurs when supplying a standpipe or sprinkler connection on a building. Two or more hoselines are connected at the building, and then one internal pipe carries the water to where it is needed.

The most efficient way of calculating this type of layout is to break down the whole layout into separate parts. In looking at figure 2–4, it is best to separate the attack line first. As discussed previously, a 1″ tip flows 210 gpm. Using that, the friction loss can be determined for this section: $(2Q^2 + Q) \times L = 21.84$. Next the friction loss in the two lines supplying the attack line can be determined. For this, the total gpm flow (210) is divided by the number of hoselines (2), and the friction loss is calculated for one of the lines. (The other line will be the same.) Each hoseline carries one-half of the total flow: $[2(1.05^2) + 1.05] \times L = 9.25$.

It is important not to add 9.25 twice. It only needs to be figured and added once. Even if there are five supply lines, the friction loss needs to be figured for one line and added only once. Note that if the hoselines that are going to be split are two different lengths, then the two should be averaged. However, it is best if the two lengths are the same, and it is much better to change the layout if possible to keep them the same lengths. It is also best if the same size hoselines are used. This makes the calculations reasonably easy to figure.

Question: What is the total friction loss when three 2½″ supply lines 400 ft long are joined into one 2½″ attack line 200 ft long using a 200-gpm fog nozzle (fig. 2–5)?

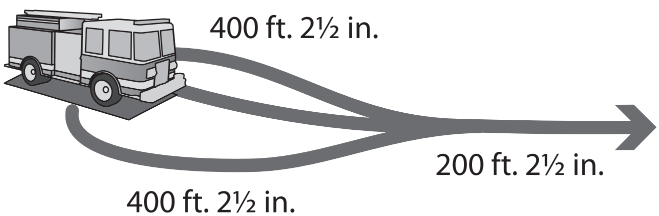

Fig. 2–5. Three 2½″ supply lines feeding one 2½″ line

Answer: First, figure the attack line.

$$FL = (2 \times 2^2 + 2) \times 2\ (L) = 20 \text{ psi}$$

Next, figure the three supply lines.

$$200 \text{ (gpm)}/3 \text{ (\# of lines)}$$

$$Q = 66.67/100 = 0.67$$

$$FL = 2 \times (0.67^2) + 0.67 \times 4$$

$$FL = (2 \times 0.45 + 0.67) \times 4$$

$$FL = 6.28 \text{ psi}$$

Add the two friction losses together to determine a total friction loss of 26.28 psi.

Another application for multiple hoselines joined into one is when supplying a standpipe or sprinkler connection. Multiple lines connect to the building and supply either attack lines or sprinkler heads. Another application is when an engine needs to supply a ladderpipe on an aerial ladder. The mistake many people make is that they forget to divide the gpm flow between however many supply lines there are. If the total flow is not divided between the separate lines, the calculations will be way too high.

Wyed lines take special considerations. The same principle applies when a supply line is split into two attack lines. Each section needs to be figured separately, but what is extremely important is that each attack line needs to be the same as the other. Each needs to be the same diameter hose, each needs to be the same length, and each needs to have the same gpm flow from the nozzle. If the attack lines are different, the friction loss will be different in each line, and it will be impossible to determine a correct overall friction loss. For example, assume the friction loss for the supply line is 30 psi. One attack line is 200 ft of 1¾″ hose with a 200-gpm fog nozzle. The friction loss for this hoseline is 120 psi. The second attack line is 200 ft of 1¾″ hose with a 100-gpm fog nozzle. The friction loss for this hoseline is 36 psi. If the 200-gpm nozzle is supplied properly, the total friction loss would be 150 psi. There is no possible way of supplying the second line with the proper 66 psi. It is not physically possible to pump two separate pressures through one hoseline.

Another situation in which more than one friction loss needs to be figured occurs when very long hose lays are needed. An example of this could occur if an engine is pumping while at a hydrant, and the fire is a long distance away. The best way to pump this is to pump through larger diameter hose up to the fireground and then have a shorter attack line that is smaller in diameter and easier to maneuver.

Question: What is the total friction loss in 700 ft of 3″ hose reduced to 200 ft of 1¾″ attack line with a 1″ straight tip (fig. 2–6)?

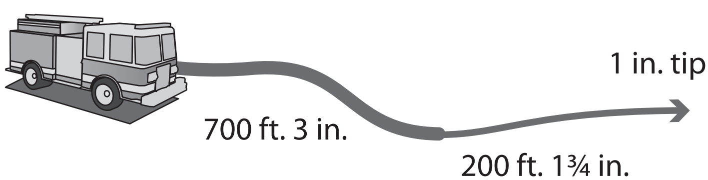

Fig. 2–6. Reduction of 700 ft of 3″ hoseline to 200 ft of 1¾″ attack line

Answer: Figure the attack line first.

$$FL = (2 \times 2.1^2 + 2.1) \times 2 \times 6$$

$$FL = 65.52 \times 2 \text{ (length)}$$

$$FL = 131.04 \text{ psi}$$

Next, figure the 3″ hose.

$$FL = (2 \times 2.1^2 + 2.1)/2.5$$

$$FL = 4.37 \times 7 \text{ (length)}$$

$$FL = 30.59 \text{ psi}$$

Finally, add the two together.

$$131.04 \text{ psi} + 30.59 \text{ psi} = 161.63 \text{ psi}$$

If the entire hoseline was 900 ft long of 1¾″ hose, the friction loss would be a total of 589.68 psi. A pressure this high would be very hard on the pumps and certainly would burst the hose. That is why it is so important to pump through a larger diameter hoseline for all the distance except for the attack line.

In a training exercise recently, the chief wanted to flow 2,000 gpm out of a tower ladder. The supply pumper was connected to a hydrant using one section of 5″ hose and was 750 ft away. Two 3″ hoses were laid between the pumper and the tower. When the pressures were calculated, it was soon discovered that the friction loss in the two 3″ lines was so extreme that the pumper would have to pump at pressures that would burst the hoses. The answer was to add at least two more supply lines between the two apparatus to cut down on the friction loss.

A pump operator on scene at a two-alarm fire does not have time to figure friction loss for every hoseline. Most fire departments calculate the friction loss for the hoses and nozzles that they carry and write them down on what is called a *pump chart*. Most charts list the nozzles that are on the apparatus, their gallons per minute, and the friction loss. The operator simply needs to look at the chart and start adding the figures. This makes operations on the fireground quicker and easier when time is critical.

Friction loss happens every time water flows through hoses, pipes, or appliances. Every time a hoseline is pulled, the pump operator needs to account for it in order to give the nozzle man the proper amount of water to extinguish the fire. It is the pump operator's primary responsibility to get the calculations right and supply the hoseline with the proper pressure and flow rate. Improper calculations can create dangerous situations for the crews inside the fire area. Too low of a pressure will create a situation where there is not enough water to extinguish the fire, and too high a pressure can possibly injure the fire crews inside the building. When calculating friction loss, it is important for the pump operator to memorize whichever formula his or her department uses, as well as remembering the friction loss rules and how they are applied.

Appliance Friction Loss

In the above section, appliances such as wyes, siameses, and reducers were never figured into the friction loss calculations. They are so special they get their own calculation in the overall equation. *Appliances* are devices designed to work in conjunction with hoses to help deliver the water. They are designed to be placed in the middle of a hose layout or at the end to deliver the water. Even fire department connections for standpipes are considered appliances. Ladderpipes on aerial trucks are also considered appliances. Appliances can be used to combine or divide hoselines, or to help deliver the water to where it needs to go.

Every water appliance used in the fire service from a simple wye to a ladderpipe has friction loss. The manufacturers of these appliances work hard to keep the amount of friction loss to a minimum, but as noted before, each time the water moves or changes direction, friction is created. Each engine company should keep track of what appliances are on the rig and who manufactured them. If manuals are not available, it should be possible to obtain this information from the company's Web site or by contacting the company directly in order to learn as much as possible about each one. There are lists and charts diagramming the friction loss for given flows.

Just as with hoselines, every time water changes direction, more friction loss is created. As the water is split, combined, or moves through the appliance, it will change direction, which causes friction loss. The same friction loss rules apply. As the inside diameter increases, the friction loss decreases. Just as the velocity increases, so does the friction loss. As with hoseline, the only way to accurately assess how much friction loss occurs in each appliance is to attach pressure gauges on each end of the appliance and subtract the difference.

Many fire departments, including the Denver Fire Department, give set values for each appliance. These friction loss values are averages based upon the flows usually associated with each appliance. When pumping at a fire, these figures are accurate enough. The Denver Fire Department gives the friction loss values for each appliance (table 2–2):

Table 2–2. Friction loss values

Appliance	Friction loss
Siamese	5 psi
Wye	5 psi
Bresnan distributor (1¾″)	3 psi
Bresnan distributor (2½″)	5 psi
Multiversal	10 psi
Deck gun	10 psi
Ladderpipe	15 psi
Standpipe system	25 psi

These are just some of the appliances in use today. A pump operator should inventory the apparatus in use and make sure that each piece of equipment is accounted for and the friction loss for each one is known. The manufacturer can be consulted, if needed, for each of the appliances to determine the friction loss for each.

Elevation

Elevation is the last calculation needed to finish the equation. The term *elevation* is used because it less cumbersome to say than "overcoming pressure differences due to the height differential between two points caused by gravity." In firefighting terms, it is pressure created by gravity. Unless the hoselines are laid on perfectly flat ground, an adjustment for elevation needs to be made. Often the elevation change is minimal, but the pump operator needs to be aware at all times. In many municipalities, a house will sit higher than the street, so the pump operator should look at the driveway and note if there is a slope to it. This pressure needs to be calculated when moving both up and down in elevation. At times, the hoseline is pulled up a hill and then down the other side. At other times, the hoselines are laid on flat ground into standpipe connections, but the attack line is being used on an upper floor of the building. Every time water is moved higher or lower than the pump, it is necessary to make adjustments.

As stated in chapter 1, the downward pressure of a liquid is directly proportional to its depth. A 1″ × 1″ column of water standing 1 ft tall will have a pressure at its base of 0.434 lb. The pressure will increase by 0.434 lb for every foot that is added to the height. Pump operators need to adjust for this pressure.

Head pressure

Head is the term used for the vertical distance from the top of the water to where it is being used. The amount of pressure created by gravity depends upon the height of the water in comparison to where it is being used. For example, a column of water 50 ft tall will create a pressure of 21.7 lb at its base. The opposite is also true. If a pressure of 21.7 lb is applied to the base of the column, the water will rise 50 ft.

Figure 2–7 shows a gravity tank that, when full, is 100 ft tall, and thus the head is 100 ft.

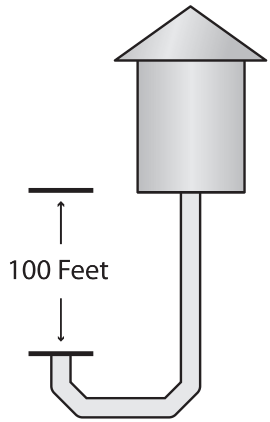

Fig. 2–7. A full gravity tank

If the tank is 20 ft tall and the top is 100 ft from where it is being used, then when the tank is one-half full, the top of the water becomes 90 ft from where it is being used. The head now is 90 ft, and the calculations need to be adjusted.

Head is only figured using the vertical distance. Figure 2–8 shows the same head of 100 ft even when the water runs down a slope.

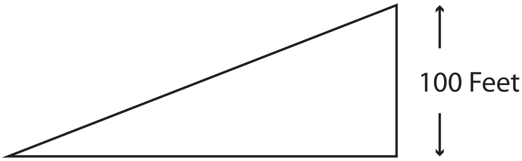

Fig. 2–8. Slope does not affect head

There is still the same vertical distance of 100 ft.

Determining the pressure when head is known

Before mechanical pumps were used on water distribution systems, gravity was used to increase pressure. Water tanks were placed on buildings and towers to deliver water to sprinkler systems and hydrants. These tanks were placed at varying heights depending how much pressure was needed. A reservoir high in the mountains can deliver the pressures needed to supply a city below. Cities such as Denver are fortunate to have tall mountains full of reservoirs nearby. The reservoirs fill up with water as the snow melts, and the cities down below use what they need throughout the year. It is all gravity fed, allowing nature to take care of the cities below. Even though the reservoir may be miles away, the only thing that matters is the vertical distance between the reservoir and where it is being used. What matters is how much higher the reservoir is than where the water is being used. A water tank raised above the ground can supply a hydrant found at ground level. The height of the tank will determine the pressure found at the hydrant. The formula for determining pressure (*P*) when head (*H*) is known is given as follows:

$$P = 0.434 \times H$$

Question: The surface of the water in a gravity tank is 134 ft above a hydrant (fig. 2–9). What will be the static pressure on the hydrant created by head?

Answer:

$$P = 0.434H$$

$$H = 134 \text{ ft}$$

$$P = (0.434)(134)$$

$$P = 58.16 \text{ psi}$$

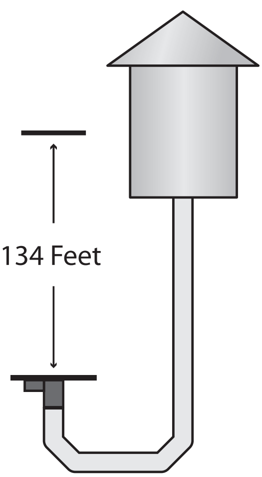

Fig. 2–9. Determine the static pressure on the hydrant in this scenario.

Question: A tank 50 ft tall is 80% full of water and supplies a standpipe. The bottom of the tank is 20 ft above the roof of a 10-story building (fig. 2–10). Assuming each floor is 10 ft apart and the fire is on the second floor, what will the static pressure be at the standpipe connection? (*Hint*: Draw a diagram; see fig. 2–10.)

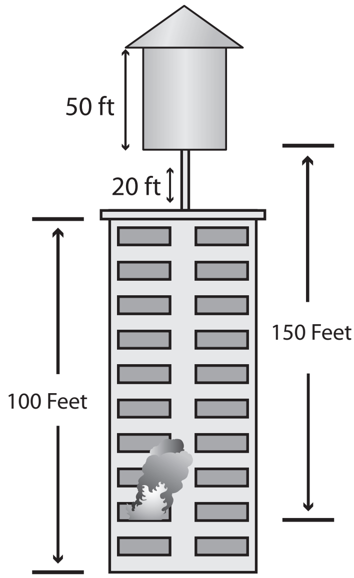

Fig. 2–10. Assuming these dimensions, what is the static pressure at the standpipe connection?

Answer:

$$P = 0.434H$$

$$H = 150 \text{ ft}$$

$$P = (0.434)(150)$$

$$P = 65.1 \text{ psi}$$

Overcoming head pressure

The examples given have only shown head pressure moving toward the ground from an elevated height. Head also applies to upward changes in elevation. When hoselines are placed up a hill or into a building, a pumper is needed to overcome the pressure caused by head. Every time a pump operator pumps into a standpipe connection on a building, an elevation calculation needs to be made. In many jurisdictions, this happens many times a day. The same formula applies, only the pump operator needs to add this pressure to the formula. If a nozzle operator is 40 ft up a hill, the pump operator needs to add pressure to overcome the head pressure working against the pump. This pressure is called *back pressure* and can be calculated as follows:

$$P = H \times 0.434$$

$$P = 40 \times 0.434$$

$$P = 17.36 \text{ psi}$$

Question: What would be the back pressure when pumping up a 35-ft hill?

Answer: Back pressure may be determined as follows:

$$P = H \times 0.434$$

$$P = 35 \times 0.434$$

$$P = 15.19 \text{ psi}$$

The pump operator needs to **add** this pressure to the calculation.

If the nozzle were 40 ft down a hill, the pump operator would need to subtract the pressure. This pressure is called *forward pressure*:

$$P = H \times 0.434$$

$$P = -40 \times 0.434$$

$$P = -17.36 \text{ psi}$$

Sometimes the lines are not laid so easily up or down a hill. Many times the hose travels down a hill and back up another hill. The pump operator simply needs to find the difference. For example, if the hoseline is pulled up a 30-ft hill and then down the other side a total of 20 ft, the operator needs to adjust for a rise of 10 ft:

$$P = H \times 0.434$$

$$P = (30 - 20) \times 0.434$$

$$P = 10 \times 0.434$$

$$P = 4.34 \text{ psi}$$

In this case, 4.34 psi must be added to the calculation because the final height is above the level of the pump. In mountain areas, the pump operator finds this a common occurrence. Most of the time it becomes a guessing game trying to figure the overall elevation change. The easiest way is to figure a starting point and an ending point and calculate the difference. One of the first fires that I pumped at happened to be a situation like this. When I looked, the terrain dropped down to the entrance of the building, but the fire was on the third floor. As I looked across, it became clear that I was on the same plane as the fire. This made for an elevation change of zero. So even though there were two elevation changes, the end result turned out to be zero.

Pumping into a building, the same formula applies. The only difference is that it is not usually necessary to account for the height of the first floor. This is because the fire department connection is usually about the same distance from the ground as the standpipe connection is from the floor where the fire is located. For example, if a fire is on the seventh floor of a building where each floor is 10 ft tall, it is only necessary to account for six floors, or 60 ft:

$$P = \mathrm{H} \times 0.434$$

$$P = 60 \times 0.434$$

$$P = 26.04 \text{ psi}$$

Question: What is the elevation pressure when pumping into a 35-story high-rise building that has a fire on the 27th floor? Assume each floor is 10 ft tall.

Answer: Elevations pressure is determined as follows:

$$P = H \times 0.434$$

$$P = 26 \times 0.434$$

$$P = 11.28 \text{ psi}$$

Question: A fire is in an office building on the 14th floor. The pumper sits on a hill 30 ft above the fire department connection (fig. 2–11). What is the head, and what is the pressure due to elevation? Should the pressure be added or subtracted from the calculation? Assume 10 ft per floor. (*Hint*: It may help to draw a diagram.)

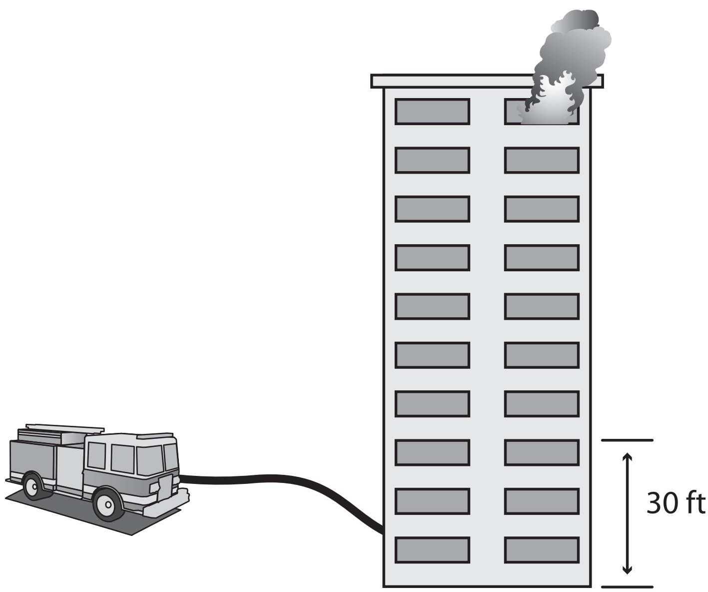

Fig. 2–11. What is the head pressure due to the elevation?

Answer: Up 130 ft minus 30 ft down is 100 ft total elevation change (*ELEV*). With this information, back pressure (*BP*) can be calculated as follows:

$$ELEV = 130 \text{ ft} - 30 \text{ ft}$$

$$ELEV = 100 \text{ ft}$$

$$BP = 100 \text{ ft} \times 0.434 \text{ psi/ft}$$

$$BP = 43.4 \text{ psi}$$

This pressure should be added because the nozzle is above the level of the pump.

Putting It All Together

Now that each part of the formula has been explained, it can all be put together. The easiest way to start is by writing down the formula. Some people find it easier to draw a diagram of the hose layout to help visualize each part of the problem. Remember, each part may be used more the once. There may be different sizes of hose or multiple appliances. Even if one or more parts of the formula are not used, it is always a good idea to write down the abbreviation anyway. All that is needed is to insert a zero in its place. Many people find that starting with the nozzle and working backwards is the best way to keep everything straight. A pump operator can follow the water backwards and simply fill in the numbers at each spot.

A common pumping problem that uses every part of the formula is when master stream operations are used. This is when large volumes of water are used. Generally, master streams are used when the volume of flow is above 350 gpm. Monitors, deck guns, elevated platforms, and ladderpipes are considered to be master streams. Even though large volumes of water are being used, the same hydraulic principles apply. The tricky part is to recognize and break down each part that needs to be figured.

Question: Two 2½″ hoselines, each 400 ft long, are laid to a monitor that is 30 ft above the pumper. The monitor has a 1½″ smooth bore tip. What is the pump discharge pressure?

Answer: Pump discharge pressure may be calculated as follows:

$$NP + FL + APP + ELEV$$

$$NP = 80 \text{ psi (master stream)}$$

$$FL = 2Q^2 + Q$$

$$FL = 2(3)^2 + 3$$

$$FL = 21/100 \text{ ft} \times 4 \text{ lengths}$$

$$FL = 84 \text{ psi}$$

$$APP = 10 \text{ psi}$$

$$ELEV = 30 \text{ ft} \times 0.434 \text{ psi/ft}$$

$$ELEV = 13 \text{ psi}$$

Thus, inserting the calculated values:

$$80 \text{ psi} + 84 \text{ psi} + 10 \text{ psi} + 13 \text{ psi} = 187 \text{ psi}$$

Question: A ladderpipe that has a 1¾″ nozzle and is elevated 80 ft is supplied by two 2½″ hoselines that are 200 ft in length. What is the pump discharge pressure? (*Hint*: 100 ft of 3″ hose is laid up the ladder.)

Answer: The pump discharge pressure is determined as follows:

$$NP + FL_{2\frac{1}{2}''\ hoseline} + FL_{3''\ hoseline} + APP + ELEV$$

$$NP = 80 \text{ psi (master stream)}$$

$$FL_{2\frac{1}{2}''\ hoseline} = 2Q^2 + Q$$

$$FL_{2\frac{1}{2}''\ hoseline} = 2(4.1)^2 + 4.1$$

$$FL_{2\frac{1}{2}''\ hoseline} = 2 \times 16.81 + 4.1$$

$$FL_{2\frac{1}{2}''\ hoseline} = 37.72\ (38) \times 2 = 76 \text{ psi}$$

$$FL_{3''\ hoseline} = CQ^2L$$

$$FL_{3''\ hoseline} = 0.80 \times 8.14^2 \times 1$$

$$FL_{3''\ hoseline} = 53 \text{ psi}$$

$$APP = 25 \text{ psi (ladderpipe + wye)}$$

$$ELEV = 80 \text{ ft} \times 0.434 \text{ psi/ft}$$

$$ELEV = 34.72 \text{ psi}$$

Thus, inserting the values determined:

$$80 \text{ psi} + 76 \text{ psi} + 53 \text{ psi} + 25 \text{ psi} + 34.72 \text{ psi} = 268.72 \text{ psi}$$

Conclusion

That's it! That is the formula that every pump operator needs to calculate each time a hoseline is laid out. For new operators or even old timers who do not practice every day, it is good to write the formula down each time a hoseline is pulled and plug in the numbers. If a number is written down for each value, the problem becomes a simple addition and subtraction problem. Sometimes more than one figure needs to be put in for each part. For example, there might be two or more friction loss figures. If the formula is written out, it is easier not to forget a calculation. Many of these calculations can be figured out ahead of time and written on a pump chart and placed on the apparatus near the pump panel. It is vital that pump operators practice, so that when they are needed at a fire, there will not be any problems.

Summary of Chapter Formulas

Nozzle discharge

$29.72D^2\sqrt{P}$

Nozzle reaction

$1.5D^2P$

Underwriters formula

$2Q^2 + Q$	for 2½″ hose 100 gpm or higher
$2Q^2 + \frac{1}{2}Q$	for 2½″ hose less than 100 gpm
$(2Q^2 + Q) \times 13$	for 1½″ hose
$(2Q^2 + Q) \times 6$	for 1¾″ hose
$(2Q^2 + Q) \times 3$	for 2″ hose
$(2Q^2 + Q)/2.5$	for 3″ hose

Coefficient formula

CQ^2L

$C = 15.5$ for 1¾″ hose

$C = 2.0$ for 2½″ hose

$C = 0.80$ for 3″ hose

$C = 0.20$ for 4″ hose

Elevation

$H \times 0.434$, where $H =$ head

Test 2

1. What is the standard nozzle pressure for handline straight tips?
2. What is the standard nozzle pressure for handline fog nozzles?
3. What is the standard nozzle pressure for straight tip master streams?
4. According to John Freedman, how large of a circle should 9⁄10 of a solid stream pass through?
5. (T or F) Generally, the nozzle diameter should not exceed one-half the size of the hose diameter.
6. What is the gpm flow from a 1¼″ straight tip?
7. What is the gpm flow from a ½″ straight tip?
8. Define nozzle reaction.
9. What is the nozzle reaction from a 1⅛″ straight tip?
10. At 212ºF, how many times will a pound of water expand?
11. Define laminar flow.
12. Define turbulent flow.
13. List the five rules that govern friction loss.
14. In the friction loss formulas, what does *Q* represent?
15. List two ways to reduce friction loss in a long hose lay.
16. (T or F) Appliances such as multiversals have no friction loss.
17. What will be the pressure at the bottom of a water tank that measures 1″ × 1″ and is 10 ft tall?
18. What is the type of pressure called when pumping up a hill?
19. What is the type of pressure called when pumping down a hill?

20. In a 15-story building, what would be the required elevation pressure for a fire on the top floor? Assume 10 ft per floor.

21. Determine the following engine pressure (fig. 2–12). Use the Underwriters formula.

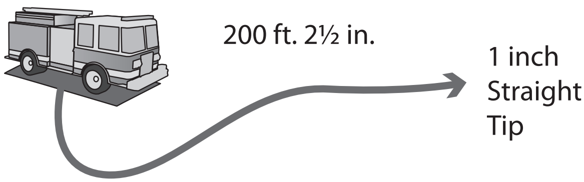

Fig. 2–12. Determine the engine pressure using the given dimensions.

22. Determine the following engine pressure (fig. 2–13). Use the Underwriters formula.

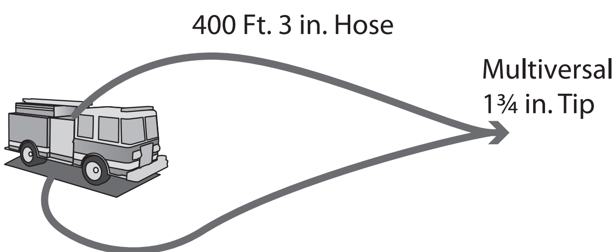

Fig. 2–13. Determine the engine pressure using the given dimensions.

23. Determine the following engine pressure (fig. 2–14). Use the coefficient formula.

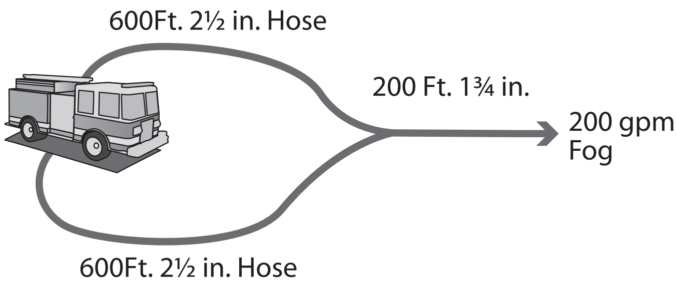

Fig. 2–14. Determine the engine pressure using the given dimensions.

24. Determine the following engine pressure (fig. 2–15). Use the Underwriters formula.

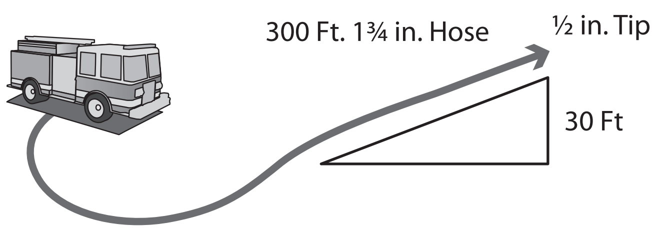

Fig. 2–15. Determine the engine pressure using the given dimensions.

25. Determine the following engine pressure (fig. 2–16). Use the coefficient formula.

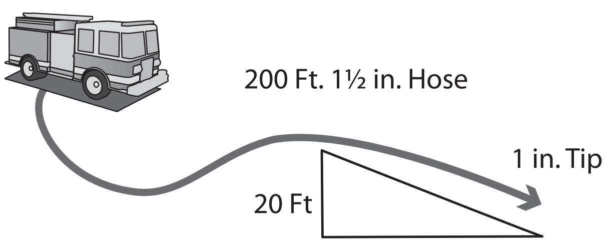

Fig. 2–16. Determine the engine pressure using the given dimensions.

Test 2 Answers

1. 50 psi
2. 100 psi
3. 80 psi
4. 15″
5. True
6. 327.77 gpm
7. 52.53 gpm
8. The amount of force pushing back against the nozzle
9. 96 psi
10. 1,700 times
11. Flow in straight lines
12. Flow moving in all directions
13. Friction loss varies with the quality of the hose.
    Friction loss varies with the length of the hose.
    Friction loss varies with the square of the velocity.
    For a given velocity, friction loss varies inversely as the fifth power of the diameter of the hose.
    For a given velocity, friction loss is independent of the pressure
14. *GPM*/100
15. Lay multiple lines.
    Lay larger diameter hoselines.
16. False
17. 4.34 psi

18. Back

19. Forward

20. 6.08 psi

21. $EP = NP + FL + APP + ELEV$
$EP = 50 + (2Q^2 + Q) + 0 + 0$
$EP = 50 + 13.02 + 0 + 0$
$EP = 63.02$ psi

22. $EP = NP + FL + APP + ELEV$
$EP = 80 + [(2Q^2 + Q)/2.5] + 10 + 0$
$EP = 80 + (37.19/2.5) + 10 + 0$
$EP = 80 + 59.52 + 10 + 0$
$EP = 149.52$ psi

23. $EP = NP + FL + FL + APP + ELEV$
$EP = 100 + (2 \times 1^2 \times 6) + (15.5 \times 2^2 \times 2) + 5 + 0$
$EP = 100 + 12 + 124 + 5 + 0$
$EP = 241$ psi

24. EP = NP + FL + APP + ELEV
$EP = 50 + [(2Q^2 + \frac{1}{2}Q) \times 6] + 0 + 13.02$
$EP = 50 + (2 \times 0.28 + 0.27 \times 6) + 0 + 13.02$
$EP = 50 + 14.94 + 0 + 13.02$
$EP = 77.96$ psi

25. $EP = NP + FL + APP + ELEV$
$EP = 50 + CQ^2L + 0 - 8.68$
$EP = 50 + 17.64 + 0 - 8.68$
$EP = 58.96$ psi

3

WATER SUPPLY

History

Hundreds of years ago, the Romans developed a series of aqueducts designed to move water over many miles from its source in the mountains to the cities where it was needed. Once there, it was stored or moved to places of consumption by smaller pipes made of lead or bored-out stone. During the 1800s, cities along the East Coast of the United States began developing wooden pipes to carry the water. This began the process of moving water to the people instead of the people having to travel to get their water. Large wooden plugs were placed along the piping. Firefighters could remove the plug, insert a supply hose, and have needed water for firefighting operations. The term *plug* is still often used in place of *hydrant*. Eventually, the underground system of pipes became the sophisticated water distribution system it is today. People can simply turn on a faucet, and water appears without a second thought. In urban areas, the ease of using a modern distribution system is taken for granted. However, in rural communities, getting water to a fireground may require either drafting from a static water source or relay pumping from the water source, which could be a long distance away. These two methods of water delivery will be discussed in later chapters. This chapter will cover municipal water delivery systems both for an entire community as well as for individual buildings.

Consumption

Consider a scenario in which a new city is being built from the ground up. One major consideration would be how much water the city would need. As a society, Americans use a lot of water, not only for drinking, but also for showers, laundry, and keeping yards looking nice. Water is also used for playing in water parks, keeping cars clean, and for decorative water features. Even though in recent years ways of using less water have been developed, people in the United States still use a tremendous amount every day. Thus in planning for this city, it will be necessary to calculate how much water will be needed and where it will come from.

Average daily consumption

A good starting point is to figure the average daily consumption of water. This is calculated by dividing the total number of gallons used in a year by the number of days in a year. Different parts of the country will consume different amounts of water depending on their climate, but the average daily consumption offers a good starting point for calculations.

Maximum daily consumption

The next step is to determine the *maximum daily consumption*, which is the maximum amount of water that is used in any given 24-hour period. Each 24-hour period is reviewed to find which one had the highest water usage. Generally, the experts look at a three-year period to find the day that the most water was used. In planning for the new city, the water system will need to be able to provide enough water to cover this peak amount.

Peak hourly rate

Reviewing how much water is being used at different times of the day reveals that there are certain hours that water use is considerably higher than others. This is called the *peak hourly consumption*. For example, during the overnight hours, people use less water than during the day when they are showering and washing clothes. So during these peak hours, more water must be provided.

Fire flow needs

In addition, other possibilities must be considered. This "what if" game is the most important to firefighters because it is also necessary to calculate how much water will be needed if a major fire were to break out somewhere in the city. Will they be able to extinguish the fire with the amount of water available to them? This is the *required fire flow* amount. The distribution system will need to carry enough water to cover the peak hourly consumption plus enough water to confine a fire to a complex of buildings or to within a city block. The amount of required fire flow will vary with the type of building in that area. The required fire flow will be considerably less in an uncongested area with small buildings than in large industrial areas. The required fire flow for lumber yards is much larger than for residential areas consisting of spread-out, single-family homes. Many distribution systems are capable of diverting water from one area to another during times of great need, such as fire operations. The water department can open and close different valves to force the water to where firefighters need it.

Water Source

Once it is known how much water is needed, its source should be considered. Water can be stored and ready for use in many different ways. Many areas use reservoirs to hold multimillion gallons of water. A river can have a dam built on it so the water will back up and flood a valley. Arguably the most famous reservoir in the United States is Lake Mead. It is located on the border of Arizona and Nevada and provides water to a large portion of the southwestern part of the country. Hoover Dam was built during the Great Depression on the Colorado River and now holds about 28,500,000 acre-feet of water. That equates to nearly 10 trillion gallons of water. Other communities may have several reservoirs built to accommodate the needs of their areas. As communities grow larger, more and more reservoirs are added to accommodate the consumption needs of the area.

Natural underground lakes called *aquifers* are found throughout the country. These can sometimes be very large bodies of water found just under the surface of the earth. These aquifers are held in a rocky layer of earth. As the water filters into the aquifer either from the surface or by underground streams, it is filtered by the rocks, making it cleaner for human consumption. Wells are drilled into these aquifers to bring the water to the surface where it can be pumped and delivered where it is needed. Depending upon the pressure underground, a pump may be needed to bring the water to the surface, or it may flow naturally upward. These aquifers are recharged by rain and snowfall throughout the year or by underground streams.

Treatment Process

From these reservoirs, either aboveground or underground, the water gets moved to a treatment plant for purification. The water can be pumped to the treatment plant or it can be fed by gravity. Colorado residents are fortunate to have the reservoirs high in the mountains. Gravity simply delivers the water downhill to the treatment plant. At the treatment plant, the water goes through several processes in order for it to become drinkable. According to the Environmental Protection Agency, the first process is to allow dirt and debris to settle out of the water by sedimentation. Sometimes chemicals like alum are added, which attracts dirt, making it heavy so it will settle out more efficiently. Next, the water flows through a series of filters. These filters try to mimic nature's filtration process by using layers of sand, gravel, and charcoal to pull out the smaller impurities in the water. Chlorine is then added to the water to kill any bacteria or microorganisms that could be harmful. Finally, the water is stored until it is needed for consumption.

Water Distribution System

From the storage facility, a distribution system needs to be developed that will move the water throughout the community to the fire hydrant where firefighters can connect and put the water to work. The water will move through three different classifications of piping. These classifications of mains are primary feeders, secondary feeders, and distributor mains (fig. 3–1).

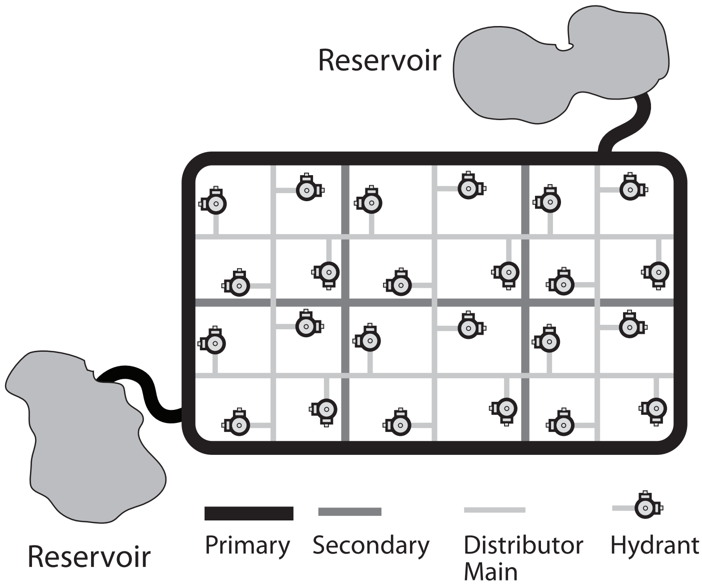

Fig. 3–1. A water distribution system

Primary feeders

The *primary feeders* are large pipes that move the water from the storage area to the secondary feeders. These pipes should be 16″ or larger in diameter and can sometimes be in excess of 60″ in diameter. These are the pipes that carry huge amounts of water into the community. These primary feeders should have enough capacity to deliver the required fire flows necessary in the community. These feeders should be taken from multiple sources to prevent a complete loss of water if one of the feeders is shut down at any given time. Spaced out along the primary feeders are valves that connect the secondary feeders.

Secondary feeders

The *secondary feeders* are smaller than the primary feeders and make the distribution system into a large interconnected grid. These pipes are generally 12″ or larger and all connect to the primary feeders or to each other by way of valves. If the secondary feeders are all connected to each other, then if one valve is closed for repairs or maintenance, the water can flow from a different direction and service will continue. If a pipe were to suddenly collapse, the valves on each side of the break can be closed so the rest of the system would not be affected. The spacing of these valves is such that when valves are closed, only small areas are without water.

Distribution mains

Connected to the secondary feeders are distribution mains. *Distribution mains* are smaller pipes that connect to individual customers and to fire hydrants. These pipes are essentially smaller grids inside the secondary feeder grids. These pipes should be at least 8″ in diameter and connected from at least two different directions. The size of the pipes and spacing of the control valves depend on what is to be protected. Industrial areas need larger pipes than business districts, and residential areas are allowed to have even smaller mains.

Sometimes a distributor main will just stop. It will not be connected to anything or looped into a grid. This is called a *dead-end main*. The problem with these is the fact that they cannot deliver the same amount of water as a looped system. Many times a fire hydrant is placed at the end of this pipe. Obviously, this reduced amount of water flow is a concern to firefighters. Dead-end mains are often found at the edge of rivers, highways, and railroad tracks, since placement of the pipes under such obstacles is difficult. Firefighters must identify these mains. If they cannot get the pipe connected to the grid, they should be aware that another hydrant may need to be used so a better water supply is maintained.

The control valves used in the distribution system are most likely a butterfly valve that can be controlled by inserting a key wrench into the top and turning until it is either opened or closed. As noted before, these are placed so a section of pipe can be shut off without sacrificing a larger area. The Insurance Services Office (ISO) recommends that valves be placed so that if a break occurs, no pipe will be shut down at any given time that is longer than 500 ft in commercial areas, 800 ft in residential areas, or one-fourth of a mile for a primary feeder line.

Fire Hydrants

In the early 1800s, the first fire hydrant was developed. It came about after the distribution system was advanced to a point where the pipes were strong enough to allow the water to be put under pressure. Instead of having holes in the pipe with a plug for firefighter access, the piping was extended above the ground and capped with valves that allowed firefighters to connect hoses. Today the fire hydrant has developed into a sophisticated appliance that many take for granted.

Types of fire hydrants

The wet barrel type of hydrant is found in areas where there is no possibility of freezing temperatures (fig. 3–2). From the distributor main, piping of at least 4″ in diameter is connected and runs a short distance to where a hydrant is to be positioned. If the hydrant has an outlet for large diameter hose, it is recommended that the pipe be at least 6″ in diameter. The pipe turns 90º upward and rises to near the surface of the ground. From here a hydrant is bolted to the pipe.

Fig. 3–2. A wet barrel hydrant

It is recommended that each hydrant have at least two outlets in case one gets damaged. These outlets have 2½″ male threads that match the threads on the fire hose couplings. Most municipalities require that in addition to the two smaller outlets, a larger outlet be designed so pumpers can connect large diameter hose for a much larger flow of water. The threads on this outlet also match the threads on the large diameter hose. Each outlet has a cap that keeps out dirt and debris. If debris gets in the hydrant, it will be forced out into the hose, clogging the hose and severely limiting the flow of water. The fire academy for the Denver Fire Department teaches that if a cap is off or nearly off, firefighter must turn on the hydrant before connecting a hose and flush the hydrant for several seconds. The water pressure will force any debris out.

The wet barrel hydrant gets its name because water is in the hydrant barrel all the way up to the outlet valves. Some wet barrel hydrants have one valve that allows water to all of the outlets. Other types have a valve for each outlet, allowing water to flow out of only the outlet that is connected to a hose. This type allows for the flexibility to connect more hoses after the first line is in use.

The advantage of this type of hydrant is that there is water at the outlet ready for use. There is no delay in getting water into the hoseline. The disadvantage of the wet hydrant (other than freezing) is that when it gets knocked off the base, water will flow like a geyser. This is often portrayed in movies because it can be very dramatic. Newer hydrants are built with a valve in the underground pipe that closes if the hydrant is damaged.

The dry barrel hydrant is the most common type of hydrant (fig. 3–3). A nut on top of the hydrant opens a valve below ground, allowing water to flow up to the outlets. The coldest ground temperature dictates how far below ground the valve is positioned.

The valve needs to be placed below where the ground, and ultimately the water, will freeze. As the nut on top of the hydrant is turned, an arm moves a plunger into or out of the piping connected to the distributor main. As the plunger is pulled away, the full amount of water is allowed to flow freely up the barrel.

Fig. 3–3. A dry barrel hydrant

At the bottom of the hydrant assembly is a drain valve. This valve automatically closes as the hydrant is opened and opens as the hydrant is closed. This allows any remaining water inside the hydrant to simply drain away, keeping the barrel dry. The hydrant needs to be installed with gravel around this drain valve, preventing it from getting clogged with dirt. If the water remains in the barrel and does freeze, it becomes almost impossible to open the valve. It is important to open the hydrant fully every time because the drain valve closes as the main valve opens. Sometimes when firefighters are in a hurry to get to the fireground, it may seem like it takes forever to fully open the hydrant. However, they should not be tempted to open the hydrant only until water is flowing. If the drain valve remains open even a small amount, water under pressure will flow out the drain, washing away the gravel and the supporting earth around the hydrant. This could make the area around the hydrant unstable, possibly damaging the hydrant and connecting pipe. (See fig. 3–4.)

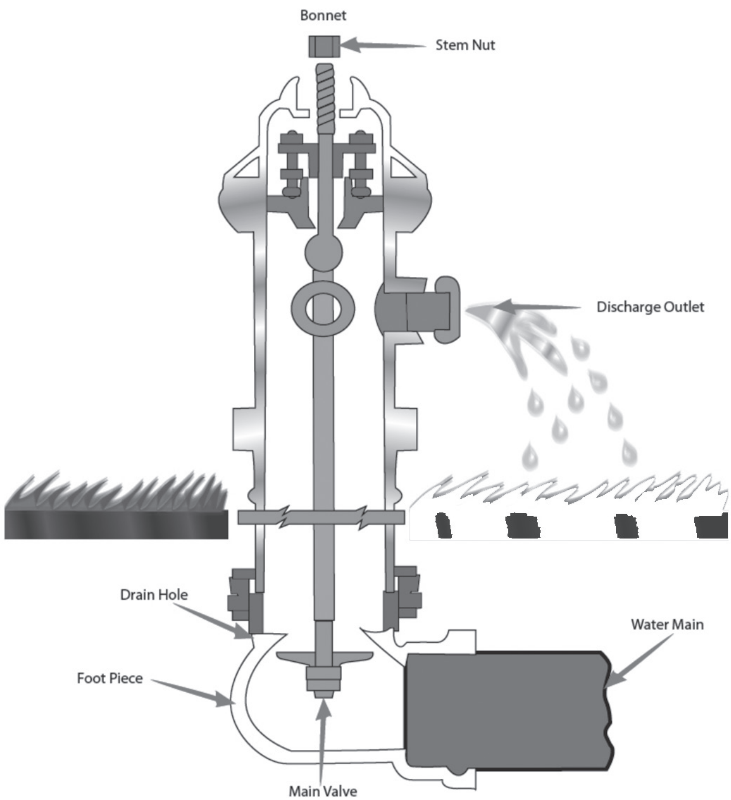

Fig. 3–4. A dry hydrant mechanism

One advantage of the dry hydrant is that if the barrel gets knocked over due to an accident, it usually will not flow water. The operating rod that connects the operating nut to the valve mechanism will break, and the valve will remain closed. I once witnessed an auto accident where a car knocked over a hydrant. Unfortunately, in this case, the operating rod did not break, and the valve was partially pushed open. Water did not shoot out of the pipe as shown in the movies, but it did gush out and flood the street. Luckily, the weather was warm, and a storm drain was nearby to disperse the water.

On both types of hydrants, a valve is placed between the distributor main and the hydrant. This is so the hydrant can be disconnected from the distribution system. From time to time, the hydrant will need to be replaced or repaired. Closing this valve allows the hydrant to be disconnected and removed from the distribution system. At a fire on the east side of Denver, we were unable to turn the hydrant off after the fire. The operating nut kept spinning as we tried to turn it. The water department came out and turned the hydrant off at this valve. We were able to disconnect our supply hose, and the hydrant was replaced. Without this valve, this would not have been possible.

Municipalities commonly install the same type of hydrant throughout the city. Even though these hydrants look and work the same, they may flow different amounts of water. Where they are placed within the distribution grid might make a huge difference in the amount of water they are capable of delivering. They might be placed on different-sized mains, or they might not be supplied from different directions.

Flow rate tests

Firefighters need to know how much water a hydrant will deliver. This tells them how much fire can be extinguished using that particular hydrant. Knowing the capacity of a hydrant is just as important as knowing the capacity of a pumper. If the hydrant cannot supply enough water, the pump capacity does not mean as much. The time to figure out the flow from a hydrant is well before the fire. Any time there has been work on the water distribution system, a hydrant near the work will need to be tested. It could be easy for the construction company to forget to reopen a valve or to mistakenly leave debris in the pipe, restricting the flow. Any time new developments are built, the hydrant system needs to be tested to make sure the fire flow matches the new building. At times when the economy is good, there could be a possibility of new building development happening faster than the water distribution system can keep up. Builders want to get the buildings built and sold so they can make a profit. Building a reliable water distribution system does not make them money. However, the responsible choice is to build the water distribution system properly to be able to protect the new buildings.

Very little equipment is needed to test a fire hydrant. A hydrant cap with a built-in pressure gauge is needed to measure the static pressure. If there is not one, it is possible to hook up a section of hose between the hydrant and the pumper. The reading is taken from the intake pressure gauge.

A pitot tube is needed to measure the forward velocity of the stream (fig. 3–5). The pitot tube was invented by a French engineer named Henri Pitot.

Pitot tubes are used to measure the forward velocity of air and other gases, as well as water. Airplanes use them to calculate their air speed, but they are also used in the fire service to calculate gpm flow in fire streams. The blade is the portion that gets placed into the stream. The handle is an empty air chamber that helps to keep the gauge needle steady. The gauge measures the pressure against the blade, and a petcock is used to bleed off any remaining pressure on the gauge.

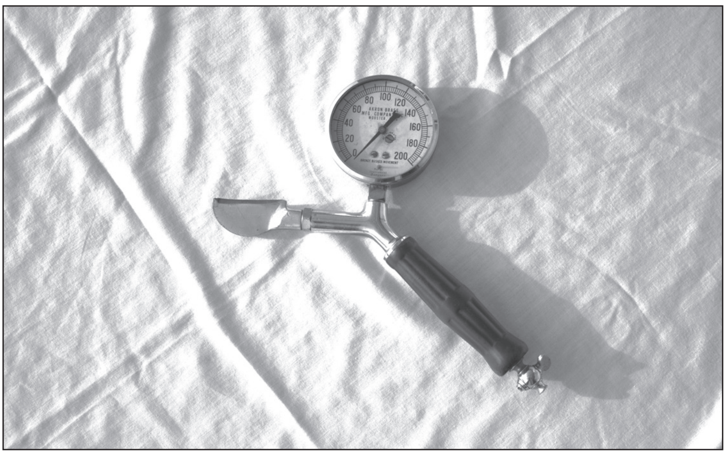

Fig. 3–5. A pitot tube

Flow rate test procedures

Two hydrants near each other will be needed for the test. The first will be the pressure hydrant. The second will be the test hydrant.

1. Attach a cap with a pressure gauge to one of the outlets on the pressure hydrant. Open the hydrant and record the pressure. If the cap has a petcock built into it, open it and bleed the air out before recording the pressure. This is the static pressure in the system.

2. On the test hydrant, open one of the 2½″ outlets and measure the inside diameter of the opening. Even though all of the hydrants in the city may be manufactured by the same company, there may be small differences in the diameters of the openings. Do not use the outlet that is used for large diameter hose. The stream from this opening has gaps, so the reading on the gauge will not be accurate.

3. Feel inside the outlet for the shape of the discharge opening. The shape will determine the coefficient to use in the formula (fig. 3–6).

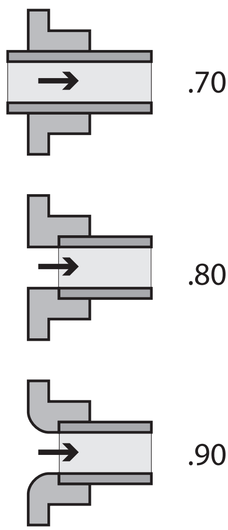

Fig. 3–6. Hydrant coefficients

4. Open the hydrant. Make sure the water from the hydrant will not do any damage to the surrounding area. Check the residual pressure on the pressure hydrant. Make sure the residual pressure

does not drop below 20 psi. If the pressure drops below 20 psi, stop the test. Record the reading on the gauge.

5. When the flow from the outlet has become a steady stream, insert the blade of the pitot tube. The blade should be inserted into the center of the stream, with the blade held a distance of one-half the diameter of the opening from the end of the outlet. If the inside diameter of the outlet measured 2½″, then the blade should be held 1¼″ away from the edge of the outlet. Record the measurement reading on the gauge. If the needle bounces, pick the reading at the midpoint of the bounce.

6. After a satisfactory reading has been recorded, shut down the flow hydrant. Replace the caps and make sure the hydrant is ready for future use. Open the petcock on the pitot tube to drain the unit.

7. Close the pressure hydrant and make it ready for future use.

8. Determine the flow rate using the following formula:

$$29.83 \times C \times D^2 \times \sqrt{P}$$

where

C = coefficient of discharge,

D = diameter of outlet opening, and

P = pressure reading on the pitot tube gauge.

People find that using the pitot tube can be a daunting task. The blade needs to be positioned in the stream very accurately, and most people do not want to blindly stick their fingers inside the hydrant outlet to find the shape of the outlet to determine the coefficient. For this reason, other devices have been developed to calculate the flow rate from a hydrant. Figure 3–7 shows a device that connects to the hydrant or a hoseline and gives a digital readout of the flow rate.

Fig. 3–7. A digital flow meter

A 2½″ tube is connected to the hydrant outlet. This has a pressure gauge for reading the flow pressure and a solenoid with a paddle wheel to calculate the flow velocity. From the other end of the tube, a hose is connected and can be run to a drain or other place so the water is discharged appropriately. The hydrant is then opened fully, and the readouts can be documented. The problem with this type of setup is that it needs electrical power to run the components. If various hydrants around town are being tested, a power source such as a generator will be needed.

Some municipalities have the fire department test the fire hydrants. Others have the water department perform the test. Whoever does the testing, the fire department needs to be aware of the flow rates to identify the good and bad areas of the system. The time to discover where a problem occurs is not during a fire. Any problem areas can be addressed ahead of time, and a plan of action can be developed to overcome any deficiencies.

Where there are discrepancies in the flow rates of different city hydrants, a system of identifying the rates of the hydrants should be available. NFPA Standard 291, *Recommended Practice for Fire Flow Testing and Marking of Hydrants*, recommends the following color coding of the hydrants:

Hydrant class	Flow capacity and color code
Class AA	1,500 gpm or greater—light blue
Class A	1,000 to 1,499 gpm—green
Class B	500 to 999 gpm—orange
Class C	Less than 500 gpm—red

NFPA 291 recommends that only the bonnet and caps be color coded. The rest of the barrel should be a different color.

Placement of hydrants

The placement and spacing of the hydrants depend upon the type of occupancies that need protection. Areas such as industrial areas not only require larger flow rates, but also more hydrants that are spaced closer together. The idea is that there should be enough hydrants to cover the needed fire flow concerns, spaced sufficiently close together so as to avoid excessively long hose lays. In high-life or high-value areas, hydrants may be found on every corner of an intersection. Hydrants in high-value districts should not be spaced further than 300 ft apart. In residential areas, there should be a hydrant at every intersection, with extra hydrants placed in between if the distance exceeds 500 ft.

When placing the hydrant in position, a few rules need to be followed:

1. **The hydrant should be close to the street so the pumper can have adequate access.** The engineer or plug catcher should not have to pull excessive amounts of hose off the apparatus to reach the hydrant.

2. **The large-diameter outlet should face the street.** It is harder and takes more space to maneuver the large diameter hose toward the pumper (fig. 3–8).

Fig. 3–8. A hydrant that is facing the wrong direction

3. **There needs to be adequate clearance between the lowest outlet and the ground (fig. 3–9).** A minimum of 15″ is needed so the hydrant wrench can spin without hitting the ground. In some extreme cases, I have seen the outlets even with ground level. This usually happens when landscaping builds up the ground around the hydrant without consideration to firefighting needs.

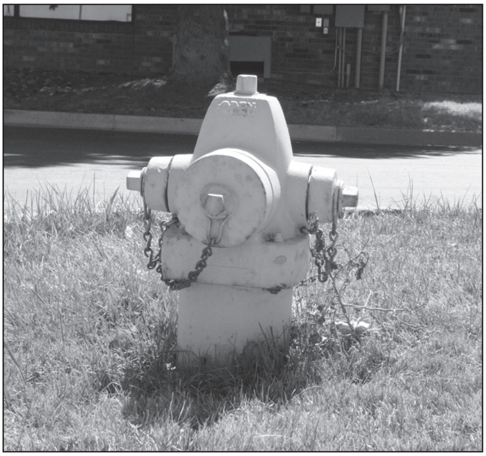

Fig. 3–9. A hydrant too close to the ground

4. **The area around the hydrant needs to be kept clear of obstructions.** In high-traffic areas such as parking lots, the hydrant may be surrounded by parking blocks or metal posts to keep cars from driving into them (fig. 3–10). Although protecting the hydrant is important, it is equally important that the obstruction allows firefighters to gain access and hook up the hoses. Furthermore, homeowners sometimes try to hide the unsightly hydrants with plants or shrubbery (fig. 3–11). Most people (with the exception of firefighters) will not design a landscaping with fire hydrants in mind.

Fig. 3–10. Posts around a hydrant

Fig. 3–11. Bushes obstructing a hydrant

Storage Tanks

Until now, the discussion has focused on a water distribution system that has underground piping and fire hydrants connected to it. What happens when the distribution system cannot handle the needed fire flow for the area or a specific building? This situation calls for an elevated storage system. An *elevated storage system* is simply an elevated storage tank large enough to handle a specific fire flow need. These tanks are elevated on pedestals or sit on a hill near where they are needed (fig. 3–12).

Fig. 3–12. An elevated storage tank

Sometimes the tanks sit on top of the building they are protecting. For elevated storage tanks to be reliable for firefighting, they need to be properly located. They should be close to where they are needed so the pressure generated by elevating them is not lost due to the friction loss in the piping.

The most important thing in a storage tank is its capacity. Whether it is designed to protect a specific building or an entire portion of town, it needs to be large enough to handle the required fire flow. If it is determined that a building or area will need 500,000 gal of water for extinguishment, a storage tank holding at least that amount can be built. A round storage tank 50 ft wide by 40 ft tall will be large enough:

$$V = \pi R^2 h$$

where

V = volume,

R = the radius, and

h = the height.

Thus the volume of the tank can be determined as follows:

$$V = 3.14 \times 25^2 \times 40$$

$$V = 3.14 \times 625 \times 40$$

$$V = 78{,}500 \text{ ft}^3$$

Next, gallon capacity (GC) can be determined:

$$GC = 7.48 \text{ gal/ft}^3 \times V$$

$$GC = 7.48 \text{ gal/ft}^3 \times 78{,}500 \text{ ft}^3$$

$$GC = 587{,}180 \text{ gal}$$

The tank will need to be elevated if it needs to be pressurized by gravity. Remember that every foot of elevation creates 0.434 lb of pressure. The base of the tank needs to be at a height of 116 ft in order to create 50 lb pressure (116 × 0.434). This should be enough pressure to supply a hydrant positioned at the base of the tank. The piping from the tank to the hydrant should be large enough to deliver the water appropriately. This is the same principle as the piping in the underground distribution system. From the hydrant, a pumper can move the water to where it needs to be used, or a tanker truck can be filled and then deliver the water to the fireground.

The elevated storage tank is a very good way of supplying enough water when the normal water distribution system cannot handle the amount of water needed for firefighting. The tank does not always need to be elevated. Many times the tank is placed on the ground but has a pump attached to provide the needed pressure. Often this is seen where a manufacturing plant has been built but the underground distribution was not expanded to cover the needed fire flow. In this case, a storage tank is built on the complex, and when the water is needed, the pump activates, pushing the water to where it can be used.

Whatever type of water distribution system is available, firefighters need to understand how it applies to firefighting. Firefighters should not only understand where the water comes from and how much will be needed if a fire occurs, but they also should prevent problems with proper preplanning. It is not acceptable to simply open a hydrant and assume there will be enough water coming out to extinguish all fires. Being able to analyze a distribution system for its strengths and weaknesses allows firefighters to make plans ahead of any fire. It may be necessary to find a hydrant further away from the fire in order to have enough water. Planning will allow firefighters to know if they need to locate a second hydrant that is on a different main so they do not take water volume from the first hydrant. These are all important facts that need to be discovered while studying the water distribution system.

Test 3

1. What is the primary consideration when developing a water distribution system?
2. Define average daily water consumption.
3. Define maximum daily consumption.
4. Define peak hourly consumption.
5. Define required fire flow.

6. Name two places where water is stored before it reaches a treatment plant.
7. List the three ways water is treated.
8. Name the three classifications of distribution system piping.
9. According to the ISO, what is the maximum spacing between hydrants in a commercial area?
10. According to the ISO, what is the maximum spacing between hydrants in a residential area?
11. (T or F) A wet barrel type of hydrant is found in warm climates.
12. What is the most common type of hydrant?
13. Where is the control valve located on a dry barrel hydrant?
14. How is the drain valve closed on a dry barrel hydrant?
15. Name two tools used to calculate the flow from a hydrant.
16. At minimum, how many hydrants are needed to conduct a flow test?
17. List the classifications and color coding for hydrant flows according to NFPA 291.
18. What is the most important consideration of a storage tank used for fire flow?

Test 3 Answers

1. How much water is needed
2. Number of gallons used in a year divided by number of days in a year
3. Maximum amount of water used in any 24-hour period
4. The hour in a day where the most water is used

5. Enough water to cover the peak hourly consumption plus enough water to confine a fire to a complex of buildings or to within a city block
6. Reservoir and aquifer
7. Sedimentation, filtration, and chemical treatment
8. Primary, secondary, and distributor main
9. 500 ft
10. 800 ft
11. True
12. Dry barrel
13. Underground below the freeze line
14. Open the hydrant fully
15. Pitot tube gauge and a digital flow meter
16. Two
17.

Class AA	1,500 gpm or greater—light blue
Class A	1,000 to 1,499 gpm—green
Class B	500 to 999 gpm—orange
Class C	Less than 500 gpm—red

18. Tank capacity

4

DRAFTING

Reasons for Drafting

Most municipal areas have a network of water mains and hydrants conveniently placed for firefighting use. Hydrants are placed on street corners or spaced close enough to each other and to buildings so firefighters can attach hoses quickly and begin firefighting activities. Rural areas may not have this luxury. Water mains and fire hydrants often are nonexistent. Even if a water distribution system is in place, it may not be adequate for firefighting. The mains may be too small to provide adequate fire flows. These rural areas often depend upon other means and sources to provide the proper quantities of water needed for fire extinguishment. Fire departments need to draft water from sources other than hydrants into the fire pumps under pressure to be effective.

Portable and natural water sources are often considered to be the only resource for providing water in these rural areas. These natural sources include lakes, ponds, streams, and irrigation ditches. Firefighters need to make note of these water sources while preplanning so no time is lost when an actual fire occurs. The source of this water needs to be clean enough and large enough to carry the amount of water that is needed for firefighting purposes.

One problem with using natural resources such as these is a lack of accessibility to the water. The pumper needs to get within 10 to 20 ft of the water to be able to draft the water into the pump. This makes many areas unacceptable for fire service use. Many lakes and ponds are large enough for this purpose, but it can be very difficult for the pumper to reach the water. The area around the lake is often too muddy or soft for the pumper to approach. Grass and weeds often hide soft spots that the apparatus can sink into. In addition, the water being used can cause the formerly dry and stable ground to become soaked and unstable. The hose couplings and the pump itself often leak, creating wet and muddy areas under the apparatus and making messy and dangerous situations for firefighters. If the apparatus gets stuck in the mud, it may become unusable at a time it is needed the most. Fire departments can counter this problem by constructing a driveway using gravel or wood, but this takes time. Finding these materials can be problematic, and it is impractical for the fire department to carry them. Good areas to use are usually man-made. These are areas such as boat ramps, roads that are close enough to the water, or bridges that are not too high above the water. These areas usually carry vehicles daily, even in poor weather conditions.

Drafting Basics

As stated before, *drafting* is the process of taking water from a source other than a hydrant and moving it to the intake side of the pump under pressure. This involves creating a vacuum inside the pump and using atmospheric pressure to force the water through the intake hose and into the pump. Atmospheric pressure is the weight of the surrounding air. The amount of atmospheric pressure depends upon the elevation above or below sea level. The atmospheric pressure at sea level is 14.7 psi, and there is a loss of about one-half pound of pressure for every 1,000 ft rise in elevation.

Equipment Needed for Drafting

The priming pump is a positive displacement pump that pumps both air and water. Since centrifugal pumps are not capable of pumping air, a priming pump is needed to expel the air. The priming pump pulls the air out of the centrifugal pump and creates a vacuum, which in turn forces water into the centrifugal pump. The priming pump does not pump water into the main centrifugal pump. It creates a vacuum that draws the water into the centrifugal pump.

The pressure gauge connected to the intake side of the pump needs to be a *compound gauge* (fig. 4–1), which means that it can read pressures both above and below zero. The readings below zero on the compound gauge are measured in inches of mercury. A zero reading on the gauge is actually reading atmospheric pressure. At sea level, the atmospheric pressure is 14.7 psi. This means that a pressure reading of zero is actually a pressure of 14.7 psi. Any pressure reading less than zero is actually a vacuum reading, and water will be forced into the centrifugal pump.

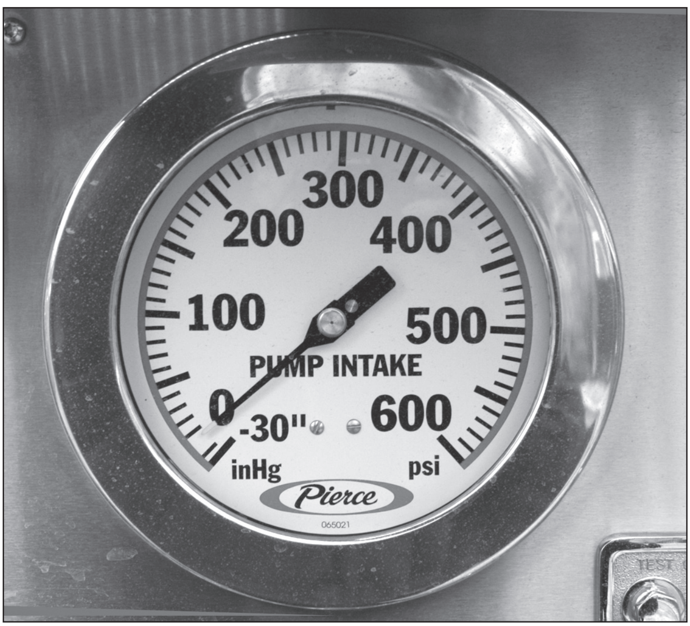

Fig. 4–1. Intake gauge

Hard suction hose is connected to the main inlet valve to the pump. This hose needs to be rigid and strong enough to withstand a negative pressure (vacuum) inside it. It is usually made of hard rubber so it is strong enough to keep its shape and not collapse. The couplings must be tight, and the gaskets at each coupling need to be in good shape so air will not leak around them, which will cause the drafting operation to lose efficiency. At the end of the hard suction, there should be a strainer that is placed in the water. This strainer floats just under the surface of the water and keeps debris out of the hose. The strainer will keep larger pieces of debris from entering the suction hose and ultimately the pump. It will not keep small debris such as sand and dirt out. If the strainer does not float, it will be necessary to find a way to keep the end of the hose off the bottom of the body of water being used for supply. A rope with one end tied to the strainer and the other tied to the pumper usually works well. If sediment or other debris gets into the pump, the drafting process is over. The pump will be damaged or even completely ruined. Sand or other debris that enters the centrifugal pump will damage the impellers and wear rings, causing the spaces between parts to widen, and the pump will lose efficiency. Larger pieces may even cause the pump to seize, causing major damage.

The equipment used in drafting is fairly simple and straightforward. It takes very little effort to put the equipment in place and get it operating, but it needs to be properly maintained and ready for use. The hose and priming pump need to have water run through them to keep them in proper working condition. It also is important to make sure the couplings work properly and the gaskets are all in good condition.

Lift

Lift is the vertical distance from the surface of the water to the center of the pump when drafting. In theory, the maximum amount of height a pump can lift would be 33.9 ft. This is calculated by multiplying atmospheric pressure (14.7) times the height that 1 lb of pressure will lift a column of water (2.304):

$$14.7 \text{ psi} \times 2.304 \text{ ft/psi} = 33.86 \text{ ft}$$

First, the pump would need to be at sea level to have the maximum atmospheric pressure of 14.7 psi available. Next, a perfect vacuum would need to be created, and thus there could not be any leaks in the connections. There also could not be any friction loss anywhere in the process. As stated earlier, this is not possible. Whenever water is moving through the hoses and couplings, there will be friction loss. In reality, the most that water can be lifted at sea level is about 23 ft.

Water will move through the suction hose and into the pump when there is a pressure difference (vacuum) between the pump and the source of the water. The pump operator creates the vacuum by engaging the primer pump. This will evacuate the air inside the centrifugal pump, creating the needed pressure difference. The compound inlet gauge will show a negative reading. Next, the inlet valve needs to be opened. Because the surrounding atmospheric pressure will be greater than the pressure inside the pump, the water will be forced through the suction hose and into the pump. Once the water is flowing into the centrifugal pump, the priming pump can be turned off, and the flow of water can be maintained. An outlet valve can then be opened, and the pump can be operated in the same manner as if it were connected to a hydrant.

How Far Can Water Be Lifted?

A compound gauge is different from other gauges in that it records pressures below zero or in a vacuum. The inlet compound gauge located on the pump panel shows positive pressure like any other gauge, but the difference is that it also has readings below zero. The marks below zero are spaced closer together, and the highest reading is usually 30. These marks actually measure inches of mercury. The pump operator needs to convert this reading into the amount of lift created by the vacuum. The amount of pressure reduction created by the priming pump can be figured by multiplying the vacuum reading in inches of mercury by 1.13. For every inch of mercury reduction, the water will rise 1.13 ft:

$$h = 1.13Hg$$

where

h = height in ft and

Hg = inches of mercury.

Question: The compound gauge reads 15″ of mercury. How far will the water rise?

Answer: The height that the water will rise is determined as follows:

$$h = 1.13\ Hg$$

$$Hg = 15$$

$$h = 1.13 \times 15$$

$$h = 16.95 \text{ ft}$$

These figures represent the theoretical world. In the real world, there is friction loss, and small air leaks occur. The theoretical figures can never be obtained. In the street, a good rule of thumb to use is that for every inch of mercury, the water will rise 1 ft.

Altitude

As noted earlier, about one-half pound of atmospheric pressure is lost for every 1,000 ft of elevation gain. Mountain climbers can attest to the fact that as they climb in elevation, there is less air pressure. It is harder for them to breathe because there is less atmospheric pressure pushing air into their lungs. Similarly, there is less atmospheric pressure pushing on the water at higher elevations. A loss of atmospheric pressure means that there is less pressure pushing the water into the pump. If there is less pressure pushing on the surface of the water, the height that the water can be lifted will be reduced. The following formula can be used to determine the amount of lift at elevation (X):

$$\frac{\textit{Atmospheric pressure at altitude}}{\textit{Atmospheric pressure at sea level}} \times \frac{X}{\textit{Lift at sea level}}$$

Question: A pumper at sea level can lift water to a height of 23 ft. How far can the pumper lift water at an altitude of 5,000 ft, where the atmospheric pressure is 12.2 psi?

Answer: The height water can be lifted at the given altitude is determined as follows:

$$\frac{12.2}{14.7} \times \frac{X}{23}$$

$$14.7X \times (12.2)\,(23)$$

$$14.7X \times 280.6$$

$$X = 19.09 \text{ ft}$$

This is the case in the Denver area. The altitude is about 5,000 ft above sea level. To determine how high a pumper is capable of lifting the water into the pump, it is necessary to know the altitude and atmospheric pressure.

The opposite can also be found. At times, the pump operator might need to know how many inches of mercury are needed to lift water to a certain height. Sometimes a pump is located a certain height from the water, and the pump operator needs to determine if the pump is close enough to the water source. One example might occur when parked on a pier or other elevated platform where the distance can be measured. The formula for this is as follows:

$$Hg = 0.885h$$

where

Hg = inches of mercury and

h = height.

Question: How many inches of mercury are needed to lift water 15 ft?

Answer:

$$Hg = 0.885h$$

$$Hg = 0.885 \times 15$$

$$Hg = 13.28$$

The pump operator needs to understand both the theory and practical application of lift. This determines how far above a water surface the pump can be placed. Bridges and overpasses may seem like good locations from which to draft because the ground is sturdy and stable, but they may be too far away to be able push the water into the pump.

Amount of Water That Can Be Lifted

The amount of water that can be lifted into the pump is first determined by the rated capacity of the pump. The rated capacity of a pump is the amount of water that can be discharged while at draft. Most modern pumpers are rated at 1,250 gpm or greater. The rated capacity of the pump is determined when the pump is discharging at 150 psi while drafting. This is the pressure at which the pump is most efficient. While the pump is discharging at 150 psi, the total amount of water is measured in gallons per minute. The elevation and atmospheric pressure will affect the pump capacity. A pumper that is rated at 1,500 gpm at sea level will only be able to produce about 1,250 gpm at 5,000 ft elevation. The size of the hard suction hose is also a major factor in determining how much water can be drafted. The same principles that apply for reducing friction loss are needed for drafting. The larger the diameter of the hose, the less friction loss will occur. A minimum of 6″ hard suction hose should be used for 1,250 gpm pumpers or larger. Smaller hose sizes make it difficult to deliver the quantity of water needed. If smaller hoses are used, it will be necessary to use multiple inlets.

Net Pump Pressure

Net pump pressure is the total amount of work being done by the pump. When drafting, it is the total pressure generated from drafting plus the pump discharge pressure. For example, if a pressure of 30 psi is needed to lift the water from the water surface to the middle of the pump, and the required discharge pressure is 150 psi, then the net pump pressure will be 180 psi. When working from a hydrant, it is the discharge pressure minus the incoming hydrant pressure. If the discharge pressure is 150 psi, and the hydrant is providing 80 psi, then the net pump pressure is 70 psi. Because of this, it is possible to pump more water than the rated capacity of the pump. If the pump discharge is set at 150 psi (its most efficient setting), and a hydrant is providing incoming pressure, it is possible to pump well above the rated capacity of the pump.

Drafting Procedures

The driver should spot the apparatus on solid, level ground as close to the edge of the water as possible. Remember, the ground needs to support the weight of the apparatus even after water spillage makes the ground wet. For safety reasons, the pump panel should be on the side of the apparatus opposite from the water.

Select the length of hard suction hose needed to reach the water. Usually two 10 ft sections of hose are required. The first step is to make sure all of the couplings have good gaskets and are airtight. Even a small leak can cause the pump to lose its prime. The hose is connected to the pumper first, and then the other end is placed into the water. It is ideal to place the strainer at least 2 ft under the surface of the water and at least 1 ft off of the bottom at all times. It may be helpful to tie a rope to the strainer to keep it off the bottom and to guide the strainer into place. If the water source is limited, such as a holding tank, the level of the water will change. A close eye must be kept on the level to make sure the hose does not come out, causing a loss of draft. If the strainer gets too close to the surface of the water, a whirlpool may develop, resulting in losing the prime. If a whirlpool does develop, and the strainer cannot be lowered, the pump operator should then place a large, flat object, such as a piece of plywood, over the strainer.

The pump operator needs to check that all drains, discharge outlets, valves, bleeders, and other openings that could prevent a prime are closed. The unused inlet valve caps must be kept tight. Any leakage, no matter how small, can result in the pump not being able to achieve a prime.

The priming pump can now be activated and the throttle opened to the required revolutions per minute. The pump operator should listen for air leaks at all accessible couplings. Water should be delivered to the pump within about 30 seconds. If the water is not delivered within this time frame, the priming pump should be turned off and the problem investigated. Usual problems include too high of lift, a clogged strainer, air leaks, or the priming pump needs to be lubricated. When the pump starts receiving water, the priming pump will begin to dump water. The water should be allowed to dump for a few seconds, and then the main centrifugal pump should be engaged and the priming pump disengaged.

The discharge outlet should then be opened slowly and the throttle increased to the desired pressure. The intake gauge should continue to show a vacuum reading. If the throttle is increased without the discharge pressure increasing, one of two things has occurred:

1. **The pump operator is trying to pump past the capacity of the pump.** The throttle should be turned down to the point where the discharge pressure begins to drop. The pump should be operated at this pressure, since this is the most that can be gotten out of the pump.

2. **The pump has not been fully primed.** The throttle should be backed down to a low setting, and then the transfer valve should be shifted between volume and pressure and back again. In many cases, this will clear the blockage.

Many rural fire departments have large water-carrying trucks called *tenders*. They are large tanker trucks that can deliver many thousands of gallons of water to the fireground. This eliminates the need to find suitable natural water sources. The tender can be filled at a hydrant or other source and delivered to the fireground. The water is cleaner and more reliable for firefighting needs. Apparatus placement becomes less of a concern. The area only needs to be large enough to position the attack pumper and the tender. If the ground is solid enough for the attack pumper, it should also be suitable for the tender. (Remember, the extra water in the tender will be much heavier.) Hoselines can be connected between the tender and the attack pumper, or a portable reservoir can be erected from which to draft. The reservoir can simply be refilled as needed.

For many rural fire departments, drafting is a part of everyday life. For urban departments, pump operators may go their entire career without ever needing to draft. Some urban departments have even taken their hard suction hose out of service. This is a mistake. There may be a time due to terrorism, a natural disaster, or other crisis that a drafting operation will be needed. Drafting operations need to be fully understood and continuously practiced.

Summary of Chapter Formulas

To determine the height that water will rise:

$$h = 1.13Hg$$

where

h = height in ft and

Hg = inches of mercury.

To determine the pressure reduction required to lift water a certain amount:

$$Hg = 0.885h$$

where

Hg = inches of mercury and

h = height.

Test 4

1. What are two problems with using natural resources for drafting?
2. (T or F) Drafting consists of creating a vacuum inside the pump and pulling water into the pump.
3. What is the atmospheric pressure at sea level?
4. How much atmospheric pressure is lost with elevation?
5. What type of pump is used for priming pumps, and why?
6. Define compound gauge.
7. (T or F) Very small leaks in the couplings are not a problem in the overall drafting process.
8. Does the strainer need to be placed directly on the bottom of the water source?
9. At sea level, what is the theoretical amount that water can be lifted?
10. At sea level, what is the realistic distance that water can be lifted?
11. How far will the water rise for every inch of mercury that is reduced?
12. Define the rated capacity of the pump.
13. At what discharge pressure is the pump most efficient?
14. What should be the minimum size of the suction hose?
15. Define net pump pressure.
16. List four causes of priming failure.
17. How long should it take for the centrifugal pump to receive water?
18. How far can a pumper lift water at an altitude of 8,000 ft?
19. The compound gauge reads 12″ of mercury. How far will the water rise?

Test 4 Answers

1. Accessibility and water quality
2. False. Atmospheric pressure pushes the water.
3. 14.7 psi
4. One-half of pound pressure for every 1,000 ft rise in elevation
5. Positive displacement pump, because it can pump air
6. Has readings below zero
7. False. Any leak makes it hard to create a vacuum.
8. No. It floats under the surface.
9. 33.9 ft
10. 23 ft
11. 1.13 ft
12. The maximum amount of water while at draft
13. 150 psi
14. 6″
15. The total amount of work being done by the pump
16. Too high of lift
    Clogged strainer
    Air leaks
    Priming pump needs to be lubricated
17. 30 seconds

18. 16.74 ft

$$\frac{10.7}{14.7} \times \frac{X}{23}$$

$$14.7X = 246.1$$
$$X = 16.74$$

19. 13.56 ft

$$h = 1.13Hg$$
$$Hg = 12$$
$$h = 1.13 \times 12$$
$$h = 13.56$$

5

RELAY PUMPING

Reasons for Relay Pumping

At times it may be necessary to move water from one pumper to another or to several pumpers in a row in order to produce an effective stream. This is usually because of the long distances between the water source and the fireground and the quantity of water needed to extinguish the fire. *Relay pumping* consists of water flowing from a source pumper to the intake side of another pumper and then to another, if necessary, on down the line until it reaches the attack pumper. Relay operations are necessary whenever there is excessive friction loss between the water source and the attack pumper or there is excessive back pressure due to elevation.

In areas where hydrants are spread long distances apart, it may be necessary to set up a relay operation. Having a single pumper connect to the hydrant and lay out hoseline to the fire would result in an excessive amount of friction loss in the supply line. To combat this, two or more pumpers are spread out along the distance to overcome the friction loss. A pumper at the water source and one at the fire may be all it takes at some fire scenes. However, at other times, it may be necessary to spread out several pumpers along the way in order to produce an effective attack on the fire.

Setting Up the Relay

When determining if a relay operation is necessary, several factors need to taken into account. The first is the amount of water necessary to fight the fire. The officer in charge should carefully determine the maximum amount of water needed because once a relay is in place, it is difficult to increase the amount of water without adding supply lines between pumpers. The amount of water that is needed may be different by the time a relay operation is set up. The officer needs to anticipate how long it will take to set up the relay and how much water will be needed at that time. It is best to overestimate the amount of water needed just to be safe.

Determining the Number of Pumpers Needed

Once the necessary maximum flow is determined, the spacing between pumpers can be figured. A maximum discharge of 200 psi is recommended for each pumper due to the fact that the hose is usually pressure tested at 250 psi. (It should be noted that some hoses currently being manufactured now have a higher test pressure.) This figure of 200 psi will allow 50 psi for safety. The next step is to subtract the nozzle pressure and 20 psi for the needed intake pressure at the next pumper. The result is the remaining pressure available for overcoming friction loss and elevation.

If the officer in charge determines that 200 gpm flow is necessary, the distance of the relay can be determined. The pump operator starts with 200 psi and subtracts 50 psi for nozzle pressure and 20 psi for the needed intake pressure. The remaining 130 psi can then be used for friction loss and overcoming elevation. Using the Underwriters formula, it can be determined that the friction loss for 200 gpm flowing through 2½″ hose is 10 psi per 100 ft. This allows the pumpers to be spaced 1,300 ft apart on level ground. If there is any elevation, it must be accounted for also. If the attack pumper is 1 mile (5,280 ft) from the water source, six pumpers will need to be placed between the water source and the attack pumper.

The first is placed at the water source, and the others are spaced 1,300 ft apart (fig. 5–1).

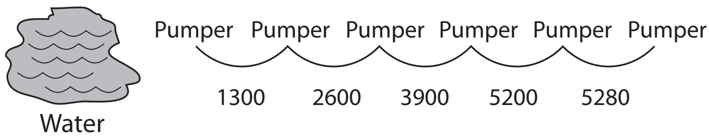

Fig. 5–1. Proper spacing of relay pumpers

Finding and placing six pumpers in place can be very time-consuming and problematic. One way to combat this problem is to lay two supply lines between pumpers. In the above problem, if two 2½″ lines are laid, the friction loss drops to 3 psi per 100 ft. That means there can be 4,300 ft between pumpers. This drops the number of pumpers to three. The first is the supply pumper, one is the attack pumper, and the other one is placed in between the two. Three pumpers are much easier to locate and place than six.

Question: A fire is 2,000 ft away from the nearest water source. The officer in charge has determined that 500 gpm flow is needed to fight the fire. How many pumpers are needed, using dual 2½″ supply lines and smooth bore tips, and how far apart must they be placed? Assume the ground is level.

Answer: First, divide the total gpm flow between the two supply lines. Each supply line now carries 250 gpm. Next, subtract the nozzle pressure and the incoming pressure needed at the next pumper from the pump discharge pressure to determine how much pressure is remaining to overcome fiction loss:

$$200 \text{ psi} - 50 \text{ psi} - 20 \text{ psi} = 130 \text{ psi}$$

Then determine the friction loss for 250 gpm in 2½″ hose:

$$FL = 2Q^2 + Q$$

$$FL = 2(2.5)^2 + 2.5$$

$$FL = 15 \text{ psi (for every 100 ft)}$$

Finally, divide the remaining pressure (130 psi) by the friction loss (15 psi/100 ft, or 0.15 psi/ft) to determine that there can be a maximum distance of 866 ft between pumpers. Because hose comes in 50-ft sections, the pumpers will be placed 850 ft apart. This means a pumper will be placed at the water source, at 850 ft, and at 1,700 ft; the attack pumper will be at the fire. Thus four pumpers are needed, placed a maximum of 850 ft apart.

When larger amounts of water are needed, it is imperative that two or more lines are laid between pumpers. Perhaps 800 gpm are needed to combat the fire. Assume smooth bore nozzles on handlines (50 psi) are being used. The friction loss per 100 ft of single 2½″ hose is 136 psi. This means that the pumpers can only be 100 ft apart. If dual 2½″ lines are used, the friction loss drops to 36 psi per 100 ft, which means that the pumpers can be placed 360 ft apart. This still is not very far if long distances need to be covered.

Using larger diameter hose reduces the friction loss even further. When the same 800 gpm flow travels through dual 3″ hoses, the friction loss becomes 14 psi per 100 ft (36/2.5). This equates to placing 900 ft between pumpers. Remember the friction loss rules from chapter 2. The larger the hoseline, the less the friction loss.

Even in larger municipalities such as Denver, relays are set up at fires in warehouses and apartment complexes where a hydrant is located at the entrance to the complex, but the fire may be hundreds or thousands of feet away. Anticipating where these areas are and planning a course of action ahead of time is critically important.

Elevation (head pressure) also factors into the equation. In the original problem, 130 psi of pressure was left for overcoming friction loss. If the fire were in mountainous terrain and the hose had to be laid up a 110-ft hill, nearly 48 psi are lost in back pressure ($110 \times 0.434 = 47.74$). This drops the remaining pressure to overcome friction loss to 82 psi. This will add more equipment, personnel, and time to the relay.

The Capacity of the Pumpers

A relay operation can only be as good as the equipment used. The pump capacity of each apparatus is the primary consideration. Pumpers are rated at full capacity at 150 psi pump pressure in the volume position. At 200 psi discharge pressure, the rated capacity drops to 70%. The capacity drops even further to 50% when pumping at 250 psi discharge pressure. Since the pumping is at 200 psi, the pumpers being used need to have larger capacities. For example, if the fire requires 800 gpm, and 1,000-gpm pumpers are being used, it will not be possible to deliver enough water to extinguish the fire. At 70% of its rated capacity, a 1,000-gpm pumper will only be able to deliver 700 gpm. Table 5–1 shows the capacity of pumpers at full capacity, 70% when at 200 psi, and 50% at 250 psi discharge pressure.

Table 5–1. Pumper capacities

Rated capacity (gpm)	At 200 psi (70%)	At 250 psi (50%)
500	350	250
1,000	700	500
1,250	875	625
1,500	1,050	750

At times, the required fire flow is greater than the rated capacity of the pumpers. A good way to combat this is to set up two or more relay operations. Two supply pumpers using two separate water sources can pump into a single attack pumper (fig. 5–2). Sometimes two or more pumpers are needed on each side of the relay. This can even be done to supply one attack pumper if the attack pumper is rated at a higher gpm flow. Two separate water sources such as hydrants are found, and relays are set up to attack the same fire. Completely separate water sources should be used so that the supply is not affected by the other pumper. Hydrants connected to the same underground main can rob water from each other. If the required fire flow is determined to be 1,000 gpm, and the rated capacity of each pumper is 1,000 gpm, then two relays are a good option. Each relay can supply 700 gpm for a total of 1,400 gpm, which gives added insurance in case the fire escalates.

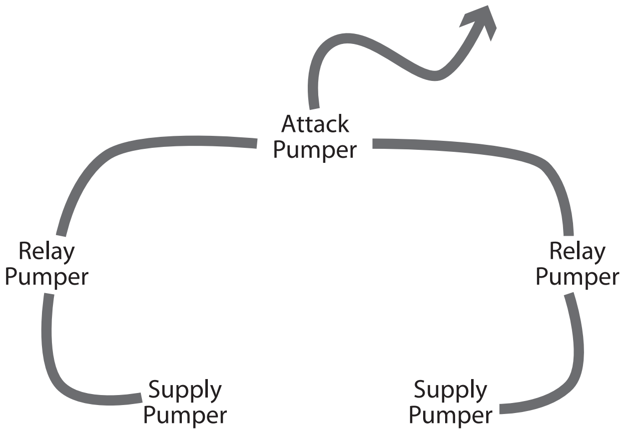

Fig. 5–2. Two relays supplying one attack pumper

Sometimes supplying the fireground with a sustainable water supply requires creativity. At times it can be one straightforward relay operation, and other times, it may take several hydrants or static water supplies. More than one pumper positioned at different water sources can supply a single attack apparatus. This works well when supplying master streams. Master streams usually require thousands of gallons of water, which is hard for a single pumper to deliver. The total amount of water can be divided between the number of pumpers to make the work easier on each piece of equipment. When long distances need to be covered, a single pumper simply cannot deliver the amount of water needed for a master stream. If the total gpm flow needed is divided between two or more pumpers or relays, the problem becomes more manageable. What is most important is to get the proper amount of water to the fire.

Pressure Relays

At times, it is more important to provide higher pressures to a fire scene than a large volume of water. If relatively small amounts of water are pumped up tall mountains or into the standpipe system of a high-rise building, the pumpers need to overcome severe back pressures. In this case, it is important to spread the pressure among two or more apparatus. If the nozzle happens to be 500 ft above the pump, the back pressure alone is 217 psi. Once nozzle pressure, friction loss, and appliance friction loss are added into the calculation, the pump discharge pressure is extreme. The way to handle this problem is to divide the pressure between two or more pumpers. For example, the calculated pump discharge pressure comes out to 320 psi. That is too much for one pumper to handle. Two pumpers placed in a relay can divide the pressure and easily and safely pump the pressure. The first pumper connects large diameter hose from the hydrant to the inlet side of the pump. This pumper delivers the water to the next pumper using two lines at 180 psi. (One-half of the required pressure is 160 psi, plus the extra 20 psi is for the inlet pressure at the next pumper.) The second pumper then takes the 160 psi and boosts it up to 320 psi. This way, each pump needs to do only one-half of the work and is never overworked.

Question: A fire is located on the 61st floor of a high-rise building. The crew has attacked the fire using 200 ft of 2½″ hose and a 1″ straight tip. The fire department connection is supplied with two 2½″ lines 100 ft long. The standpipe system has a friction loss of 25 psi. Using two pumpers, what is the pump discharge pressure for each pumper, and what is the total pump discharge pressure? Assume 10 ft per floor.

Answer: The total pump discharge pressure (engine pressure, EP) may be determined from the following:

Nozzle pressure (NP) = 50 psi

Friction loss (FL_{attack}) in the attack line:

$GPM = 210$

$FL_{attack} = 2Q^2 + Q$

$FL_{attack} = 2(2.1)^2 + 2.1$

$FL_{attack} = 11$ psi per 100 ft × 2 lengths = 22 psi

Standpipe friction loss = 25 psi

Elevation (*ELEV*):

$$60 \text{ floors} \times 10 \text{ ft/floor} = 600 \text{ ft}$$

$$ELEV = 600 \text{ ft} \times 0.434 = 260.4 \text{ psi}$$

Friction loss in supply lines (FL_{supply}):

$$FL_{supply} = 2Q^2 + Q$$

$$FL_{supply} = 2(1.05)^2 + 1.05$$

$$FL_{supply} = 3.25 \text{ psi}$$

The calculated values are inserted into the following equation:

$$EP = NP + FL_{attack} + APP + ELEV + FL_{supply}$$

$$EP = 50 \text{ psi} + 22 \text{ psi} + 25 \text{ psi} + 260 \text{ psi} + 3 \text{ psi}$$

$$EP = 360 \text{ psi}$$

Divide the total 360 psi pressure between the two pumpers (180 psi). The first pumper has a pump discharge pressure of 200 psi (180 psi + 20 psi intake). The second pumper has a pump discharge pressure of 180 psi.

Each of the apparatus performs at a good efficient work load. Neither has to work too hard or in an unsafe way. Remember, the first pumper should be connected to the hydrant using large diameter hose, if possible. Supply the second pumper with at least two lines of 2½″ hose or larger. This keeps the friction loss to a minimum, lowering the pump discharge pressure. When relay pumping for pressure, keep in mind how important it is not to overwork the equipment.

Shutting down the relay needs to be coordinated between every operator down the line. When the nozzle or one hoseline is closed, the pressures in the relay can build to dangerous levels. The pump discharge pressures should be lowered together, and the pumps disengaged together. Each line needs to be closed slowly to prevent a water hammer. A pressure surge at any point in the relay will be felt at every other point throughout the line. A water hammer can do significant damage to every connection or hoseline and pump part throughout the process.

Relay pumping is an operation that should be used with regularity. It is a time-consuming operation that uses large amounts of personnel and equipment. Everything needs to be set up efficiently and smoothly. The pump operators, company officers, and chiefs all need to understand the principles of relay operations and how they are used to combat friction loss problems. Many fire departments designate one person to be the water supply officer. This person has the responsibility of figuring all needed calculations and positioning apparatus where they are most efficient.

Communications are a very important part of the process. If possible, a separate radio channel from the fireground should be used. This allows the pump operators to talk to each other while not affecting the rest of the fireground operations. In long relays, the pump operators can communicate the needed adjustments and also coordinate the shutdown operation. Each time an adjustment is made by one apparatus, all of the others along the line need to make adjustments accordingly. By communicating on a separate radio channel, the overall fireground communications will not be affected.

Relay operations are not used or even thought of often enough. This may be because people feel that they are too difficult to calculate and set up. It may be pride in laying out a supply line and attacking the fire first that keeps firefighters from thinking about relay operations. This may result in not having enough water for complete extinguishment. With the proper training and practice, relay operations can become easier and more efficient. Whether setting up a relay for distance or to overcome back pressure, it is important to calculate carefully and set up properly. If the relay is not set up properly, there might not be enough water placed on the fire to overcome the heat energy created by the fire. Using the proper equipment and spacing keeps the operation working smoothly. It is important to keep the equipment working at safe levels while supplying the right amount of water. Overtaxing the equipment simply causes problems that can cause the relay operations to fail.

Test 5

1. List two reasons for setting up a relay.
2. When setting up a relay for distance, what is the biggest factor to overcome?
3. What is the first thing that needs to be calculated when determining if a relay is needed?
4. What pump discharge pressure should each pumper in a relay be set at, and why?
5. Name two ways to cut friction loss and increase the spacing between pumpers.
6. After nozzle and inlet pressure, what other pressure needs to be accounted for before figuring how much pressure is left to overcome friction loss?
7. A pump is rated at full capacity at what discharge pressure?
8. What is the percentage of the rated capacity of a pump when pumping at 200 psi?
9. What is the best way to overcome back pressure when pumping into high-rise buildings?
10. (T or F) A pumper in a relay can shut down any line at any time.
11. Why should a relay operation have its own designated radio channel?
12. What is the maximum distance pumpers can be spaced when supplying 600 gal to a fireground using 2½″ hoses and straight tips?
13. What would the maximum distance be if two 3″ hoselines are used to deliver the same 600 gpm stream?

14. What would the discharge pressures of two pumpers be if they are supplying a standpipe in a high-rise building where 200 ft of 2½″ hose with a 1″ straight tip is operating on the 55th floor? Assume the pumper supplying the standpipe is 100 ft from the building and is using two 2½″ hoselines, and each floor is 10 ft in height.

Test 5 Answers

1. To overcome distance
   To overcome back pressure due to elevation
2. Overcoming friction loss
3. The maximum needed fire flow
4. The pump discharge pressure should be set at 200 psi because the hose is usually tested at 250 psi. There is a safety factor of 50 psi.
5. Lay multiple hoselines.
   Lay larger diameter hoselines.
6. Elevation or head pressure
7. 150 psi
8. 70%
9. Divide the pressure between two or more pumpers.
10. False. It will create dangerous pressures along the relay.
11. So communications will not interfere with fireground operations
12. 600 ft
    $FL = 21/100$ ft
    130 psi remaining to overcome friction loss divided by 21 psi/100 ft
    $130/21 = 6$, or 600 ft

13. 1,600 ft
    $FL = 8/100$ ft
    130 /8 = 16.25, or 1,600 ft

14. Total pressure is 334 psi:
    $EP = NP + FL_{handline} + APP + ELEV + FL_{supply}$
    $EP = 50 + 22 + 25 + 234 + 3 = 334$ psi
    1st pumper = 187 psi (½ the total + 20 psi intake)
    2nd pumper = 167 psi

6

SPRINKLER AND STANDPIPE SYSTEMS

Getting to the seat of a fire can take a lot of time and equipment. Hundreds of feet of hose may need to be laid up several floors of a building or deep into a large structure. Stretching hose up a staircase requires a lot of manpower and numerous sections of hose. By the time the hose and extra equipment are put in place, the fire will have ample time to grow and overcome an entire building. Therefore, standpipes and sprinkler systems were developed, and standards were set by fire codes to assist the firefighters in handling these situations. The standards of today are designed with the goal of keeping a fire small enough for a fire department to handle or to make access to the fire easier for the firefighters. They allow firefighters to get to the fire quickly while the fire is smaller and more manageable.

Sprinkler Systems

There are several types of sprinkler systems in use around the country today. They are designed as a first line of defense for a building. At the first outbreak of fire, the sprinkler system will be activated. The type of system and the spacing of the discharge heads depend upon the type of occupancy and what is being protected. An apartment building will need a different type of system than a building storing fireworks. A room filled with computers or electrical equipment should not have a system that uses water. It will require a system that uses an inert gas like halon or carbon dioxide. The fireworks manufacturing plant might need a deluge system, whereas an airport hangar would need a foam system. The type of sprinkler system should be spelled out in the local fire code.

Types of sprinkler systems

Wet pipe systems are designed to be fast acting, with water discharging immediately after a sprinkler head is activated. The system is filled with water and kept under pressure at all times. A pump is connected to the domestic water supply and should supply enough water to at least keep a fire from advancing. The fire can activate a single head or multiple heads, depending on the size of the fire. If the system is connected to an alarm, it will be activated when the static pressure changes. Pressure changes in the domestic water supply can set off the alarm. Since there is always water in the piping, it is important to keep the pipes from freezing. Frozen pipes can cause thousands of dollars in damage when they burst.

Dry pipe systems are built the same way as a wet system, except they are filled with air and kept under pressure at all times. The air pressure keeps a clapper valve closed, preventing water from the domestic supply and pump from entering the piping. The alarm system is activated when the air pressure drops and allows water into the pipes. These systems are used in areas where the pipes cannot be protected from freezing temperatures, such as in parking garages or other outside areas.

One problem with this type of system is that the discharge of water is not immediate. Once the sprinkler head is opened, the air needs to exit the pipes, allowing water to fill the pipes and finally discharge through the head. Depending on how far away the sprinkler head that opens is from the fire pump, it could take time before water is being placed on the fire.

Another problem with dry pipe systems is the fact that there is air in the piping. Once a sprinkler head is opened by the fire, the only place for the air to escape is onto the fire. The goal is generally to remove air from the fire tetrahedron, and instead, more air is added, further fueling the fire. However, this is sometimes more practical than having the pipes burst every time the temperature drops below freezing, breaking the pipes and ultimately flooding the entire area.

One type of dry pipe system is a *preaction system*, in which the piping gets filled with water only after a fire alarm system is activated. Water is delivered to all sprinkler heads, but only the head or heads that are activated by the fire will discharge water. This allows a system to keep from freezing, but when a fire is detected, all heads become ready to fight the fire. A problem with this type of system is that if the fire alarm system malfunctions or the system loses air pressure for any reason, the piping fills with water. Once the piping is filled, it will need to be drained before the water freezes. The advantage of this type of system is that it can be installed in places where water will otherwise damage the building's contents if a head is knocked off or the piping gets damaged.

A *deluge system* delivers water to a large area all at once. The difference between a deluge system and a regular wet system is that when a fire activates the system, all of the sprinkler heads will discharge water. These systems are designed to protect high hazard areas where a fire can expand very quickly and become very dangerous. They use huge amounts of water to combat a fire that will increase very quickly.

Foam systems inject a foam concentrate into an ordinary sprinkler system. These systems are placed where hazardous materials exist. Manufacturing plants with flammable liquids are a good example. Fuel storage containers are often protected with foam systems. These systems work the same way firefighters use foam on hazardous materials when using pumpers and hoselines (see chapter 9). A new use for foam systems is to protect homes from wild fires. The system covers the entire home, protecting it from advancing fires.

Sprinkler system components

The *fire department connection* (*FDC*) consists of a single or up to several female couplings placed outside of a building (figs. 6–1 and 6–2). This allows the fire department to connect hoses and pump water directly into the sprinkler system. It is the first part of the sprinkler system that firefighters notice.

Fig. 6–1. A siamese-type FDC

Fig. 6–2. A multioutlet FDC

It is important to note if the fire department connection is for the sprinkler system or the standpipe system, or both. If the connections are for just the sprinkler system, the pump discharge pressures must be calculated accordingly. If the connections are for the standpipe system, the standpipe must be included in the calculations. If the connections are for both types of systems, the discharge calculations must be for the standpipe system. It is more important to deliver the proper amount of water to the hoselines where people are working. Firefighter safety must always take priority.

Valve types. Another component that may be found inside or outside a building is a control valve. *Control valves* are placed between the water supply line and the fire pump, and they allow water into the system. There are two main types of control valves: the outside stem and yolk (OS&Y) valve (fig. 6–3) and the post indicator valve (fig. 6–4).

The first type of control valve is the OS&Y valve. The main parts consist of a hand wheel and a threaded stem that moves in and out as the wheel is turned.

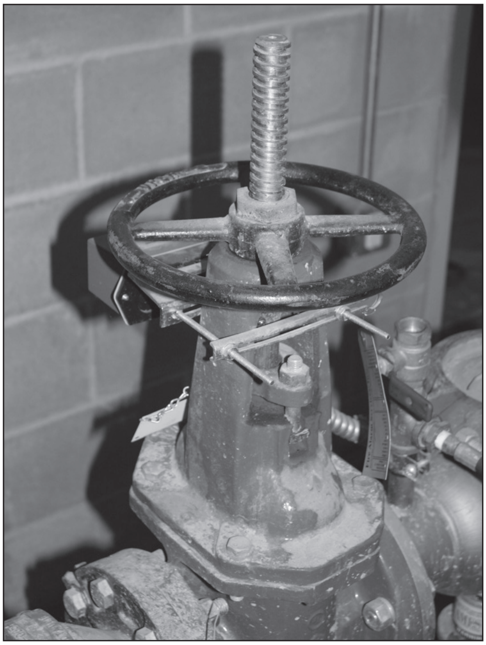

Fig. 6–3. OS&Y valve in the open position

As the wheel is turned, the stem will force the valve to open or close. An open valve is indicated by the stem extending out from the wheel. Think of a stopper that is placed at the end of the stem. As the stem is pulled out of the valve, the stopper is pulled out of the way of the water.

Another type of control valve is the post indicator valve. This type usually sits outside and looks like a hydrant without the outlets. It has a nut on top that controls the movement of the valve. Just like a hydrant, the nut moves a mechanism inside the valve that allows the water to flow.

Fig. 6–4. A post indicator valve

A window on the face of the post tells if the valve is in the OPEN or SHUT position. The choice of words on the valve is deliberate; SHUT is used instead of CLOSED, because in the dark or if the window is dirty, it would be easy to confuse the **O** in OPEN with the **O** in CLOSED. SHUT is easier to distinguish in adverse conditions.

As noted before, a problem with a dry pipe system is the amount of time it takes for the air to escape the piping, allowing the water to reach the discharge heads. To combat this problem, air exhausters are installed. When the system is activated, the exhauster is opened, and the air is forced out quickly, allowing the water to more rapidly reach the head where it is needed.

A water flow alarm needs to be installed so the fire department can be notified. These alarms can be an audible alarm that can be heard by employees or people passing by the building, or they can be part of a whole building fire alarm system. The alarm is triggered by flowing water past a sensor (fig. 6–5).

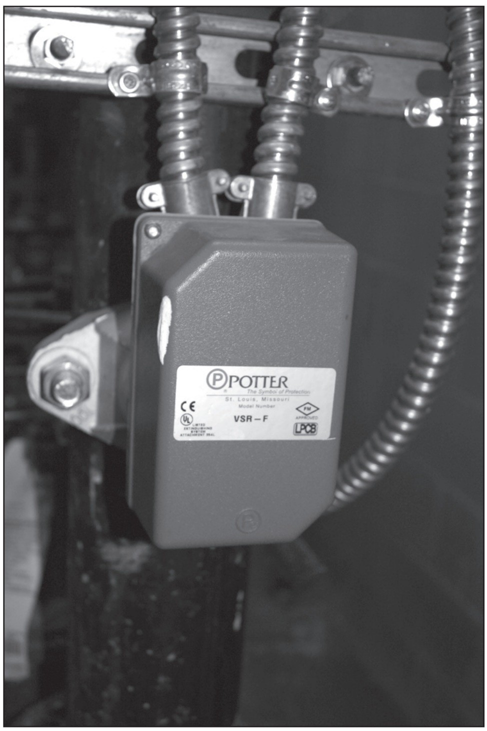

Fig. 6–5. A water flow alarm

The audible alarm may be dependent upon people to call the fire department when it is activated. When the alarm is connected to a whole building alarm system, it will usually be monitored by a private agency, or the alarm may be sent directly to the fire department.

A *retard chamber* is a device placed between the pump and the water flow alarm to minimize water surges (fig. 6–6). As water flows through a domestic distribution system, the water does not always flow smoothly. A pressure surge in the system might be recognized by the flow alarm as water moving in the sprinkler system. A chamber is designed to absorb the pressure surge for a predetermined amount of time.

Fig. 6–6. A retard chamber

If there is pressure in the retard chamber longer than a predetermined time, the alarm will be allowed to activate. This simple device greatly reduces false alarms.

Risers are the piping that carries the water throughout the building. The size of the piping depends on the distance between the pump and the heads and the total number of heads that are served on that line (fig. 6–7).

Fig. 6–7. A standard riser

Sprinkler head types. *Sprinkler heads* are the discharge outlets for the water. They are the nozzles for the sprinkler system. Sprinkler heads are devices that are activated by heat. When the temperature at the head reaches a predetermined level, the head opens up, and water will flow. The type of occupancy and what is being protected determine at what temperature the heads will be activated.

There are two common types of heads. The first type is called a *fusible link head* (figs. 6–8 and 6–9), which has two small arms placed so they block the water from flowing. Attached to the end of the arms are two fusible links. These fusible links are the key. They are connected together using temperature-sensitive solder. The solder is designed to melt at a predetermined temperature. When the solder melts, the two fusible links separate, releasing the arms and allowing the water to flow freely. As the water leaves the discharge opening, it collides with a deflector, which gives the water its shape and pattern.

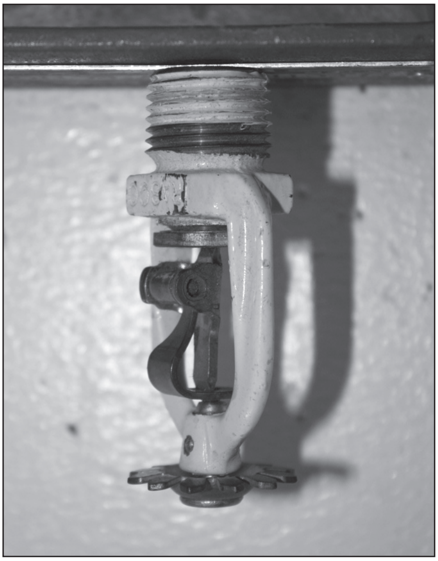

Fig. 6–8. A pendant fusible link head

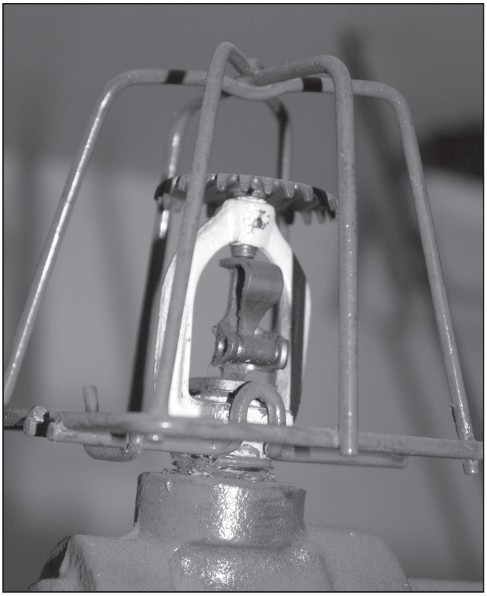

Fig. 6–9. An upright fusible link head

These heads can be placed in an upright position or hanging in a pendant position. The deflector is shaped differently for each different position. Each type is marked with initials and should not be interchanged. If they are used in place of each other, the spray pattern will be wrong.

The other common type of sprinkler head is called the *frangible bulb*. Instead of fusible links, a glass bulb is inserted in place of the arms to keep the water from flowing. The glass bulb is partially filled with a liquid and partially with air. The amount of liquid determines the temperature at which the bulb will break (fig. 6–10).

Fig. 6–10. A frangible bulb head

As the temperature of the liquid increases, it expands. When it expands enough, it will force the bulb to break, releasing the stoppers and allowing the water to flow.

Both the fusible links and the glass bulbs are color coded to indicate the temperature at which they will operate. The required temperature at which they will operate is determined by the type of occupancy and what is to be protected. Table 6–1 indicates at what temperature the head will open.

Table 6–1. Operating temperatures

Ceiling temperature (ºF)	Solder temperature (ºF)	Color
100	155–165	Bronze
150	212	White
225	286	Blue
300	360	Red

Painters have a tendency to paint right over sprinkler heads. This not only hides the color coding of the head, it can render them completely inoperable. If fire service personnel encounter this, they should make the occupant change the head immediately. It is important that when a head needs to be replaced, it is replaced with the same color and type of head, so the area that is being protected will continue to be protected at the required level.

Water supply

When supplying water to handlines or master streams, pump operators can calculate the discharge pressures based upon what nozzles are being used and ultimately the gpm flow that they are providing. In contrast, when supplying a sprinkler system, there is no way of knowing how much water is actually flowing. It is impossible to tell from the outside of a building how many heads have been activated, how much pipe is between the siamese and the activated heads, or the diameter of the piping. Without this information, there is no way to make any calculations. For this reason, it is best to place the pump into the volume position (if it is a two-stage pump) and set the discharge pressure at 150 psi. This gives the sprinkler system the largest amount of water available. Also, it is important to pump into as many inlets as the building has available. If the fire department connection has two female couplings, then it can be supplied with two 2½″ hoselines.

Whenever there is a fire in a building with a sprinkler system, the fire department must pump into the siamese in order to augment the system. It is impossible to tell from the outside if the fire pump is working normally. The pump could be broken or shut off for some reason. When pumping into the system, pump operators will bypass the pump and supply directly into the riser. The siamese is connected to the riser after the pump, so if there is a problem with the pump, the fire department can still supply the system.

On tall high-rise buildings, there may be a need for multiple fire pumps. These smaller pumps are placed on different floors of the building so one pump does not have to do all of the work. The water is pumped from one pump to the next so the top levels can maintain the proper pressure and volume of water. This insures that there is not a huge discrepancy in pressure between the various floors. If one pump is used, the pressure on the first floor could be hundreds of pounds higher than the top floor where the pressure may not be enough to fight a fire. *Note:* On some buildings, there are what appear to be additional fire department connections near the main siamese. The difference is that this set of connections has male couplings. This is not a fire department connection. This is a test connection (fig. 6–11).

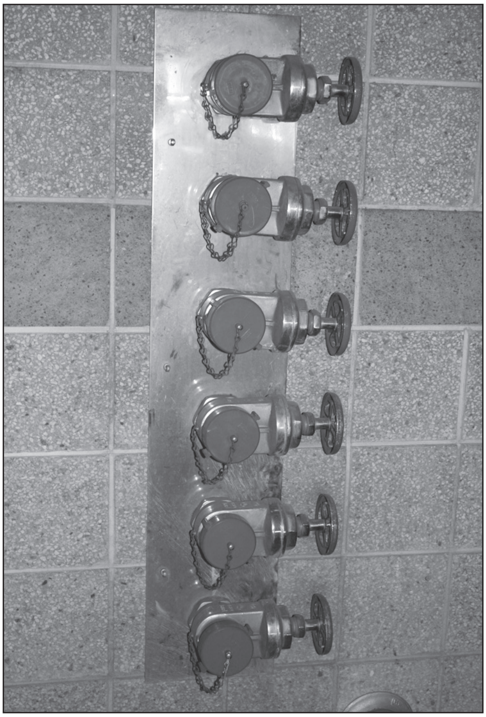

Fig. 6–11. A fire pump test connection

Periodically the fire pump needs to be tested and drained. The temptation to hook up to this connection and try to pump into the system *must be avoided*. This has disastrous results, as it will burn up the pump.

Standpipe Systems

In buildings that are too tall or too large to realistically fight a fire using the hose on the apparatus, a prepiped water system needs to be installed that will allow firefighters to hook up their hoselines closer to the fire and attack from there. High-rise buildings are the most common example. Municipal fire codes determine which buildings need standpipe systems. It is not practical to drag hose up 20 flights of stairs to fight the fire. This could take up to 1,000 ft of hose, plus whatever is needed for the attack line. This just is not practical. The pump discharge pressures would be way too high, and by the time the hose is put in place, the fire would overwhelm any firefighting efforts. The same can be said for large one- or two-story buildings. Some buildings are so large that it does not make sense to drag hose to the middle of the structure.

Classifications

A built-in standpipe system replaces the need for all this hose. There are hose connections placed throughout the buildings so firefighters can simply hook up their hoselines and attack the fire. Firefighters can attach hoses to a nearby outlet and advance from there. The National Fire Protection Agency (NFPA) has three classifications of standpipes (table 6–2 and figs. 6–12, 6–13, and 6–14):

Table 6–2. Standpipe classifications

Type	Use	Outlet size	Riser size	Water flow
Class I	By trained firefighters for use on large fires	2½″ outlet. Must be within 130 ft of any part of the floor	4″ minimum on any building less than 100 ft, 6″ minimum on buildings over 100 ft	First standpipe must flow a minimum of 500 gmp. Each additional standpipe must flow a minimum of 250 gpm. After water is flowing, there must be a minimum of 65 psi at the top outlet
Class II	By occupants	1½″ outlet. Must be within 95 ft of any part of the floor	Under 50 ft: 2″ minimum. Over 50 ft: 2½″ minimum	Flow of 100 gpm with minimum of 65 psi at the top outlet
Class III	For large and small streams	2½″ outlet and 2½″ with 1½″ reducer. Must be within 130 ft of any part of the floor	Same as class I	Same as class I

Fig. 6–12. A class I standpipe

Fig. 6–13. A class II standpipe

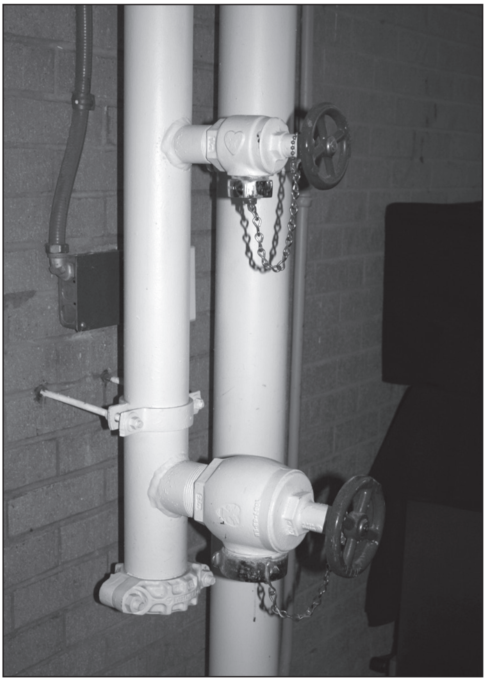

Fig. 6–14. A class III standpipe

As with sprinkler systems, there are different ways to supply the standpipe with water. Although the system may be connected to the domestic water supply, firefighters should treat the system as if they are the only water supply. This ensures that the handlines operated by firefighters are supplied with the proper amount of water.

Dry system. Systems that are subject to freezing may be completely dry. These systems may be charged with water in several ways: either manually with a control device, automatically when connected with an alarm system, or completely supplied by the fire department. If it is to be supplied by the fire department only, it may not be connected to the domestic water system.

Wet system. This system is under pressure at all times. This allows for water to quickly be delivered to the fire area. The system is connected to the domestic water distribution system or has a separate self-designated supply system, such as a gravity holding tank. In some cases, a combination supply system may be in place. A hand wheel at the outlet allows the water to flow into the hoselines.

Standpipe system components

A fire department connection (FDC) is a siamese connection with female couplings (fig. 6–15). It is placed on the outside of the building, usually facing the street.

A clapper valve is placed at each connection so water cannot flow backward out of the system. Each connection has a separate clapper valve so a single hoseline can be charged before the other one is connected.

A fire pump may be installed if the system has a sustained water supply, such as a water tank, or when it is connected to the domestic water system. A *fire pump* is a centrifugal pump large enough to deliver the required fire flow with enough pressure to reach the top outlet and maintain the required residual pressure. The pump needs to be supplied by at least two water mains when it is connected only to the domestic water supply. This allows the system to remain supplied even if one of the mains is turned off for repairs or maintenance. If only one water main is available, an elevated holding tank is required. This tank must be large enough to supply the standpipe system for a minimum of 30 minutes.

Fig. 6–15. A standpipe FDC

The *riser* is the piping that delivers the water to the various outlets through the building. The size of the risers depends on which class of standpipe system is installed in the building.

A pressure reducer may be installed inside or near the discharge opening. *Pressure reducers* are devices designed to keep the flow pressure low enough that civilians can handle the hoseline and to insure that pressures do not become too extreme for fire service use. When installed and maintained properly, they can prove useful. When installed improperly or not maintained, they can be dangerous. If they are not set at the correct discharge pressure, the flow pressure may be too low for firefighting operations. Many major fires have occurred where the reducer was set at the wrong pressure, and the firefighters, no matter how hard they tried, could not produce an adequate stream to extinguish the fire.

There are many different types of these devices. Some are adjustable, while some can simply be removed. Although this is not the medium to discuss pressure-reducing valves, it is imperative that fire service personnel inspect the standpipe systems in their jurisdiction and know how to adjust or remove these devices. They should also ensure that all the proper tools are available so if the pressure reducing valve needs to be adjusted at a fire, it can be done quickly and efficiently.

Some jurisdictions allow hose to remain connected to the standpipe system at all times. This hose is usually lightweight, unlined, and has a smooth bore tip connected. When firefighters arrive at the outlet during a working fire, they need to disconnect this hose and use their own. The house hose is to be used by civilians only. It usually is not in very good shape and cannot withstand the pressures needed for firefighting purposes. It can simply be unhooked and a fire service hose connected.

A *roof outlet* is a riser and outlet valve that extends above the roof line. It can be used for roof fires or can be used to protect exposures at nearby buildings. The difference with these outlets is that they are exposed to freezing temperatures. There should be a valve nearby that will need to be opened to allow water to reach the discharge outlet.

Tools to be carried

Most fire departments that work with standpipes carry supplemental equipment that may be necessary during a fire operation (fig. 6–16). These tools may not always be needed on every fire, but when they are needed, it is good to have them at hand. After climbing 50 flights of stairs, nobody wants to find out that they need a tool that is back with the apparatus, and they must go get it before any extinguishment can begin.

These tools include, but are not limited to, the following:

- Hose packs bundled together in a way that works best for each department. Enough hose is needed to be able to stretch to the furthest point inside the structure. This will be determined by preplanning the building.

- Various nozzle tip sizes for adjusting to various fire flow conditions.
- Spanner wrenches for removing outlet caps and tightening couplings.
- Double male and double female adapters to connect hoses.
- Pipe wrench, which works in place of valve wheels or to remove pressure reducers.
- Flow pressure gauge for knowing the pressure in the handline.
- Both 45° and 90° elbows for the outlet facing the wrong direction.
- Extra hand wheel to replace the one on the outlet that is invariably missing.
- Various wedges, sprinkler tongs, door stops, etc., which are needed at every fire.

Fig. 6–16. The tools needed for a high-rise pack

Hydraulic calculations

This goes back to chapter 2, where the entire hydraulic formula must be calculated. For standpipe operations, all portions of the formula will usually need to be used. The pump operator needs to know what hoselines and nozzles are being used. If the department adopts a standard operating procedure that states what hose and nozzle should be used, things remain simplified. For example, in Denver, we allow the first handline to be 1¾″ in size with a 15/16″ smooth bore tip. Any additional lines are 2½″ with a smooth bore stack tip of 1″, 1⅛″, and 1½″ size. From here the calculations can be figured:

1. Pick the line that will have the highest discharge pressure and figure that line.
2. Add elevation. Remember not to add the first floor.
3. Add the standpipe appliance friction loss. (In Denver, we use 25 psi.)
4. Add the friction loss in the lines between the pumper and the fire department connection. Add the total gpm flow together and divide between the number of lines connected to the building.
5. Add together to get the pump discharge pressure.

Remember that if the crews working inside the building change anything, such as add a line or change the nozzle tip, they need to communicate with the pump operator so he or she can make the proper adjustments. Most of the time, they can radio and tell the pump operator to increase or decrease the pressure. Of course, pump operators have intense pride and want to get the pressures right the first time.

Question: A fire has broken out on the seventh floor of a high-rise office building. The first crew is equipped with 150 ft of 2½″ hose with a 1″ smooth bore tip. They hook up to the sixth floor and advance to the fire floor. The second crew is using 250 ft of 2½″ hose with a 1⅛″ smooth bore tip. They connect to the fifth floor and advance to the fire floor. The apparatus is connected to a hydrant positioned 100 ft away from the fire department connection. What is the pump discharge pressure (*PDP*)?

Assume each floor level is 12 ft tall. (*Hint*: Calculate only the line with the highest discharge pressure.)

Answer: The pump discharge pressure is calculated as follows:

$$NP + FL_{attack\ line} + FL_{supply\ line} + APP + ELEV = PDP$$

$$50 + 42.05 + 13.7 + 25 + 31.25 = 162 \text{ psi}$$

where

$NP = 50$ psi (smooth bore tip);

$FL_{attack\ line} = 2Q^2 + Q$

$= 2(2.66^2) + 2.66$

$= 2 \times 7.08 + 2.66$

$= 16.82 \times 2.5$

$= 42.05$ psi;

$FL_{supply\ line} = 2Q^2 + Q$

$= 2(2.38^2) + 2.38$

$= 2(5.66) + 2.38$

$= 13.7$ psi, and then divide the gpm flow by two for two supply lines;

$APP = 25$ psi standpipe friction loss; and

$ELEV = 31.25$ psi $(6 \times 12 \times 0.434)$. Do not count the first floor.

Question: A fire has broken out in the back corner of a warehouse equipped with a standpipe system. The structure also has a sprinkler system that is supplied with the domestic water supply. The fire department connection supplies both systems. The crew takes in 200 ft of 1¾″ hose with a 200-gpm fog nozzle. They connect to the nearest standpipe outlet that is safe to connect to and attack the fire. The siamese is supplied with two lines of 2½″ hose, each 200 ft long. What is the pump discharge pressure (*PDP*)?

Answer: The pump discharge pressure is determined as follows:

$$NP + FL_{attack\ line} + FL_{supply\ line} + APP + ELEV = PDP$$

$$100 + 20 + 6 + 25 + 0 = 151 \text{ psi}$$

where

$NP = 100$ psi (fog nozzle);

$FL_{attack\ line} = 2Q^2 + Q$
$= 2 \times (2^2) + 2$
$= 2 \times 4 + 2$
$= 10 \times 2$ lengths of 100 ft hose
$= 20$ psi;

$FL_{supply\ line} = 2Q^2 + Q$
$= 2 \times (1^2) + 1$
$= 2 \times 1 \times + 1$
$= 3 \times 2$
$= 6$ psi;

$APP = 25$ psi (standpipe friction loss); and

$ELEV = 0$ psi.

This example works out perfectly. The pump discharge pressure for the standpipe system ends up being the same as what is needed for the sprinkler system. The only thing that must be remembered is to place the pump in the volume position if a two-stage pump is used.

Sprinkler and standpipe systems are another way of delivering water from a water source to the fire where it is needed. Sprinkler systems help to keep small fires from becoming large fires that are much harder to handle. Standpipe systems move the hose connections from the apparatus to an area near the fire. This saves time and effort on the part of firefighters, helping them to ultimately extinguish the fire more quickly and efficiently. The important thing to remember is to recognize which buildings have these systems and what type they are. Pump operators need to know if there are multiple fire department connections and if they service just one of the systems, or both. On a preplan of the standpipe system, it is important to check whether or not there are any pressure-reducing valves installed. The fire crew must also know how to adjust them or remove them, if possible. The time to learn about these systems is before a fire.

Test 6

1. What determines the type of sprinkler head and spacing in a building?
2. In a heated office building, what type of sprinkler system would be installed?
3. In an open parking garage, what type of sprinkler system would be installed?
4. (T or F) A dry sprinkler system contains air under pressure at all times.
5. How many heads are activated on a deluge sprinkler system?
6. What do firefighters hook their hoses to when supplying a sprinkler system?
7. Name two types of sprinkler control valves.
8. What type of valve is labeled OPEN and SHUT?
9. Name the two most common types of sprinkler heads.
10. (T or F) When a sprinkler head needs to be replaced, it should be replaced immediately with the first type available.

11. When supplying only a sprinkler system with a two-stage pump, in what position should the transfer valve be, and at what pressure should it be operated?

12. Why are standpipe systems installed?

13. (T or F) When a standpipe system is connected to the domestic water system, the fire department does not need to supply the system.

14. What part of the standpipe system should be adjusted or removed by firefighters?

15. When two handlines with two different pressures are connected to a standpipe, at what pressure should the pump be operated?

Test 6 Answers

1. The occupancy and what is being protected

2. Wet pipe

3. Dry pipe

4. True

5. All heads

6. Fire department connection (FDC)

7. OS&Y and post indicator

8. Post indicator

9. Fusible link and frangible link

10. False. Always use the same type and temperature.

11. Volume position at 150 psi

12. So firefighters do not have to drag as much hose through a large or tall building

13. False. Always pump at the required pump discharge pressure.

14. Pressure reducer

15. The highest pressure

7

TYPES OF PUMPS

Piston Pumps

The first pumps used for firefighting were very simple machines called *piston displacement pumps*. They consisted of a plunger placed inside a cylinder. The cylinder had two openings; one allowed water into the cylinder, and the other allowed water to exit the cylinder. As the plunger was pushed into the cylinder filled with water, pressure built up. If the cylinder discharge was opened, giving the water a place to go, the flow of water could be controlled, sending the water in the desired direction.

Sometimes movies set in the 1800s depict a house or barn on fire, with people pushing and pulling on the handles of a fire pump (a piston pump), and water squirting out onto the fire. Surprisingly, the development of this type of pump predates the 1800s. In fact, historians have determined that the first mechanical pump was developed around 200 BC. The pump was made of two brass cylinders fitted with tight-fitting pistons that drew water through the base and discharged it through outlet valves. Marco Polo reported people using hand-operated siphons in Cathay about AD 1300. As time passed, these piston pumps became more sophisticated and had better results. The materials became better, and the space between the piston and the cylinder became tighter.

The piston pump is a simple operation. A piston (or plunger) slides into a cylinder, tightly fitted so no water or air can slide around the side of the piston. As it slides back and forth, the cylinder volume will increase or decrease. The cylinder has two openings, an inlet and a discharge. As the piston is pulled, creating a larger space in the cylinder, a vacuum is created. A valve opens to allow water into the space. As the water fills the cylinder, a valve on the discharge opening closes so the water that just left the pump cannot flow backward into the cylinder. The piston then moves back toward the other end, the discharge valve opens, and the intake valve closes, pushing the water out through the discharge opening.

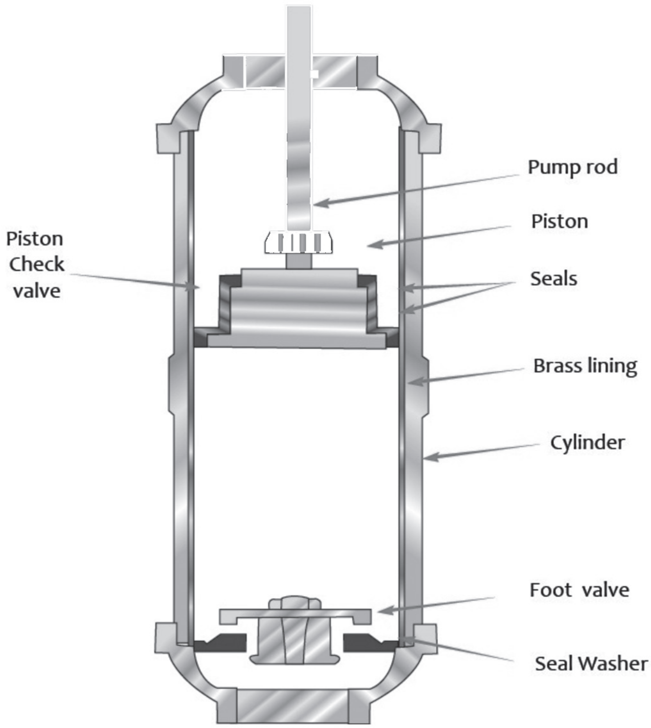

Fig. 7–1. A piston pump

The amount of water discharged from this type of pump is determined by the following:

1. The size of the piston
2. The length of the stroke
3. The number of strokes per minute
4. The number of pistons

The size of the piston and the length of stroke are based on the size of the cylinder. As discussed in chapter 1, the size of the cylinder determines the volume that can be held. If the piston is not pulled to the full length of the cylinder, the volume will be decreased. If the piston is pulled only one-half of the length, the volume will be one-half of the capacity. The faster the piston is pushed and pulled, the more water can be ultimately discharged. The internal engine works the same way. Small engines that have 1 or 2 small cylinders produce small amounts of energy, and a small amount of work gets done. Larger engines with more and bigger pistons produce more power and therefore get more work done. Just compare a lawn mower engine with 1 or 2 cylinders to a race car with 12 cylinders, capable of propelling the car faster than 200 miles per hour.

Finally, people found ways to add more than one cylinder and piston. The pump was set up so that as one cylinder was discharging, the other was filling. This can be seen in the movies where two people were on the platform. One person was pushing down on the handle while the other person was pulling up. One cylinder was filling while the other was discharging. This maneuver doubled the overall capacity of water delivered. If four cylinders are used together, the total capacity will be four times as much as if only one pump is used.

Another innovation allowed the cylinder to fill on both sides of the piston. The intake and discharge outlets were placed on both ends of the cylinder. As the piston moves to one end of the cylinder, pushing the water out, the intake valve on the other end is allowed to open, and water fills in behind the piston. As the piston moves back to where it started, the intake valve closes, and the discharge valve opens. This allows water to discharge at both ends of the stroke, doubling the volume.

One problem with this type of action is the pulsating effect on the nozzle. The cylinder can hold only a certain amount of water at a time. At the moment in time when the cylinder refills, there is not any discharge, and a void space is created between discharges. This creates pockets of air between the discharges of water. It is like bullets fired from a gun; each bullet is fired one after the other, with a space between each one. Each bullet is not connected to the one in front of it.

To combat this problem, an air chamber was placed along the discharge piping. The amount of air and water inside the chamber fluctuates during the stroke, smoothing out the pulsating. This allows water to constantly be in the discharge outlet. This concept helps but does not completely eliminate the problem of pulsating water. During the return stroke, there is not any pressure being applied to the water, permitting the pulsating effect.

Another problem with piston pumps is the amount of wear that occurs. With the constant movement of the piston and the opening and closing of the valves, the parts wear out. The piston needs to fit tightly inside the cylinder. If there is a space between the piston and the side of the cylinder, the airtight seal is lost, and a vacuum cannot be created that allows the water to be drawn into the cylinder. As the space increases, the pump will lose efficiency. Water and air can leak around the piston instead of being forced out. Consider the people on the end of the handles before motors replaced the person—the pushing and pulling would tire them out quickly. They did not need to add an inefficient pump to their problems.

Piston pumps are still used today for firefighting. They are good for high-pressure applications such as brush and wildland firefighting. Gas or electric motors replace the hand lever, allowing continuous and faster revolutions per minute. Even though piston pumps are not used as widely as they once were, they can still be effective in certain applications.

Centrifugal Pumps

Centrifugal pumps are the most common type of pump used in the fire service today. Their versatility makes them ideal for most firefighting needs. They can be used as stationary pumps in buildings or even placed in the back of pickups and used for brush fires. In high-rise buildings, they are placed several floors apart to combat pressure loss due to elevation. It works the same as relay pumping. One pump sends the water up to the next pump, where it boosts the pressure and sends it to the next pump, and so on.

The centrifugal pump is used as the main fire pump in most fire engines because they are capable of supplying the amount of water needed at a fire. They can be mounted on the front, rear, or midships on the apparatus. They are also used to supply sprinkler and standpipe systems (fig. 7–2).

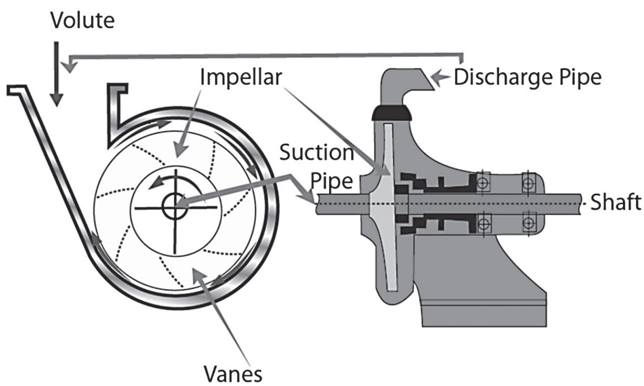

Fig. 7–2. A centrifugal pump

When water is placed at the center of a spinning disk, it will be thrown outward. This is caused by centrifugal force. As the disk spins faster, the water will move farther and faster. Three factors affect the efficiency of the centrifugal pump: pressure, speed, and quantity. They all work together. If the pressure is kept the same and the speed is increased, the quantity is increased. If the quantity is kept the same and the speed is increased, the pressure will increase. All that is needed is a way to control where the water will flow.

It is important to always keep water in a centrifugal pump when it is spinning. If the pump runs dry, it will cavitate. If the pump runs dry by not having enough intake water or trying to pump more water than what is available, the last remaining water droplets will heat up to the point that they become vapor bubbles. As these bubbles pop, they create a void space of low pressure. The surrounding area of higher pressure rushes in to fill the void. This action causes a sound much like rocks being thrown into the impellers, and it causes as much damage as rocks would. As the bubble pops, there is enough force to create small indentations in the impeller. Enough of these will cause the pump to lose efficiency. It is very important to always keep enough water in a spinning centrifugal pump to avoid this.

Parts of the centrifugal pump

The major part of any centrifugal pump is the impellers (fig. 7–3). This is what provides the velocity to the water. The impellers consist of sides called *shrouds*. They hold the water inside the impeller.

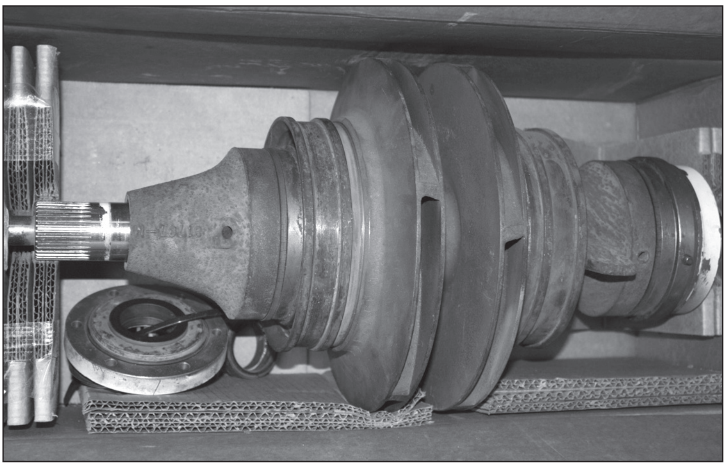

Fig. 7–3. A side view of the impellers from a centrifugal pump

The vanes pick up the water and guide it to the edge, and they are usually curved to help direct the flow. The impeller is mounted on a shaft that spins at various speeds. This shaft can be driven by the apparatus engine or a separate motor. Water enters the impeller at the eye. The impellers can be either single-suction or double-suction type, depending on how much pressure and volume are needed. A single-suction type has one eye, and the double-suction has an eye on both sides of the impeller. At the eye a wear ring (or clearance ring) is placed to prevent water from leaking back into the impeller once it has left the discharge. These rings have very tight clearances. If the pump is operated without water, it will overheat and cause the rings to expand, resulting in damage to the pump. The discharge opening is called the *volute*. Bearings provide support and alignment for the shaft so the impeller rotates smoothly. Packing is installed where the shaft passes from outside the pump to the inside, providing an airtight seal. This packing is designed to be lubricated by the water itself. It is important to operate the pump at least once a week to prevent the packing from drying out. A flinger ring is placed outside the packing and keeps water from traveling along the shaft.

Series vs. parallel

A shaft may carry more than one impeller. In fact, it may have several. Many centrifugal pumps on fire apparatus are *dual stage*, meaning they have two impellers. Dual stage pumps are more versatile than single stage pumps. A transfer valve directs the water to one impeller and then the other, or to both impellers at the same time. When the transfer valve is placed in the series (or pressure) position, the first impeller receives water and increases the pressure. The water is then sent into the next impeller, and the pressure is increased even further. The advantage of this setting is that the engine and pump work at slower revolutions per minute. This is the position needed to overcome high back pressures. If 300-gpm flow enters the first impeller, its pressure is increased, and then it is sent to the next impeller, where more pressure is added to the same 300 gpm. If the transfer valve is in the series setting, the pump will be able to pump only one-half of its rated capacity, since the water has to travel from one impeller and then on to the next impeller.

When the transfer valve is set to the parallel (or volume) position, each impeller receives water independently from the other. Water enters each impeller separately but at the same time, builds pressure, and then exits. Each impeller takes in the 300 gpm flow as before and then builds pressure, but the result is a 600-gpm stream. Each impeller is doing the same amount of work, but because they are working side by side, they can send out twice as much volume of water. This setting allows the pump to deliver its full rated capacity. The advantage of this setting is that more volume of water is provided. The disadvantage is that the engine and pump have to work harder to achieve the same pressure. The parallel setting allows the pump to flow the rated capacity of the pump. If the rated capacity of the pump is 2,000 gpm, the transfer valve needs to be in the parallel position to flow the full 2,000 gpm.

Powering the pump

In the history of using pumps to fight fires, the goal has always been to be able to power the pump more efficiently. Early efforts involved people using their muscles. In 1839, the first steam engine was used in London. This was soon followed in 1853 by the use of a horse-drawn steam engine in Cincinnati. More than 50 years later, in 1906, a gasoline-driven engine was introduced. Finally, in 1910, a gas engine was developed that could drive both the engine and pump. Today most pumps are powered by the same engine that drives the apparatus down the road. There are three ways this happens, differing by placement of the pump:

1. The pump operates from the front of the crankshaft.
2. The pump operates from the drive shaft.
3. The pump operates from a power take-off.

When the pump is operated in front of the crankshaft, a clutch is engaged, and power is given to the pump. The advantages to this type of system are as follows:

1. It is simple to operate, with simple controls, and it is easy to engage.
2. The operations are in the front of the truck.
3. It is independent of the drive shaft. This allows the apparatus to pump while moving.

The disadvantages of this system included the following:

1. The pump sits out in the open where it is unprotected and can freeze.

2. The size of the pump is limited to the space provided.

3. While moving, the pump discharge will depend upon the engine speed.

4. The clutch can slip due to the movement of the apparatus.

The midships-mounted pump is the most common type of pump drive found on structure firefighting apparatus. The pump transmission is placed between the engine and the rear wheels. When the apparatus needs to be driven down the road, the power is directed to the rear wheels via the drive shaft. When the pump needs to be activated, a switch, usually found in the cab, is moved. The power is transferred to the pump either electronically, manually, or with a vacuum. Most manufacturers place a manual lever near the pump so the power can be switched from the road to the pump when the switch in the cab fails to work. The method of transfer depends upon the manufacturer. Some use a sliding collar. The collar slides back and forth between gears, sending power to the rear wheels or to the pump. Another way to transfer power is by the use of a chain. A lubricated chain slides over to a gear that drives the pump. Either way works to direct the power from the engine to the pump.

The advantages of a midships-mounted pump are as follows:

1. The full power of the engine is available for pumping operations.

2. Larger pump sizes are available.

The disadvantages of a midships-mounted pump are the following:

1. The power is directed either to the wheels or the pump (no pump-and-roll capability).

2. More mechanical parts are needed.

3. A manual override is needed for an electrical shift operation.

Since the midships-mounted pump sits between the engine and the rear wheels, the transmission needs to be in gear. Most manufacturers require the transmission to be in the highest gear available. People are sometimes confused as to whether or not they have a midships-mounted pump because of the location of the pump panel. The pump panel can be located on the side of the apparatus, up on top, or on the rear step. Different manufacturers place the panel at various locations, but they work the same. As long as the pump is between the engine and the rear wheels, it is considered a midships-mounted pump.

Another type of pump drive is called a *power take-off* (*PTO*). The PTO unit is placed between the engine and transmission and runs at the same speed as the engine. This type of drive can be used on full-sized pumps, and a clutch mechanism is used to engage the pump. This type of drive is best suited for brush trucks where pump-and-roll capabilities are a must. When used in brush trucks, it is appropriate that the clutch be activated from both the pump panel and inside the cab. This keeps the operator in the safer confines of the truck cab.

The advantages of a PTO drive are as follows:

1. It allows pump-and-roll capabilities.
2. Larger pumps may be used.

The disadvantage of a PTO drive is that a limited amount of power may be available for some engines.

Whatever type of drive system is used on the apparatus, it is important to know how it works, as well as its capabilities and limitations. These pumps are designed to perform a specific task. It would not make sense to ask a low-gpm brush truck to work at a large warehouse fire, where thousands of gallons of water are needed. If the various types of pumps are understood, they can be used in situations where they are best suited.

Rotary Pumps

Centrifugal pumps have one large disadvantage—they cannot pump air. When air enters a centrifugal pump, it can cause the pump to stop flowing water altogether. If air enters centrifugal pump, something is needed to expel the air. This is where the rotary pump comes in. Rotary pumps are another type of positive displacement pump, which means they are self-priming and that they can expel the air. They pump out the air, leaving a vacuum that is filled by the incoming water. They create a situation where the air is pulled out of the pump, causing a lower pressure that is filled by water. This is called *priming the pump*.

There are two main types of rotary pumps: rotary gear pumps and rotary vane pumps.

Rotary gear pumps

The first type of rotary pump is a *rotary gear pump* (fig. 7–4), which looks like two gears turning together. Either one gear or both can be driven by a motor.

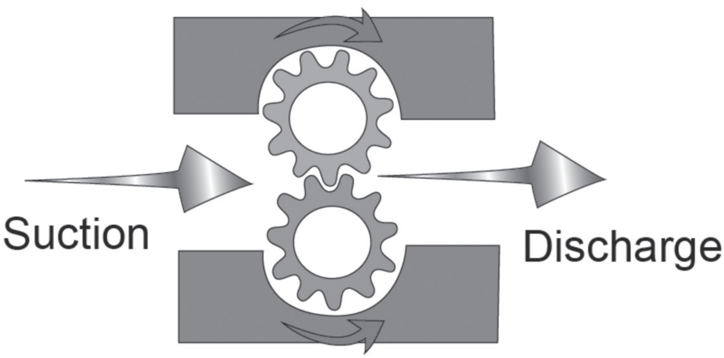

Fig. 7–4. A rotary gear pump

The amount of water that can be delivered from this type of pump is determined by the space between the gear teeth and the number of revolutions per minute.

The operation of these pumps is very simple. Water enters the intake side and is picked up between the teeth of the gears. As the teeth rotate, the water is moved to the discharge. The water or air, or both, have no place to go but out through the discharge. These pumps are ideal for high-pressure situations. The gears can rotate at very high speeds and are relatively quiet.

Rotary vane pumps

A rotary vane pump uses a single rotor that is offset inside the housing (fig. 7–5). Water or air enters the intake due to a pressure drop created by the increasing space between the vanes. As the vanes rotate, the water is moved toward the discharge opening. As the water moves toward the discharge opening, the space narrows due to the offset rotor. As the space narrows, pressure is built up, forcing the water or air out. The vanes are designed to float in the housing so they automatically move to compensate for wear problems.

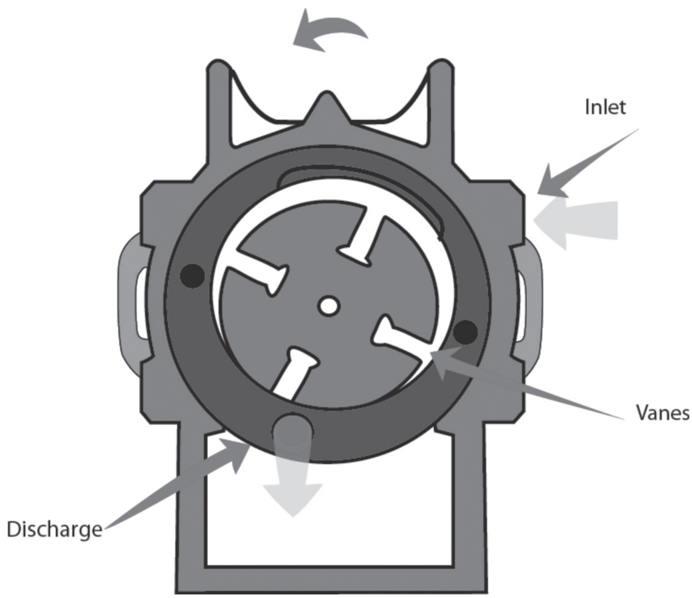

Fig. 7–5. A rotary vane pump

Rotary pumps are excellent to use in conjunction with centrifugal pumps. They can be small electric motorized units designed solely for creating a vacuum inside the bigger centrifugal pump. As a vacuum is created, water fills the void, and the centrifugal pump can operate. Since centrifugal pumps are not self-priming, rotary pumps are a necessity in fire apparatus pumping systems.

In the real world, sometimes things break or do not function as they should. If the priming pump suddenly does not work when it is needed the most, a good way to evacuate the air from the centrifugal pump is to simply let it rise out of the pump. This can be done by engaging the pump and opening the highest outlet (usually the deck gun) and a drain valve. This gives the air some place to escape. It is important to insure that there is some water ready to replace the air when the void is created.

History has shown remarkable innovations in the ability to move water for firefighting. Technology has allowed people to move water from point A to point B with relative ease. It has permitted the delivery of larger volumes of water and at higher pressures, and to do so while stationary or while moving. Each type of pump has its unique purpose. They can be used together or individually. They are designed for high-volume applications or for high-pressure needs. Whatever pump is used by the fire department, it is important for pump operators to know which type it is, and not only how it works, but why it is used for different situations.

Test 7

1. What were the first types of firefighting pumps called?
2. Describe how a piston pump works.
3. What determines the amount of discharge from a piston pump?
4. Name one problem with the way water is discharged from a piston pump.
5. Where are piston pumps used in firefighting today?
6. What is the biggest advantage to using centrifugal pumps for firefighting apparatus?
7. Name the three factors that determine how efficient a centrifugal pump will be.
8. What will happen if a centrifugal pump runs dry?

9. What does the impeller of a centrifugal pump do?
10. Where does the water enter the centrifugal pump?
11. What does the transfer valve do?
12. What is it called when the water is sent to one impeller and then on to another?
13. What is it called when the transfer valve sends water to all of the impellers at the same time?
14. Name three ways the pump is powered from the same engine that drives the apparatus.
15. Give two advantages of a midships-mounted pump.
16. What type of pump is most commonly used for priming pumps? Why?
17. Name the two types of rotary pump.
18. On a rotary gear pump, what determines how much water can be delivered?
19. What type of rotary pump is designed to float inside the housing to compensate for wear?

Test 7 Answers

1. Piston displacement pump
2. A piston fits tightly into a cylinder. It slides from one end to the other. An inlet valve allows water into the cylinder, and a discharge opening allows the water out.

3. The size of the piston
   The length of the stroke
   The number of strokes per minute
   The number of pistons
4. The pulsating effect
5. Brush and wildland firefighting
6. They supply larger amounts of water.
7. Pressure, speed, and quantity
8. The pump will cavitate.
9. Provides the velocity to the water
10. The eye
11. It directs the water to either one impeller or to two or more impellers at the same time.
12. Series or pressure
13. Parallel or volume
14. Operates from the front of the crankshaft
    Operates from the drive shaft
    Operates from a power take-off
15. The full power from the engine is available for the pump.
    Larger pump sizes are available.
16. Rotary pump; they pump air.
17. Rotary gear, rotary vane
18. The size of the space between the gears and the number of revolutions per minute
19. Rotary vane

8

THE PUMP PANEL

Every pump panel on every apparatus is designed for one purpose—to allow the operator to efficiently supply the proper amount of water to wherever it is needed. When a novice walks up to the pump panel for the first time, it can be very intimidating. There are knobs, levers, gauges, valves, lights, and who knows what else. Once that person takes time to study and understand what is displayed, however, it all becomes clear. Every knob has a purpose. Every lever and gauge does something. The easiest way to understand how the water gets from its source to the end of the hoseline is to follow it all the way through the process. The pump operator should never need to leave his or her position at the pump panel. All of the information that is needed is right there.

As the apparatus arrives at the scene, the driver positions the apparatus, sets the parking brake, and places the pump into gear according to the manufacturer. From there, everything happens at the pump panel. Other than moving hoses around, the operator should never have to leave the pump panel. After a decision is made about what hoseline is pulled and what nozzle is attached, the hydraulic calculations are figured.

The first decision that is made is about water supply. How much water is needed, and where does it come from? Most apparatus have a built-in storage tank. These tanks range anywhere in size from 200 gal up to a few thousand gallons. Most are from 250 gal to 500 gal. This amount allows for the ability to extinguish small fires or allows enough time to establish a more sustained water supply. A lever or knob on the pump panel needs to be moved to allow the water from the tank to flow into the pump via gravity (fig. 8–1).

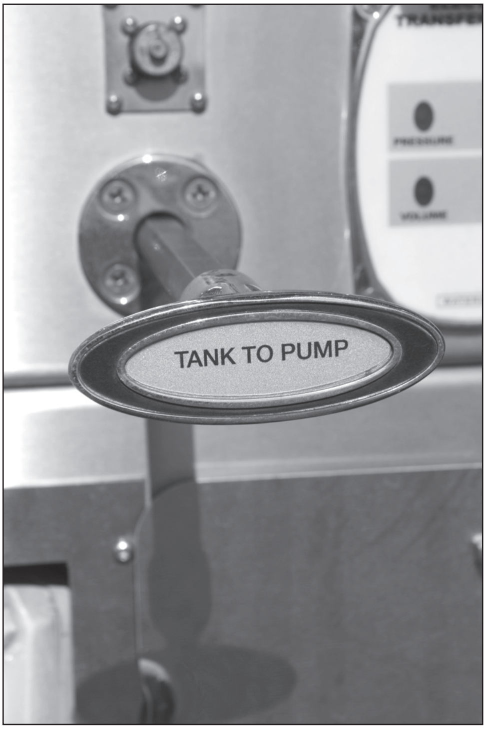

Fig. 8–1. Tank to pump valve

Remember, if the nozzle that is being used is for a 200-gpm flow, there is only enough water in the tank to last from 1 minute up to about 2½ minutes, and that does not count the water that is needed to fill the hose. Another water source will probably be needed. That water can come from a hydrant in an urban setting, or it may need to come from a static source. (Drafting operations are discussed in chapter 4.)

Intake Valves

The *intake valves* allow the water from the outside source into the pump. One valve will be for large diameter hose (fig. 8–2). It has couplings designed to fit the type of couplings that are on the hose. Obviously, the large diameter hose can carry a lot of water (see chapter 1) for larger pumping operations. Newer apparatus have butterfly valves between the coupling and the internal piping that need to be opened to allow the water into the pump. (With older models, we got our boots filled!)

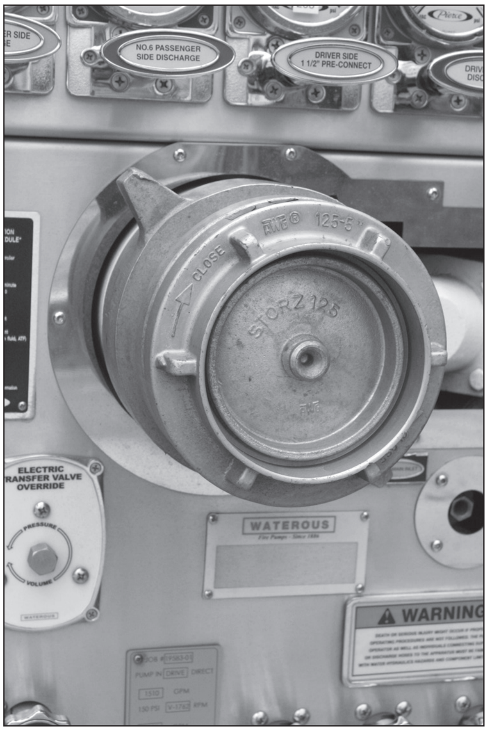

Fig. 8–2. A large-diameter intake valve

Smaller intake valves are usually equipped with 2½″ couplings. This allows medium-sized hoses to connect and supply the needed amount of water (fig. 8–3).

Fig. 8–3. An intake valve

These inlets also have a valve, usually a ball valve, that needs to be opened to allow water to reach the pump. These valves do not necessarily need to be placed at the pump panel, but it helps to have the controls at the panel. If the hoseline is charged using the tank water, and then the pump operator tries to switch to an incoming water supply, it will be necessary to account for the extra water pressure. For example, consider a hoseline that is supplied using the tank water. The pump discharge pressure is calculated to be 120 psi, and an intake valve is opened that is connected to a hydrant that supplies another 60 psi. It is important to account for that extra 60 psi of pressure, or the hoseline will be overpressured by 60 psi. This is done by opening the intake valve slowly and adjusting the pump revolutions per minute downward using the throttle to keep the discharge pressure at 120 psi. Often there are two or more of each size of valve arranged in different locations (for example, on each side of the apparatus) to allow easier connections. A lot of pump operators like to hook up the intake hoses on the opposite side to keep the hoses out of the way.

Next the water reaches the pump itself. Most of the time, the pressure needs to be increased to reach the proper pump discharge pressure. This is accomplished with the throttle (fig. 8–4). As stated in the last chapter, as the pump impellers spin faster, the pressure of the water will increase.

Fig. 8–4. Throttle control

The throttle controls are either knobs or are push-button activated. The knob controls are simple. The knob is turned counterclockwise to increase the revolutions per minute or clockwise to decrease them. The knob is also spring loaded, so in an emergency, it can be pushed in to bring the revolutions per minute all the way down quickly. It is recommended that this emergency button not be used for bringing the throttle down in ordinary situations because the spring mechanism will wear out quickly. Behind the main knob sits a smaller nut. It is designed to lock the throttle knob in place so it cannot move during long operations. Many newer apparatus have electronic throttles. These have push pads for increasing or decreasing the revolutions per minute, along with a digital readout that displays the pressure or flow rate in gallons per minute.

There are two large gauges that are noticeable on the panel. They are the main intake and discharge gauges.

Master Discharge Gauge

The discharge gauge shows the pressure on the discharge side of the pump (fig. 8–5).

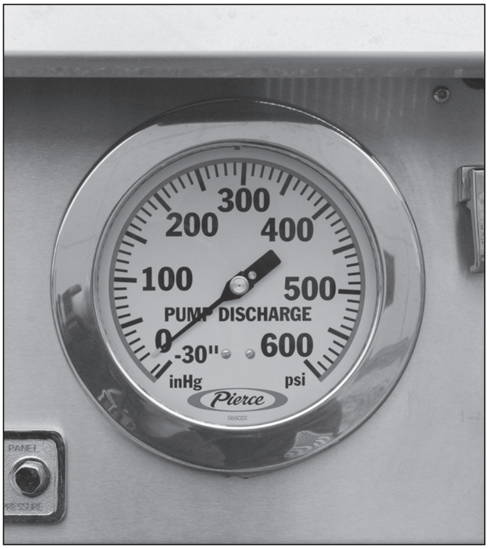

Fig. 8–5. Master discharge gauge

This will always match the pressure for the highest outlet pressure. If multiple hoselines are in use, the one with the highest pressure will be displayed here.

Intake Gauge

The intake gauge shows the pressure on the intake side of the pump (fig. 8–6). This is a compound gauge, which means it can read pressures below zero, as explained previously.

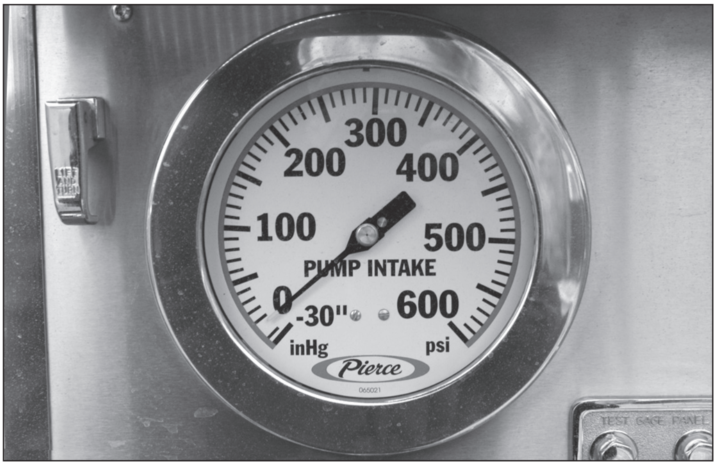

Fig. 8–6. A master intake gauge

If the water from the tank is being used, the pressure gauge will read zero. The head pressure between the tank and the pump is minimal. When drafting from a static water source, the pressure will read below zero. However, if the water coming into the pump is from a hydrant or from another pumper, it will be delivered under pressure. It is important to keep a positive pressure on this gauge to prevent cavitating the pump. If water is coming from a hydrant or another pumper and the gauge reads zero or below, it means that the pump operator is trying to pump more water out than what is coming in. A minimum of 20 psi intake pressure should be kept. This allows room for pressure fluctuations and mistakes. If the intake pressure drops below this 20 psi, it is time to add more water into the intake or decrease the amount of discharge.

The amount of pressure drop on the intake gauge will also indicate how much water is still available for adding additional hoselines. The best way to calculate how much water is available is to subtract the residual pressure from the static pressure and calculate the percentage drop. For example, if the static pressure is 60 psi and the residual pressure drops to 54 psi, the pressure drop is 10%. From there it is possible to determine how much more water can be delivered. The following are guidelines for pressure drops:

- If pressure drops 0%–10%, then three times the current gallons per minute can be flowed.
- If pressure drops 11%–15%, then two times the current gallons per minute can be flowed.
- If pressure drops 16%–20%, then one times the current gallons per minute can be flowed.

Note that it is the amount of gpm flow that is calculated. It is not the amount of hoselines. If three hoselines are flowing a total of 750 gpm, the additional water that is available should be calculated based on this.

Question: With a total of 600 gpm flowing, the static pressure is 80 psi and the residual pressure is 69 psi. How much more water can be available?

Answer: 80 psi – 69 psi = 11 psi

11 psi/80 psi = 0.1375, which is 13.75% (roughly 14%)

Thus, two times the current gpm flow of 600 will be available.

Discharge Outlets and Valves

After the water leaves the volute, it gets pushed out through any of a number of discharge outlets. These range in size from 1″ for booster lines to 1¾″ to 2½″. From these, the various hoses and appliances are attached. Connected to each individual outlet is a control valve. These are usually ball-type valves (fig. 8–7).

Fig. 8–7. Outlet discharge

They can be controlled by pull knobs or levers, or they can be controlled electronically. The outlets can be placed at many different locations around the apparatus. They are spread around to make operating the hoselines more convenient, but the controls will be at the panel. Many apparatus have outlets on each side of the pump, on the rear and front of the apparatus, and, of course, placed in the hosebeds for preconnected hoselays. These valves can be opened across a wide range, from a tiny amount up to fully open. The reason for this is to control the amount of pressure through the discharge. If multiple hoselines are operating and have different calculated pressures, the valve for the smaller pressure will not need to be opened fully.

For example, if outlet 1 has a discharge pressure of 160 psi, and outlet 2 has a discharge pressure of 120 psi, then the valve for outlet 1 will be fully open and the valve for discharge 2 will be only partially open. The exact amount will depend upon the amount of flow through the outlets. This process will be repeated for each hoseline that is pulled.

Things get a little trickier if the second hoseline has a higher pressure than the first. What happens is the first hoseline is pulled, and the pump discharge pressure is set. When the second hoseline is pulled and needs a higher pressure than the pump is producing, the valve for the second hoseline needs to be opened fully. At this point, both discharges will read the same pressure. In order to increase the pressure on the second outlet, the throttle needs to be increased. As the throttle is increasing the pressure on the second discharge, the valve on the first discharge needs to be closed slowly so that the hoseline will not be overpressurized. It is important to coordinate increasing the throttle and closing the discharge so the crew on the nozzle will not feel any change in pressure. If even more outlets are opened, this adjustment will be needed for each outlet. Sometimes it feels like a person needs 15 hands to accomplish this.

Each discharge outlet will have a pressure gauge (fig. 8–8). These will be smaller versions of the master discharge gauge. They do not need to be compound gauges since they do not need to measure pressures below zero.

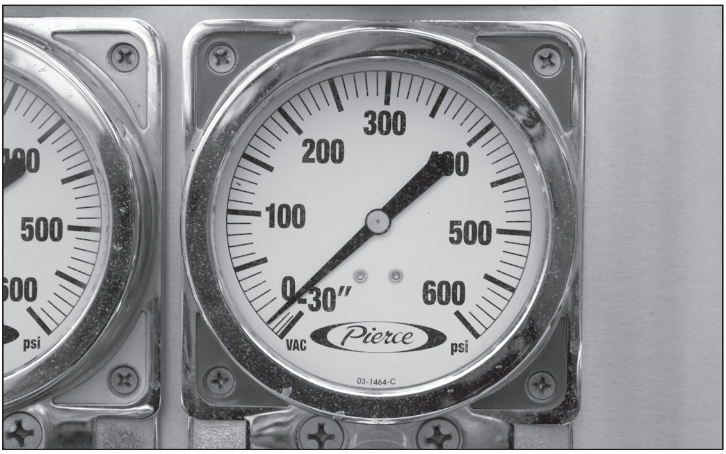

Fig. 8–8. An outlet discharge gauge

Even if the discharge outlet is remote from the panel, the valve controls and discharge gauge will be together so they can be used in conjunction with each other.

Transfer Valve

The transfer valve, as explained in chapter 7, operates a valve in a multistage pump so water is delivered either to both impellers at the same time or to one impeller and then the next (fig. 8–9). When this valve is operated by a lever, a manual pull slides the gate in one direction or the other.

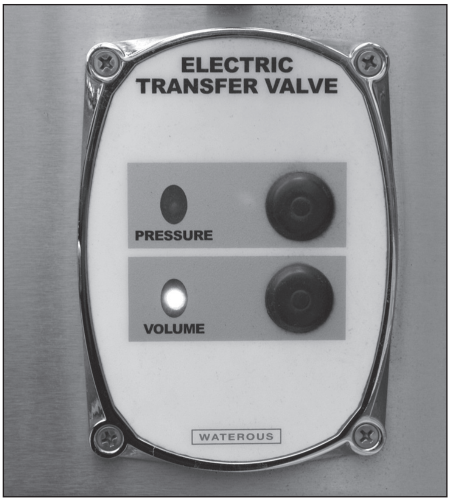

Fig. 8–9. An electronic transfer valve

The gate can also be moved electronically using a push button. Obviously, this valve needs to be fully in the series position or the parallel position. It is important to estimate how much water will be needed at the fire and switch the transfer valve to the correct position before any discharge outlet is opened. Once the pump reaches operating pressures, the transfer valve is nearly impossible to move. The throttle will need to be turned all the way down, the transfer valve activated, and then the pump discharge pressure brought back up to where it needs to be. If the pump operator correctly anticipates which position the transfer valve needs to be in ahead of time, all of this hassle will be avoided. The pump operator needs to anticipate how much water will be needed to extinguish the fire. It is recommended that if the total fire flow is above one-half of the rated capacity of the pump, the pump should be placed in the volume position.

Again, this needs to be calculated before there is any water flowing. If the pump operator thinks it might be close, it is better to switch over to volume ahead of time. A mechanic for the Denver Fire Department once asked a group of pump operators, including myself, why we did not just keep the pump in the volume position all the time, since we rarely needed to pump high pressures. The best answer we could come up with was that on the apparatus we used at the time, the lever used to transfer to the volume position would stick out too far, where it would be in the way and could possibly be damaged. In today's world of electronic valves, this is not a concern. Now the pump can be left in the volume position where it is needed most. However, it is still important to exercise the valve regularly to keep it in good working order for when a switch is necessary. A pump operator should know which setting best fits the situation at hand.

Newer apparatus also have a manual method of changing the transfer valve. This should only be used when the normal procedures for transferring the valve position fail. Usually a hand crank can be attached to a nut and rotated until the transfer valve moves from one position to the other. The pump operator should make sure the valve is completely moved from one position to the other. Again, the discharge pressure needs to be completely reduced, or it will be nearly impossible to move the handle.

Pressure Relief Valve or Pressure Governor

When more than one handline is operating at the same time, the pump builds up enough pressure to accommodate both lines. If one of the lines gets shut down suddenly, a surge of pressure is sent to the other handline. This surge of pressure can be dangerous for the people operating the handline. It is enough force to throw them around or knock them off balance, possibly injuring them. It also can burst the hose, preventing the water from being delivered to the nozzle where it is needed. This is where the pressure relief valve comes in. A pressure relief valve bypasses excess water from the discharge side of the pump back to the intake side. This prevents the pressure surges by changing the volume of water that flows through the pump.

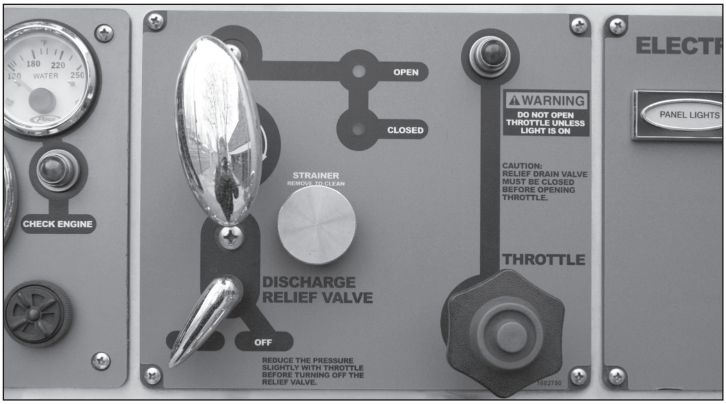

Fig. 8–10. A pressure relief control valve

There are some rules that always need to be adhered to regarding the pressure relief valve. The first is that whenever there is more than one hoseline operating, the relief valve **must** be set. This is a safety device that must be used to prevent injuries. Next, the relief valve must be used in relay operations. This prevents pressure surges from traveling down through all sections of the relay. The pressure relief valve needs to be set at the highest discharge pressure at that moment. For example, if three outlets have discharge pressures of 100 psi, 150 psi, and 200 psi, the relief valve needs to be set at 200 psi.

The simplest type of relief valve is the spring type. This type is placed on the discharge side and eliminates excess water by dumping it to the intake side. A tension spring is adjusted by turning a handle to increase or decrease the tension on a spring that is attached to a valve. The more the spring is compressed, the higher the pressure necessary to open the valve. This is a very basic pressure relief valve design. The numerous manufacturers of these valves have made them more accurate and more reliable. Most use a pilot valve that uses a small amount of water to control the relief valve. The pilot valve moves water through a strainer. This strainer needs to be pulled out and cleaned on a regular basis. If the strainer is not cleaned, the pressure relief valve will not operate properly. To learn more about the type in use on a particular apparatus, the manufacturer can be consulted for specific diagrams (fig. 8–11).

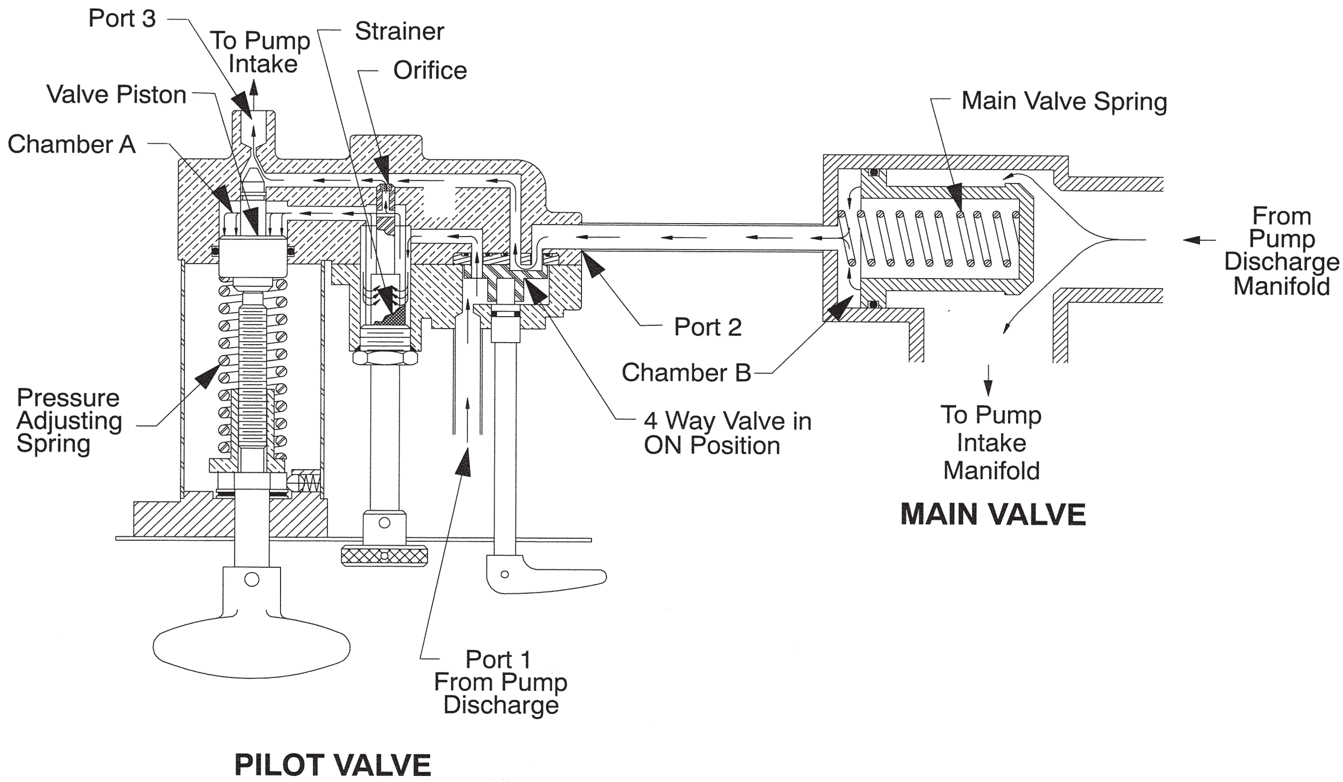

Fig. 8–11. Waterous pressure relief valve

The operations of all types of relief valves are pretty much alike. Again the relief valve needs to be set whenever two or more discharges are opened. The following procedure should be followed to place the pressure relief valve in operation:

1. Set the discharge pressures to the desired setting.
2. Turn the relief valve to the ON position.
3. Turn the knob until the relief valve pressure is higher than the highest discharge pressure. Many people leave the valve at a predetermined pressure and adjust the knob before turning the relief valve to the ON position. It takes practice to know how much to turn the knob to get close to the desired pressure.
4. Turn the knob back until the relief valve opens slightly. Move the knob the other direction slightly until the valve closes again. Some people leave the relief valve open at all times. This practice allows for tighter control of the valve, but it is not recommended because it causes more wear on the valve.

When another discharge outlet is opened that has a higher pressure than what the pressure relief valve is set at, the operator needs to adjust the setting. The first step is to bring the outlet pressure up to match the previous highest pressure. Then the throttle, pressure relief valve, and all other outlet pressures need to be adjusted at the same time. This is accomplished by increasing the pressure relief valve and the throttle slightly. Then the amount that the other discharge outlets are open is decreased by closing the discharge valve to keep those pressures where they need to be. These adjustments are continued in small increments in order to keep all pressures at a safe level. The pump operator needs to practice this often in order to be able to accomplish all of these tasks smoothly with only two hands.

Some apparatus manufacturers install pressure governors in place of pressure relief valves to compensate for pressure changes when the volumes of water flow are changed. The pressure governor accomplishes this by changing the speed of the engine to compensate for the change in pressure. The controls allow for the display to read either pressure or gallons per minute. The gpm readout is easier to figure. All that is needed is to know how much each nozzle is supposed to flow and match the readout. The problem with the gpm mode is it will increase or decrease the discharge pressure, but it will not compensate for the nozzle being opened or closed.

The pressure mode uses a pressure transducer on the discharge side of the pump to tell the engine how many revolutions per minute are needed to maintain a desired pump pressure. This allows the pump pressure to remain at a set pump pressure. This setting is needed when the nozzle keeps opening and closing.

When using a pressure governor, the operator needs to remain alert to pump cavitation. If the pump cavitates, the governor will attempt to maintain the set pressure by increasing the engine speed. The engine speed will continue to try to adjust, while the pump continues to get damaged. A pump operator must always make sure that water is entering the pump by watching the intake gauge.

Drain Valves

A drain valve is installed at each discharge outlet and each inlet valve, along with one to drain the entire pump. The discharge drain relieves the pressure on the hoseline after the fire when the hoseline needs to be drained and picked up. It makes disconnecting the couplings much easier.

Fig. 8–12. Outlet drain valves

Having a drain at the inlet valve not only relieves the pressure on the couplings, but also helps to keep air out of the pump. Before opening the inlet valve when being supplied from a water source such as from a hydrant, it is important to open the drain to allow the air to escape before entering the pump. Once water flows freely out of the drain, it should be closed, and the intake valve should be opened. This prevents the need to prime the pump.

A main pump drain is needed whenever the pump needs to be emptied of its water.

The pump needs to be drained for maintenance and inspection. The most common reason to empty the pump is to keep it from freezing (fig. 8–13).

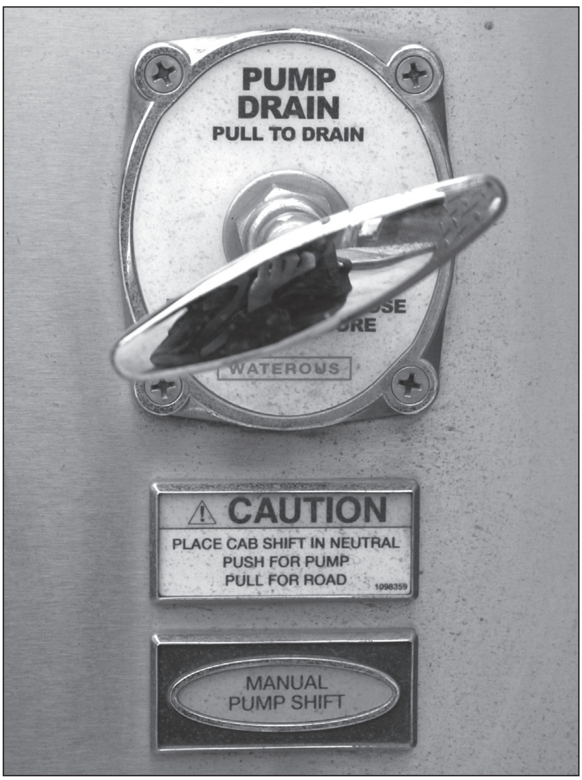

Fig. 8–13. A main pump drain

Winter's freezing temperatures can wreak havoc on centrifugal pump parts. If the impellers are frozen, it could take a long time to thaw out when it is needed most. Draining the pump provides a little preventative insurance against major problems.

Miscellaneous Knobs, Levers, and Switches

There are also other knobs, gauges, and switches on the pump panel. Although these are listed last, they are just as important as any other thing on the panel.

The first is the tank fill lever. After the water from the tank gets used, it needs to be replenished from another water source (fig. 8–14).

Fig. 8–14. A water tank fill valve

Many times water from the tank gets used first, and then a sustainable water source is found, and the tank will need to be refilled.

Although it is important to refill the tank early to have a backup water source, care must be taken to avoid using too much water to fill the tank when it is needed to fight the fire. By opening the tank fill lever too wide, too much water will be diverted, taking it away from the needed fire attack. The tank fill valve should be cracked a small amount, allowing the tank to fill slowly while the other operations continue.

Opening this valve will allow water to circulate through the pump itself. If there is not any water moving through the pump, it will overheat and cause problems. The excessive heat will cause damage to the impellers, rings, and packing. Many times this happens after the fire is out and overhaul operations are underway. If the apparatus in use does not have a circulating feature with the tank fill, a small hoseline such as the booster line can be placed in the top of the tank and the nozzle opened a small amount to keep water moving through the pump.

Along with the tank fill lever, there is a gauge that tells how full the tank is at the time (fig. 8–15). This not only tells when the tank is full, but tells how much water remains in the tank. The operator can estimate how much time is remaining until they run out of water.

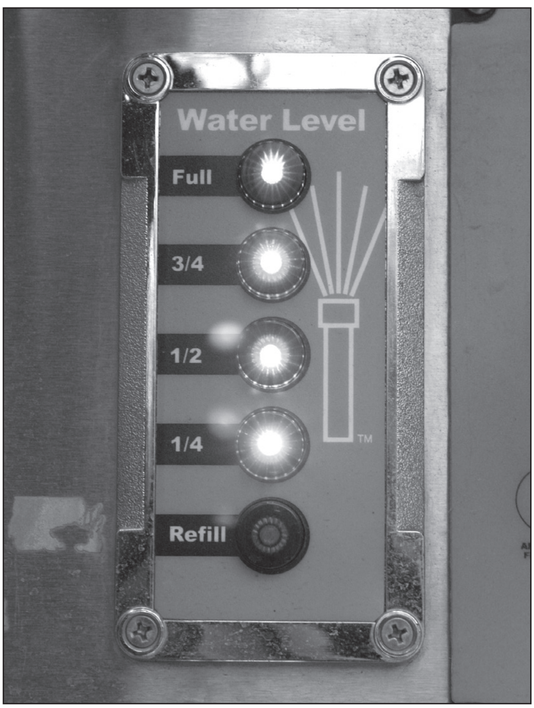

Fig. 8–15. A water tank level gauge

Newer apparatus have a way to keep the engine cool during pumping operations (fig. 8–16). This valve should be open whenever the pump is operating.

Fig. 8–16. An engine coolant valve

A water pipe runs from the pump to the engine radiator and back to keep the engine cool. A water temperature gauge shows how warm the engine is. It is important to keep an eye on the gauge to prevent overheating or running the engine too cool, both of which could damage the engine.

Because centrifugal pumps are not self-priming, a way to expel the air is needed. Thus a priming pump is used. These pumps are usually rotary vane type and run electronically. If air enters the pump, the primer pump should be operated until oily water spills onto the ground. This should be enough to expel the air and prime the pump. More on priming is discussed in chapter 4 concerning drafting operations.

A set of gauges are provided to display the health of the engine (fig. 8–17).

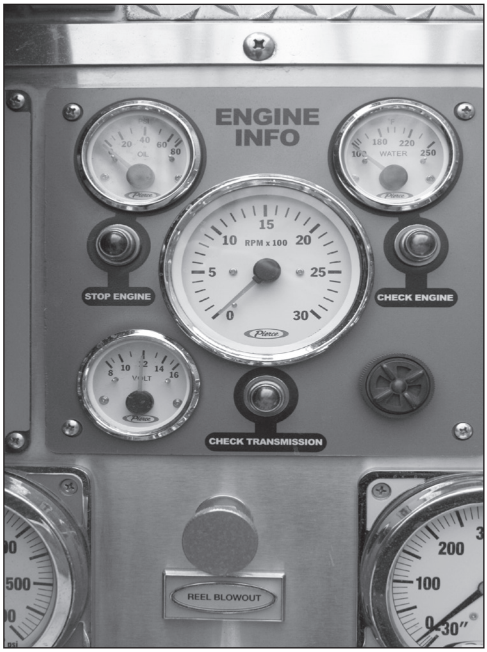

Fig. 8–17. Engine information gauges

The first is the water temperature gauge. The manufacturer sets what the temperature should be (usually near 180°F). As noted, the operator should watch the gauge to make sure that the temperature does not get too hot or cold. This can cause very costly problems. If the temperature is too cool, the fuel may not burn adequately, and the engine may not provide full power. If the temperature is too hot, the oil may be too thin to adequately lubricate the engine. The next gauge shows the oil pressure in the engine. Again, the oil pressure needs to stay within the normal range, otherwise the engine could possibly seize. This gauge should also read the same as the one in the cab.

The rpm gauge shows how fast the engine is running. Once pumping operations are underway, the revolutions per minute should be noted. If the engine speed should suddenly increase or decrease for no apparent reason, a problem may be arising. It could be that the pump is cavitating, or there could be an engine problem. Whatever the problem, a solution needs to be found quickly in order to prevent bigger problems from occurring.

The voltmeter indicates the health of the electrical system. The most common indication of a problem is when the voltmeter shows less than the proper charge. This means the alternator is not charging the batteries properly. This may be caused by a bad alternator or from loose or broken belts connected to the alternator.

All of these gauges need close attention. During daily apparatus checks and training, the pump operator should make note of how these gauges should read. This offers a good baseline of their normal ranges. If they show any abnormal readings, corrections should be made immediately or the mechanic contacted to fix the problem. Newer apparatus have buzzers and indicator lights to warn against problems. Pump operators should know what the gauges are for and what their normal readings should be in order to prevent experiencing problems when they really cannot afford them.

The pump operator can control all pump operations from one position. While standing at the pump panel, the operator can know what is happening from the hydrant all the way to the fire. The operator should be able to tell if water is being placed on the fire or if there is a problem. The pump operator knows when water is flowing or if there is a burst hoseline. All of the information that is needed is right there at the pump panel.

Test 8

1. Upon arriving at a fire, what does the driver need to do inside the cab?
2. What does the intake valve do?
3. How does the pump operator control the extra inlet pressure that comes from a hydrant?
4. What does the throttle do?

5. What will happen if the intake gauge reads zero when working from a hydrant?
6. When working from a hydrant, what should the minimum intake pressure reading be?
7. If the pressure difference between static and residual is 6%, how much more water can be delivered?
8. If the pressure difference between static and residual is 13%, how much more water can be delivered?
9. If the pressure difference between static and residual is 17%, how much more water can be delivered?
10. If outlet 1 has a pressure of 200 psi, how can the pump operator open outlet 2 to only 150 psi?
11. Do outlet gauges need to be compound gauges?
12. (T or F) The throttle needs to be turned all the way down in order to switch the transfer valve between pressure and volume.
13. What is the purpose of the pressure relief valve?
14. What is the first rule regarding the use of the pressure relief valve?
15. When multiple discharge pressures are in use, what should the pressure relief valve be set at?
16. How does a pressure governor work?
17. When using a pressure governor, what will be the first indication that the pump is cavitating?
18. How does the engine cooling valve operate?
19. What gauges on the pump panel show the health of the engine?
20. (T or F) The gauges on the pump panel should read the same as the ones inside the cab.

Test 8 Answers

1. Set the parking brake and place the apparatus in pump gear.
2. Allows water from an outside source into the pump
3. The pump operator opens the inlet valve slowly and decreases the revolutions per minute at the same time.
4. Increases or decreases the revolutions per minute
5. The pump will cavitate.
6. 20 psi
7. Three times the current gpm flow
8. Two times the current gpm flow
9. One times the current gpm flow
10. The second valve is not opened fully.
11. No. They only read positive pressures.
12. True
13. Prevents pressure surges from reaching hoselines
14. When more than one hoseline is operating, the pressure relief valve will **always** be used.
15. The highest pressure
16. It changes the speed of the engine to compensate for pressure changes.
17. The engine speeds up.
18. It runs water from the pump around the radiator and back.
19. Temperature, oil pressure, revolutions per minute, and voltmeter
20. True

9

FOAM

Firefighting foam was developed during the 20th century as a way to fight flammable liquid fires. Today the need for foam can be found everywhere. Industrial plants have large quantities of fuels and chemicals stored on their properties. Tanker trucks and railcars transport thousands of gallons of these flammable liquids every day. Cars and trucks need these fuels for transporting people and goods. Even lawn equipment carries small amounts. These flammable liquids are very common, and when they catch on fire, it is important to be able to extinguish them.

Because most flammable liquids have a density less than that of water, they float on water. Firefighting foams are made to float on top of these flammable liquids. They are not only useful to extinguish a flammable liquid fire, but also to prevent the fire from ever starting in the first place. A blanket of foam can spread across the flammable liquid, preventing the vapors from burning.

The Foam Tetrahedron

Figure 9–1 shows the four sides of the foam tetrahedron, which is needed to make finished foam.

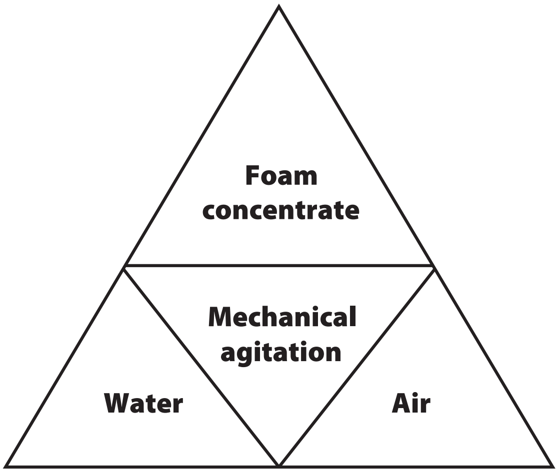

Fig. 9–1. The foam tetrahedron

Finished foam is a combination of the foam concentrate, water, and air. When these components are mixed together in the right proportions, the finished foam is produced. If the mixture is not in the right proportion, the vapors will be able to escape where they can continue to burn.

How Foam Works

Firefighting foam is a mass of air-filled bubbles with a lower density than flammable liquids. It is a blanketing and cooling agent that is produced by mixing air into a foam solution that contains a foam concentrate and water (fig. 9–2). Foam extinguishes flammable or combustible liquid fires in four ways:

1. Excludes air from the flammable vapors, preventing a flammable mixture.

2. Does not allow the fuel to release vapors from its surface. The foam holds the vapors in place, preventing them from reaching ignition sources.

3. Separates the flames from the fuel surface, stopping the burning process.

4. Cools the fuel surface and the surrounding areas. The foam brings the temperature down to where there is not enough vapor production to support the burning process.

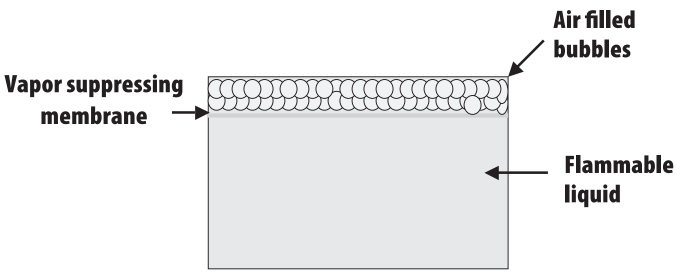

Fig. 9–2. A foam blanket

When Can Foam Be Used Effectively?

Firefighting foams are effective on Class B fires by suppressing their vapors. *Class B fires* are defined as fires involving flammable or combustible liquids. These liquids can be further divided into two categories: hydrocarbons and polar solvents.

Hydrocarbons are by-products of crude oil or have been extracted from vegetable fiber, and they are defined as having a specific gravity of less than 1.0. Water has a specific gravity of 1.0, and therefore hydrocarbons float on water. This can be seen when an oil spill occurs in the ocean. The oil floats on the water, where it washes ashore and coats animals and birds. Water will sink to the bottom of a container of fuel. This will force the level of fuel in the container to rise and spill out, creating a fire that can travel. If water is simply sprayed onto a burning fuel reservoir, the water will sink to the bottom of the container. This forces the fuel to the top and over the sides, resulting in a traveling liquid fuel fire.

Examples of hydrocarbon fuels include the following:

- Gasoline
- Diesel
- Heptane
- Kerosene
- Jet fuel (JP4)

Polar solvents are products that have been synthetically produced and are not found in nature. These products are used in dry cleaning products, paint thinners, nail polish removers, glue solvents, and even in perfumes. Polar solvents create problems because they mix with water. In addition, they are usually destructive to foams designed for use on hydrocarbons. Because these polar solvents break down ordinary foams, different types of foams were developed.

Examples of polar solvents include the following:

- Alcohol, including ethyl alcohol (ethanol)
- Methyl tertiary-butyl ether (MTBE)
- Acetone
- Ethanol
- Paint thinners

When Is Foam Not Effective?

Foam is not effective on energized electrical equipment. Since foam contains mostly water, it will conduct electricity. Electrical fires (Class C) are best extinguished using dry chemical agents, carbon dioxide, or halon. If the equipment is deenergized, then it is safe to use foam.

Foam is not effective on three-dimensional fires. A three-dimensional fire is a liquid fuel fire that is being discharged from an elevated position or is under pressure. A fuel that is spilling over the sides of a tank or a ruptured pressurized propane tank is a three-dimensional fire. It is best to control the flow of liquid and then use foam on the spill.

Foam is not effective on pressurized gases. Even though many gases when stored under pressure are liquids, they will return to a gas state when the pressure is released. The foam will not cover the gas under pressure. It is best to cool the tank and let the gas burn until the flow of gas can be controlled.

Examples of pressurized gases include the following:

- Propane
- Butane
- Acetylene
- Nitrogen
- Argon

Foam is not effective on combustible metals. Class D fires involve combustible metals such as aluminum, magnesium, sodium, and potassium. Since these metals react with water, foam will make these fires worse. A Class D powder is best used for these types of combustible metal fires.

Types of Foam

Protein foam

Protein foams were the first types of mechanical foam to be marketed extensively and have been in use since World War II. These foams are made by the hydrolysis of granulized animal protein, such as hooves and horns, as well as feathers and beaks. Additives need to be injected to prevent corrosion, resist bacteria, and control viscosity.

Regular protein foams are intended for use on hydrocarbon fuels only. They produce an even, stable foam blanket that has excellent heat resistance, burn back, and drainage characteristics. A drawback of these foams is their slow knockdown ability. However, they have excellent postfire security. They work in temperatures that range from 20°F up to 100°F. Protein foams may be used with either fresh or salt water. These foams must be adequately aspirated and should not be used with nonaspirating nozzles.

Fluoroprotein foam

Fluoroprotein foams have fluorochemical additives that create a lower surface tension and allow the foam to flow more freely. They are for use on hydrocarbon fuels and a few oxygenated fuel additives. They have excellent heat resistance, burn back, and postfire security. They can be used with both fresh and sea water. Since these foams are made by adding fluorochemical surfactants to protein foam, they have many of the same characteristics, but with improved fluidity, which allows for greater knockdown ability.

Film-forming fluoroprotein foam (FFFP)

FFFP foam is the same as fluoroprotein foam but with added chemical surfactants. These additives create a thin film on the surface of the fuel, which suppresses the fuel vapors. These foams have the same characteristics of fluoroprotein foam with an increase in knockdown ability. One advantage of FFFP is that it is excellent for subsurface injection. It will move to the top, creating an aqueous film on top of the fuel.

Aqueous film-forming foam (AFFF)

AFFF is a synthetic foaming agent with fluorochemical surfactants added. It is designed for rapid knockdown with good heat resistance and long-term stability. The fluidity of these agents allows them to quickly flow around objects such as wreckage and debris. Most AFFFs are premixable, dry chemical compatible, and can be used with either fresh or salt water. Although AFFFs can be used with nonaspirating nozzles, for best results, air-aspirating nozzles should be used. AFFFs first work by spreading a strong foam blanket over the fuel, smothering the fire. AFFFs also extinguish fires by forming a vapor barrier layer over the top of the fuel. This barrier will suppress any vapors and separate the burning material from the fuel. The water in the solution will cool the surrounding area, preventing any reigniting of the fuel.

Alcohol-resistant aqueous film-forming foam (AR-AFFF)

AR-AFFF is a combination of foaming agents, synthetic stabilizers, fluorochemicals, and synthetic polymers designed for use on polar solvents. Polar solvents break down regular AFFF. The added synthetic polymers form a strong membrane that separates the foam from the fuel. Most concentrates are designed for use on hydrocarbons at 3% solution and at 6% for polar solvents. That is, a mixture of 3% foam solution and 97% water is used for hydrocarbons, and 6% foam solution and 94% water is used for polar solvents. The pump operator needs to know what type of fuel is burning or needs to be covered in order to set the proportioning device properly. AR-AFFF is the most versatile foam on the market today. Since it covers both polar solvents as well as hydrocarbons, it is the only type of foam carried by many fire departments.

Synthetic detergent foam

Synthetic detergent foams work on both Class A and Class B fires. These foams are designed for use on warehouses or other enclosed spaces, such as airport hangars. The entire area is flooded, providing a cooling, as well as smothering, effect. Small amounts of foam concentrate are highly aerated and pumped into the area. Huge amounts of finished foam can fill the area in a very short time. The finished foam creates a barrier between the fuel and the fire, as well as cooling the area with the water. When used as a Class A foam, the agent is used as a wetting agent. The foam concentrate lowers the surface tension of the water, allowing it to soak into the burning material. This is good for deep-seated fires such as baled materials.

Whatever type of foam is used, it is vital to know its designed use. Firefighters should know what its best use is, along with its limitations. Table 9–1 lists the different types of foam and how their properties rate.

Table 9–1. Different types of foam

Property	Protein	Fluoroprotein	FFFP	AFFF	AR-AFFF
Knockdown	2	3	3	4	4
Heat resistance	4	4	3	2	3
Fuel resistance	2	4	3	3	3
Vapor suppression	4	4	3	3	3
Alcohol resistance	0	0	0	0	4

4 = Excellent
3 = Good
2 = Above average
1 = Below average
0 = None

Foam Proportioning Devices

Finished foam is a combination of foam concentrate, water, and air. The effectiveness of foam depends on proper proportioning and the ability to deliver the finished foam to where it is needed. There are a number of ways to proportion the foam. These include the following:

- Inline eductors
- Balanced pressure systems
- Around-the-pump systems
- Foam nozzles

Inline eductors are the most common type of proportioner (fig. 9–3). These devices can be placed anywhere in the hoselay. They can be attached anywhere from the pump panel to near the nozzle. The placement of the eductor depends upon the length of the hoseline and where it is easy and safe to use.

Fig. 9–3. An inline foam eductor

Eductors work on the venturi principle. Water is introduced at the inlet of the eductor. The eductor narrows, forcing the water to speed up. This creates a vacuum effect, which in turns creates suction on the pickup tube. As the foam concentrate is pulled up the tube, it passes through a metering valve that allows the proper amount of concentrate to be mixed with the water stream. The metering valve needs to be set to the proper percentage depending on type of fuel covered (1%, 3%, or 6% solution).

Eductors have some rules that need to be followed:

1. **Eductors have a set gpm flow rating.** Typically, these flows range from 60 to 250 gpm. The gpm rating for the eductor must match the gpm rating of the nozzle. Flow rates that differ will result in poor-quality finished foam. The solution may be weak or the concentrate might not get picked up at all.

2. **Eductors require adequate inlet pressure.** A pressure loss between the inlet and discharge sides of the eductor can be excessive. To counter this loss, the inlet pressure needs to be relatively high. Most manufacturers recommend inlet pressures **at the eductor** of between 180 psi and 200 psi. Lower inlet pressures will create poor finished foam. It may not be adequate to control a fire or spill.

3. **Eductors do not like back pressure.** Too much back pressure can shut down the concentrate pick up. It is important to follow these rules:

- The nozzle must be fully opened or fully closed.
- There must not be any kinks in the hose between the eductor and nozzle.
- The nozzle should not be elevated higher than the eductor.
- Do not exceed the manufacturer's recommended length of hoselay. If the hoselay is too long, place the eductor in the middle of the line between the pump panel and the nozzle.

4. **Keep the eductor clean.** The eductor must be flushed completely after each use.

   Foam that dries inside the eductor will harden and block the pick up.

As noted before, the eductor must have a set inlet pressure. When determining pump discharge pressures, the eductor inlet pressure should be treated as the nozzle pressure. For example, if the inlet pressure needs to be 200 psi, the calculations start with that figure, working backwards toward the pump.

Example: The eductor is 100 ft away from the pump. Between the pump and the eductor is 100 ft of 2½″ hose. After the eductor is 200 ft of 1¾″ hose, with a 125 gpm fog nozzle (fig. 9–4).

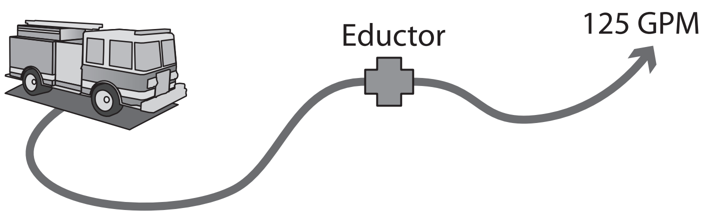

Fig. 9–4. Using an eductor to mix foam

All that needs to be figured is the inlet pressure plus the friction loss in the 2½″ hose:

$$200\ psi + 4.37(2Q^2 + Q) = 204.37\ psi$$

Many people when trying to figure a foam problem want to add the friction loss and nozzle pressure after the eductor. This creates a pressure that is too high for the eductor. Remember, it is the pressure at the inlet that is most important.

Balanced pressure systems are very versatile and extremely accurate. Most of these systems are found on fixed systems and mobile equipment. Large fuel tanks and chemical plants use these because they deliver large amounts of foam at an accurate rate. The principle of operation is based on a modified venturi proportioner called a *ratio controller*. This controller causes a reduction in pressure, which in turn causes the foam to flow through a metering device. The advantage of this type of system is that as the water pressure increases or decreases, the amount of foam concentrate will adjust to keep the proper amount of proportioning.

Around-the-pump systems use an eductor on the discharge side of the pump. The same venturi principle is used as the inline educator, with several advantages:

- **Variable flow rate.** The discharge rate can be adjusted to meet the specific application.
- **Variable pressure.** The system will operate at any pressure above 125 psi.
- **No back pressure restrictions.** The unit is not affected by back pressure like the inline eductor.
- **No nozzle restrictions.** The unit operates with any type or size of nozzle.

Around-the-pump systems have their own restrictions:

- A minimum pressure of 10 psi is needed at the pump inlet to prevent the system from shutting down caused by back pressure.
- It is not possible to flow both water and foam at the same time.
- The pump operator must continually monitor the proportioning valve to correspond with the gpm flow.
- Clean-up can be more difficult since all discharges need to be flushed, even if they were not opened.

Foam nozzles

For the foam to be most effective, the solution needs to be air aspirated. Foam nozzles are specifically designed to expand the foam solution at the nozzle. There are two types of foam nozzles:

1. *Foam-aspirating nozzles* use the venturi principle and have the pickup tube connected to the nozzle. These nozzles are used on monitors for large master streams. The advantages of foam-aspirating nozzles are the following:

- They deliver large amounts of finished foam.
- They are easy to operate.
- They are easy to clean.
- There are no moving parts.
- There is no additional foam equipment needed.

2. *Air-aspirating nozzles* are foam-generating nozzles that pull in air to mix with the foam solution. These nozzles produce an expansion ratio of between 8:1 and 10:1, producing good quality, low-expansion foam. Regular fog nozzles will agitate the foam to expand the foam, but for best results, a good air-aspirating nozzle works much better. The final result is a better-expanded, more consistent foam blanket.

Whatever type of foam and equipment a fire department uses, it is important to know how and when it should be used. If necessary, the manufacturer can be consulted on the best proportioning ratios and the limitations associated with their foam. Fire personnel should know how the equipment works best and train with it, as well as find application techniques that work.

Test 9

1. Do flammable liquids have a density less or greater than water?
2. What mixture makes finished foam?
3. List four ways that foam extinguishes flammable liquid fires.
4. List three hydrocarbon fuels.
5. Define polar solvents.
6. List at least three polar solvents.
7. Can foam be used on energized electrical equipment?
8. (T or F) Foam clings to the sides of storage tanks, making it ideal for use with three-dimensional fires.
9. List the seven types of foam.
10. What percentage AFFF is best suited for hydrocarbon fuels?
11. What percentage AFFF is best suited for polar solvent fuels?
12. List four foam-proportioning devices.
13. (T or F) Inline eductors must match their flow rates with the nozzle being used.
14. Which type of proportioning device can have an inlet pressure as low as 10 psi?

Test 9 Answers

1. Less
2. Foam concentrate, water, air
3. Four ways foam extinguishes flammable liquid fires:
    - It excludes air from the flammable vapors, preventing a flammable mixture.
    - It does not allow the fuel to release vapors from its surface. The foam holds the vapors in place, preventing them from reaching ignition sources.
    - It separates the flames from the fuel surface, stopping the burning process.
    - It cools the fuel surface and the surrounding areas. It also brings the temperature down to where there is not enough vapor production to support the burning process.
4. Gasoline, diesel, heptane, kerosene, and jet fuel
5. Products that have been synthetically produced and mix with water
6. Alcohol, MTBE, acetone, ethanol, and paint thinner
7. No
8. False
9. Protein
Fluoroprotein
Film-forming fluoroprotein
Aqueous film-forming (AFFF)
Alcohol-resistant AFFF
Synthetic detergent
10. 3%

11. 6%

12. Inline eductors
    Balanced pressure system
    Around-the-pump system
    Foam nozzle

13. True

14. Around-the-pump system

APPENDIX

The following is a series of problems designed to test your overall knowledge of hydraulics. Each problem will need to be solved using the appropriate formula. If there is more than one formula available to solve the problem, the question will indicate which formula should be used. Round each calculation to the nearest hundredths (i.e., two places to the right of the decimal).

Each problem needs to contain answers for the following:

PDP = Pump discharge pressure
OP = Outlet pressure
NP = Nozzle pressure
FL = Friction loss (There may be more than one.)
APP = Appliance friction loss (There may be more than one.)
ELEV = Elevation
GPM = Total flow
NR = Nozzle reaction (For fog nozzles, use zero.)
SP = Static pressure
FP = Flow pressure
RP = Residual pressure
RGPM = Remaining gpm flow available after all lines are flowing

Problem Set

1. Upon arrival at a single-story house fire, the officer decides to pull 200 ft of 1¾″ hose with a 7/8″ straight tip. This line is connected to outlet 1. The line is pulled through the front door into the kitchen. Another crew arrives and pulls another 1¾″ line 200 ft long with a 200-gpm fog nozzle to back up the first crew. This line is connected to outlet 2. Your static pressure from the hydrant is 70 psi. Your residual pressure is 65 psi. Use the Underwriters formula for friction loss.
   PDP =
   OP =
   NP =
   FL =
   APP =
   ELEV =
   GPM =
   NR =
   SP =
   FP =
   RP =
   RGPM =

2. A large semi-trailer has caught on fire. After securing a hydrant and spotting the apparatus, the first line pulled is connected to outlet 3. This line consists of 300 ft of 1¾″ hose with a 200-gpm fog nozzle. A backup line gets charged from outlet 4 and consists of 300 ft of 2½″ hose with a 1¼″ straight tip. Your static pressure is 82 psi, and your residual pressure is 70 psi. Use the Underwriters friction loss formula.
   PDP =
   OP =
   NP =
   FL =
   APP =
   ELEV =
   GPM =

NR =
SP =
FP =
RP =
RGPM =

3. You are called to a weed fire. After securing a hydrant and spotting your apparatus, a 1¾″ hoseline 100 ft long with a 95-gpm fog nozzle is connected to outlet 1 and stretched west up a 30-ft hill. A second 1¾″ hoseline 200 ft long with a 15⁄16″ tip is connected to outlet 2 and pulled east down a 30-ft hill. The static pressure reads 66 psi, and the residual pressure reads 60 psi. Use the coefficient friction loss formula.
   PDP =
   OP =
   NP =
   FL =
   APP =
   ELEV =
   GPM =
   NR =
   SP =
   FP =
   RP =
   RGPM =

4. A bedroom fire has broken out on the second floor of a two-story house. You immediately lay out from a hydrant to the front of the house. The first line that is pulled is connected to outlet 5 and consists of 200 ft of 2½″ hose with a 1″ straight tip. The second line that is pulled is connected to outlet 6 and is 200 ft of 2½″ hose with a 1¼″ straight tip. A third line is connected to outlet 1 and is 150 ft of 1¾″ hose with a 200-gpm fog nozzle. It is stretched around the side of the house and is protecting an exposure from the ground. The static pressure is 77 psi. The residual pressure is 60 psi. Use the coefficient friction loss formula.
   PDP =
   OP =
   NP =

FL =
APP =
ELEV =
GPM =
NR =
SP =
FP =
RP =
RGPM =

5. At a lumber yard fire, you connect to the nearest hydrant with two 3″ supply lines, each 50 ft long. From both outlets 1 and 2, there are 200 ft of 2½″ hose connected to a multiversal with a 1½″ tip. Your static pressure is 60 psi, and the residual pressure is 40 psi. Use the Underwriters friction loss formula.
   PDP =
   OP =
   NP =
   FL =
   APP =
   ELEV =
   GPM =
   NR =
   SP =
   FP =
   RP =
   RGPM =

6. Due to weight restrictions, your pumper is forced to spot at a hydrant. You connect to the hydrant using 15 ft of 5″ hose. From outlet 2, 600 ft of 3″ hose is laid out. Connected to the end of the 3″ hose is 100 ft of 1¾″ hose with a ⅞″ straight tip. The static pressure is 77 psi, and the residual pressure is 75 psi. Use the coefficient friction loss formula.
   PDP =
   OP =
   NP =
   FL =
   APP =

ELEV =
GPM =
NR =
SP =
FP =
RP =
RGPM =

7. At the same incident as problem 6, the officer in charge decides to place a wye at the end of the 3″ hose and have two 1¾″ lines, each 100 ft long and using a ⅞″ tip. Your residual pressure now drops to 71 psi. Use the Underwriters friction loss formula.
   PDP =
   OP =
   NP =
   FL =
   APP =
   ELEV =
   GPM =
   NR =
   SP =
   FP =
   RP =
   RGPM =

8. A large warehouse fire has just gone defensive. You connect to a hydrant using 15 ft of 5″ hose. From outlet 1, your crew stretches 100 ft of 2½″ hose to a siamese at the base of a ladder truck. From the siamese, a single 3″ hose is laid up the ladder to a ladderpipe connected to the tip of the ladder. The ladder is elevated 80 ft. The ladderpipe has a 1½″ tip. Your static pressure is 82 psi, and the residual pressure is 77 psi. Use the Underwriters friction loss formula.
   PDP =
   OP =
   NP =
   FL =
   APP =
   ELEV =

GPM =
NR =
SP =
FP =
RP =
RGPM =

9. At the same evolution as problem 8, your crew now has stretched a second 2½″ line 100 ft long to the same siamese using outlet 2. Nothing else has changed. Recalculate the problem.
   PDP =
   OP =
   NP =
   FL =
   APP =
   ELEV =
   GPM =
   NR =
   SP =
   FP =
   RP =
   RGPM =

10. At the same evolution as problems 8 and 9, a third 2½″ hoseline 100 ft long has been laid to the siamese using outlet 3. Nothing else has changed. Recalculate the problem.
    PDP =
    OP =
    NP =
    FL =
    APP =
    ELEV =
    GPM =
    NR =
    SP =
    FP =
    RP =
    RGPM =

11. A fire has broken out on the ninth floor of a high-rise apartment building. You secure a hydrant and stretch two lines of 2½″ hose, each 200 ft long, to the standpipe connection using outlets 3 and 4. The first crew connects 200 ft of 1¾″ hose with a ⅞″ tip to a connection on the eighth floor and stretches it to the fire floor. A second crew connects 300 ft of 2½″ hose with a 1″ tip to the seventh floor and stretches it to the fire floor. Your static pressure is 74 psi, and the residual pressure is 68 psi. Assume 10 ft per floor. Use the Underwriters friction loss formula.
PDP =
OP =
NP =
FL =
APP =
ELEV =
GPM =
NR =
SP =
FP =
RP =
RGPM =

12. A tanker truck has ruptured and filled an intersection with diesel fuel. Your crew needs to cover the spill with AFFF foam. You secure a hydrant and connect a 125-gpm venturi-type eductor to the pump panel using outlet 4. From the educator, 150 ft of 1¾″ hose using a 125-gpm fog nozzle is laid out. The static pressure is 65 psi, and the residual pressure is 57 psi.
PDP =
OP =
NP =
FL =
APP =
ELEV =
GPM =
NR =
SP =
FP =

RP =
RGPM =

13. A fire has started 1,900 ft away from the nearest hydrant. The officer in charge has ordered that 600 gpm be placed on the fire. Your job is to set up a relay. Calculate this problem using two 2½″ lines between pumpers, and solid stream nozzles. There are no elevation concerns. Assume your hose has a maximum pressure of 200 psi. Use the coefficient friction loss formula. How many pumpers will be needed? How far apart will they be spaced?

14. A relay needs to be set up to a fire that needs 500 gpm and is 3,600 ft away and over a hill. The hill rises 200 ft and then drops 130 ft on the other side. Use dual 2½″ hoselines between pumpers. Use a maximum pressure of 200 psi and solid stream nozzles. Use the Underwriters friction loss formula. How many pumpers will be needed? How far apart will they be spaced? How much pressure (in psi) is lost or gained due to elevation?

15. You secure a hydrant on the top of Mammoth Hill. From outlets 2 and 4, two 3″ lines are laid down the 75-ft hill 700 ft into a siamese. From the siamese, 200 ft of 2½″ hose is stretched to the fire. The officer attaches a 1″ smooth bore tip. The static pressure is 72 psi, and the residual pressure is 56 psi. Use the Underwriters friction loss formula.
PDP =
OP =
NP =
FL =
APP =
ELEV =
GPM =
NR =
SP =
FP =
RP =
RGPM =

Answers

1.

	Line 1	Line 2
PDP =	**220**	
OP =	132.32	220
NP =	50	100
FL =	82.32	120
APP =	0	0
ELEV =	0	0
GPM =	161.76	200
NR =	58	0
SP =	70	
FP =	5	
RP =	65	
RGPM =	7%; able to flow three times the total gpm flow	

2.

	Line 1	Line 2
PDP =	**280**	
OP =	280	124.4
NP =	100	50
FL =	180	74.4
APP =	0	0
ELEV =	0	0
GPM =	200	327.76
NR =	0	117
SP =	82	
FP =	8	
RP =	70	
RGPM =	10%; able to flow three times the total gpm flow	

3.

	Line 1	Line 2
PDP =	**166.03**	
OP =	166.03	141.26
NP =	100	50
FL =	53.01	104.28
APP =	0	0
ELEV =	+ 13.02	– 13.02
GPM =	95	184.88

NR =	0	66
SP =	66	
FP =	6	
RP =	60	
RGPM =	9%; able to flow three times the total gpm flow	

4.

	Line 1	**Line 2**	**Line 3**
PDP =	**193**		
OP =	67.64	93.04	193
NP =	50	50	100
FL =	17.64	43.04	93
APP =	0	0	0
ELEV =	0	0	0
GPM =	210	327.76	200
NR =	75	117	0
SP =	77		
FP =	17		
RP =	60		
RGPM =	22%; able to flow less than one times the total gpm flow		

5.

	Lines 1 and 2
PDP =	**131.74**
OP =	131.74
NP =	80
FL =	41.74
APP =	10
ELEV =	0
GPM =	595.14
NR =	169
SP =	60
FP =	20
RP =	40
RGPM =	33%; able to flow zero times the total gpm flow

Divide the total gallons per minute between the two lines.

6.

	Line 1
PDP =	**103.21**
OP =	103.21
NP =	5.0

FL =	3″ = 12.6	1¾″ = 40.61
APP =	0	
ELEV =	0	
GPM =	161.76	
NR =	58	
SP =	77	
FP =	2	
RP =	75	
RGPM =	2.5%; able to flow three times the total gpm flow	

7. *PDP* = **146.56**

OP =	146.56	
NP =	50	
FL =	3″ = 50.4	1¾″ = 41.16
APP =	5	
ELEV =	0	
GPM =	323.52	
NR =	58	
SP =	77	
FP =	6	
RP =	71	
RGPM =	7%; able to flow three times the total gpm	

8. *PDP* = **203.98**

OP =	203.98	
NP =	80	
FL =	3″ = 19.79	2½″ = 49.47
APP =	20	
ELEV =	34.72	
GPM =	472.77	
NR =	169	
SP =	82	
FP =	5	
RP =	77	
RGPM =	6%; able to flow three times the total gpm flow	

Two appliances: ladderpipe = 15 psi, siamese = 5 psi.
The 3″ hose is 100 ft long.

9. *PDP* = **168.01**
   OP = 168.01
   NP = 80
   FL = 3″ = 19.79 2½″ = 13.5
   APP = 20
   ELEV = 34.72
   GPM = 472.77
   NR = 169
   SP = 82
   FP = 5
   RP = 77
   RGPM = 6%; able to flow three times the total gpm flow
   Divide the gpm flow in half for the two 2½″ lines.

10. *PDP* = **161.09**
   OP = 161.09
   NP = 80
   FL = 3″ = 19.79 2½″ = 6.58
   APP = 20
   ELEV = 34.72
   GPM = 472.77
   NR = 169
   SP = 82
   FP = 5
   RP = 77
   RGPM = 6%; able to flow three times the total flow
   Divide the gpm flow by the three lines.

11.

	Line 1	**Line 2**
PDP =	**210.60**	
OP =	210.60	160.04
NP =	50	50
FL_{supply} =	17.56	17.56
FL_{attack} =	83.32	32.76
APP =	25	25
ELEV =	34.72	34.72
GPM =	161.76	210
NR =	58	75

SP = 74
FP = 6
RP = 68
RGPM = 8%; able to flow three times the total gpm flow
Total gpm flow = 371.76.
Friction loss in supply line = 17.56 psi.
Elevation: Do not count the first floor; total 80 ft.

12. *PDP* = **200**
OP = 200
GPM = 125
NR = 0
SP = 65
FP = 8
RP = 57
RGPM = 12%; able to flow two times the total gpm flow
Foam eductors need 200 psi at the educator, or the manufacturer's recommended pressure.

13. How many pumpers will be needed? **4 total**
Supply pumper
700 ft
1,400 ft
Attack pumper
How far apart will they be spaced? **Every 700 ft**

14. How many pumpers will be needed? **7 total pumpers**
Supply pumper
650 ft
1,300 ft
1,950 ft
2,600 ft
3,250 ft
Attack pumper
How far apart will they be spaced? **650 ft**
How much pressure (in psi) is lost or gained due to elevation? **30.38 psi**

15. *PDP* = **53.39**
OP = 53.39
NP = 50
FL = 3″ = 9.1   2½″ = 21.84
APP = 5
ELEV = –32.55
GPM = 210
NR = 75
SP = 72
FP = 16
RP = 56
RGPM = 22%; able to flow zero times the current gpm flow

GLOSSARY

air exhauster. A device that forces air out of a dry sprinkler system, allowing faster water flow.

alternator. An electrical generator designed to produce an alternating current.

appliance. A device designed to work in conjunction with hoses to help deliver water.

appliance friction loss. The friction loss in appliances such as Siamese, wyes, and standpipes.

aquifer. An underground body of water.

atmospheric pressure. The weight of the surrounding air. At sea level the atmospheric pressure is approximately 14.7 psi.

attack pumper. The pumper that is positioned nearest the fireground.

average daily consumption. Total number of gallons of water used in a year divided by the number of days in a year.

back pressure. The pressure that needs to be overcome due to head when hoselines are laid to an elevation that is higher than the pump.

ball valve. A valve that has an opening on one side that rotates to allow water to pass through piping.

bearing. A machine part that provides support and alignment for the drive shaft.

bleeder valve. A valve that either allows air to escape the hoseline before entering the pump or is connected to the discharge outlet, allowing pressure to be relieved in the hoseline.

Bresnan distributor. An appliance that spins distributing water in all directions.

brush truck. A type of pumper that can be driven while spraying water to extinguish brush and weed fires.

Byington, E.M. A Boston firefighter who developed the formula for determining nozzle reaction.

capacity. The amount that something can hold or produce.

cavitate. Air bubbles that form in a centrifugal pump when the pump tries to discharge more water than what is incoming.

centrifugal force. The force felt by an object moving in a curved path away from the center of a spinning disk.

centrifugal pump. A pump that uses impellers to provide velocity to water using centrifugal force.

clapper valve. A flap in a pipe that allows water to flow only in one direction.

clearance rings. A packing material that prevents water from leaking back into the impeller once it has left the volute.

coefficient formula. A mathematical calculation to figure friction loss.

combination layout. A hose layout using more than one type or size of hose.

compound gauge. A gauge connected to the intake side of the pump that reads pressure above and below zero.

couplings. Devices that connect hoses and appliances together.

cubic inch. A volume measurement that is 1 inch wide, 1 inch long, and 1 inch tall.

cubic foot. A volume measurement that is 1 foot wide, 1 foot long, and 1 foot tall.

dead end main. A section of piping not connected to the distribution grid.

deck gun. A prepiped master stream device on top of an apparatus.

deluge sprinkler. A system in which all sprinkler heads are activated to flood an area.

density. The weight per unit volume of a substance.

dilution. The thinning out of a liquid.

discharge. The amount of water being discharged.

discharge gauge. A gauge that measures the amount or pressure of the water being discharged.

discharge outlet. An opening on the apparatus where discharge hoses are connected.

discharge pressure. The force of the water created by the pump.

distribution mains. Smaller pipes that connect the distribution system to individual customers and hydrants.

double female. An adapter used to connect two male couplings.

double male. An adapter used to connect two female couplings.

drafting. The process of taking water from a source other than a hydrant and moving it to the intake side of the pump.

drain valve. A valve designed to drain water from a discharge outlet or from the pump itself.

drive shaft. A long tube that sends an engine's power either to the rear wheels or to the pump.

dry barrel hydrant. A hydrant with a control valve below ground.

dry pipe system. Piping that is pressurized with air. Used where pipes will freeze.

elevation. The height above or below the pump.

engine pressure. *See* discharge pressure.

engineer. The driver/operator.

eye of the impeller. Where water enters the impeller.

filtration. Passing water through a medium to trap dirt.

fire department connection. A siamese connection for a sprinkler or standpipe system.

fireground. The area where firefighting activities occur.

fire pump. A pump in a sprinkler or standpipe system.

fire stream. A stream of water once it leaves the nozzle until it reaches the intended point.

flammable liquid. A liquid that produces enough vapors to ignite and burn.

flinger ring. A device that prevents water from traveling the length of the shaft.

flow pressure. The pressure of the water when it is flowing.

foam. A water additive designed for use on flammable liquid fires.

foam sprinkler. A system that sprays foam.

fog nozzle. An adjustable type of nozzle that produces small water droplets.

force. The amount of energy applied at any given point.

frangible bulb head. A type of sprinkler head with a glass bulb.

Freeman, John R. Conducted experiments to develop standards for solid streams.

friction. The rubbing of one object against another.

friction loss. The loss of energy, in pressure, whenever water runs through hoses, fittings, and appliances.

fusible link head. A type of sprinkler head using metal plates.

gauge pressure. The pressure reading above zero.

gpm. gallons per minute.

gravity tank. A water storage tank that is placed at a higher elevation than where it will be used.

handline. A hoseline using less than 300 gpm.

head. The vertical distance from the surface of the water to where it will be used.

hoseline. A water-carrying vessel.

hydrant. A fire department connection to a water distribution system.

hydraulics. The study of the movement of water.

impeller. The part of the pump that provides velocity to the water.

indirect attack. A method of applying water to an enclosed space and allowing it to turn to steam, smothering the fire.

inlet pressure. The pressure as water enters the pump.

intake gauge. A device that measures the inlet pressure.

intake valve. A device that allows the flow of water into the pump.

ladder pipe. A master stream device that connects to an aerial ladder.

laminar flow. The flow of water through a hose in straight, parallel lines.

latent heat of fusion. The amount of heat absorbed or given off as a substance changes from a liquid and a solid.

latent heat of vaporization. The amount of heat absorbed or given off as a substance changes from a liquid and a gas.

Layman, Lloyd. Developer of the indirect attack.

lift. The vertical distance between the water surface and the midpoint of the pump.

master discharge gauge. The main discharge gauge that shows the highest pump discharge pressure.

master stream. Flows exceeding 300 gpm delivered from larger appliances.

maximum daily consumption. The maximum amount of water that is used in any given 24-hour period.

maximum lift. The maximum height that water can be drafted.

midship mount. A pump positioned between the engine and the rear wheels.

multiversal. A master stream device.

negative pressure. Pressure that reads below zero.

net pump pressure. The total amount of work being done by the pump.

nozzle. A device placed on the end of a hoseline giving the stream its shape, reach, and velocity.

nozzle pressure. The discharge pressure from the nozzle.

nozzle reaction. The amount of force pushing back against the nozzle.

oil pressure gauge. A device that measures the amount of pressure in the engine's oil lubricating system.

packing. Provides an airtight seal around the shaft where it enters the pump.

parallel. Having two or more impellers working independently, allowing the pump to work at full capacity.

peak hourly consumption. The hour that has the most amount of water consumption.

piston pump. A positive displacement pump consisting of a cylinder that fills with water and a piston that forces the water out.

pitot tube. An instrument used for measuring forward velocity.

positive displacement pump. A pump capable of pumping air as well as water.

positive pressure. Pressure that reads above zero.

power take-off. A device placed between the engine and transmission that provides power to a pump, allowing pump and roll capabilities.

power transfer. Methods of shifting power between the engine and pump.

preaction sprinkler. A dry system that gets charged with water when an alarm is activated.

pressure. Force per unit area.

pressure gauge. A gauge connected to the outlet discharge.

pressure governor. A device that changes engine speed to control changes in flow pressure or gpm.

pressure reducer. A device found in standpipe systems designed to lower water pressure for civilian use.

pressure relief valve. A device that bypasses excess water from the discharge side of the pump back to the intake side to prevent pressure surges.

primary feeder. The largest pipe in a water distribution system.

priming pump. A positive displacement pump that expels air from a centrifugal pump.

pump capacity. The maximum flow from a pump while at draft.

pump chart. Set calculations written down to help aid the pump operator.

pump drain. A device that allows a pump to be drained of water for maintenance or freezing weather.

pump gear. When power has been switched from wheels to pump.

pump panel. An area on apparatus where all pump controls and readouts are placed.

pumper. Apparatus capable of pumping water from a source to working hoselines.

Q. A symbol for total gpm divided by 100.

reach. The distance a stream can be thrown and be called a good stream.

relay. Operations consisting of moving water from one pumper to the intake of another pumper.

required fire flow. The total amount of water needed to extinguish a fire.

reservoir. An artificial lake used as a water supply.

residual pressure. The remaining pressure in a water distribution system.

retard chamber. A device placed between the fire pump and the alarm system to minimize water surges.

riser. Piping that carries water in a sprinkler or standpipe system.

rotary gear pump. A rotary pump that uses two gears to move water.

rotary vane pump. A rotary pump that uses a single rotor, which is offset inside the housing.

rpm. Revolutions per minute.

secondary feeder. Pipes in a water distribution system used to make an interconnecting grid.

sedimentation. Dirt that falls out of water due to gravity.

series. The flow of water from one impeller to the next.

shroud. Sides of an impeller.

siamese lines. Water from two or more hoselines combined into one.

smooth bore tip. A nozzle that produces a solid stream.

smothering. Excluding air by covering.

spanner wrench. A tool used to tighten or loosen hose couplings.

specific heat. The amount of heat required to raise the temperature of one pound of a substance 1°F.

sprinkler head. The discharge outlet for a sprinkler system.

sprinkler system. An automatic water distribution system in buildings.

standpipe system. A water piping system that allows hoselines to be connected to fight fires.

static pressure. The pressure in a system when water is not moving.

static water source. A water source used for drafting.

straight stream. A stream produced by a smooth bore tip.

strainer. A device placed on end of suction hose that prevents debris from entering the hose.

suction. A vacuum.

suction hose. Hard hose used for drafting.

supply line. Hose used from the water source to the intake side of the pump.

tank fill valve. A lever used to fill the apparatus water tank using water from the pump.

throttle. A device that controls the speed of the impeller.

transfer valve. A device that controls whether a dual stage pump is in the pressure or volume position.

turbulent flow. Caused in hoselines when water bounces off itself and inside the hose.

Underwriters formula. A formula used to figure friction loss.

vacuum. A space from which air has been evacuated.

valve. A device that controls the flow of water in and out of the pump.

vanes. Part of the impeller that picks up the water and directs it outward.

velocity. Speed.

viscosity. The thickness of a liquid.

voltmeter. A device that indicates the health of the electrical system.

volume. The amount of space something holds.

volute. The discharge opening of the pump.

water hammer. A sudden change of direction in the water, possibly causing damage to the hose, pipes, and fittings.

water supply. Any water source delivered to the pump intake.

water tank. An onboard apparatus supply tank.

water temperature gauge. A device that monitors engine temperature.

water treatment plant. The place where water is cleaned for consumption.

wear rings. Devices that prevent discharge water from entering the impeller.

wet barrel hydrant. A hydrant that is always full of water.

wet pipe system. Piping filled with water constantly.

whirlpool. The spinning of static water, preventing a draft.

wyed lines. Water from a single hoseline splitting into two or more hoselines.

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About the Author

A 20-year veteran of the fire service, Paul Spurgeon began his career with the Denver Fire Department in 1991. After probation, he was first assigned to Truck 19 on Denver's east side and then transferred to Engine 19. In 1998, he was promoted to the rank of engineer and assigned to Engine 7 in northwest Denver. He continues his career with the Denver Fire Department. Spurgeon received his AAS degree in fire science technology from Red Rocks Community College.

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