Applied Sprinkler Technology 202: Hydraulic Calculations, Part 2

Course Description

This one hour online course is the second in a 4-part series covering the topic of hydraulic calculations for automatic sprinkler systems. The course is designed to assist system layout technicians, and others who are seeking NICET certification, and for Authorities Having Jurisdiction desiring an understanding of calculation models and applications.

Performance Objectives

Upon completion of Part Two of Hydraulic Calculations for Fire Sprinkler Systems the student will:

- Understand principle of elevation pressure
- Understand concept of friction loss including utilization of the Hazen-Williams formula
- Understand how to use equivalent lengths
- Be able to calculate sprinkler flows for multiple sprinklers
- Be able to perform simple single line hydraulic calculations

Introduction

The ability to perform manual hydraulic calculations is quickly becoming a lost art. Computer programs for hydraulics are easy to use, extremely fast, and accurate. However, because these wonderful tools allow layout technicians to perform the computations without understanding the underlying principles, the resultant system layout, while meeting the design criteria, is often not the most efficient or cost effective. It is the role of the system layout technician to, not only deliver a product that meets the requirements of the fire codes and standards, but to do so at the very best value possible.

This value proposition is one of the major reasons NICET, and other organizations that certify the competency of layout technicians, require the technician to demonstrate both an understanding of hydraulic principles and the ability to perform manual hydraulic calculations. Mastering these skills comes through learning the calculation steps and then practicing these steps over and over. Most of those who have been through this learning curve report that the steps were easy to learn but it took continuous repetition to finally have the "light turn on." Once it did, the skill of performing manual hydraulics was much like the skill of riding a bicycle: once you have it, you never lose it.

When a system layout technician understands the computations the computer is performing and why, he or she can input a variety of options such as different piping configurations, sprinkler types and coverage, pipe sizes, and a host of other variables. That will lead to a sprinkler system layout that delivers the required protection at the very best value. The great advantage of the computer is in its ability to take an option and very quickly determine its viability. However, if the layout technician does not know what variables to try, because of a lack of understanding the underlying principles, the resultant layout will be unimaginative and most likely not the best solution. The computer is a wonderful tool but its full potential is only available when in the hands of the knowledgeable system layout technician.

Reference

To successfully complete this module, the student will need the following materials:

- *NFPA 13, Standard for the Installation of Sprinkler Systems* (all references in this module refer to the 2007 edition)

- Scientific Calculator with trigonometry functions, preferably a TI-85

The following materials are not required but are helpful reference materials:

- *Automatic Sprinkler Systems Handbook, 2007 Edition.* Published by NFPA.

- *Fire Protection Handbook, Nineteenth Edition.* Published by NFPA.

Glossary

Area of Coverage: The total area covered by a single operating sprinkler. Measured in English Units as square feet.

C-Value (C-factor): Friction loss coefficient given to pipe based on the relative roughness of the inside surface.

Density: The rate of water application over a specific unit of area for a specific unit of time. Expressed in English Units as gallons per minute (gpm) over an area of one square foot.

Design Criteria: The combination of density and the area of sprinkler operation specific to a defined hazard.

Equivalent Length: The friction loss that occurs in fittings and devices expressed in the equivalent length of straight tube or pipe of the same diameter.

Grid System: A piping configuration with a primary main (connected to the water supply) and a parallel secondary main that are connected with multiple branch lines which allows water to follow multiple paths to the operating sprinkler(s).

Head: Pressure expressed in terms of elevation. A column of water one foot in height will exert a pressure of .433 psi.

Hydraulic Calculations: A series of mathematical equations that demonstrate that the water supply and fire sprinkler system layout is sufficient to deliver adequate water to meet the design criteria.

K-Factor: The discharge coefficient based on the size of an opening and the roughness of the bore. Fire sprinklers have a factory established K-Factor.

Loop System: A piping configuration in which water follows two or more mains from the supply to the branch lines feeding the operating sprinkler(s).

Normal Pressure: The pressure of water acting against, or perpendicular to, a tube or pipe wall.

Occupancy (hazard) Classification: Combination of characteristics and factors that contribute to fire severity. The characteristics include such things as combustibility, quantity, and arrangement of materials. The probability of a fire occurring is not a consideration of Occupancy Classification.

Pressure: The unit that measures force caused by compression per unit area in a fluid.

Residual Pressure: The pressure remaining in a system from the flow resulting upon a discharge from the system.

Static Pressure: The pressure in a system with no flow.

Total Pressure: The sum of normal pressure and velocity pressure added together.

Tree System: A piping configuration in which water follows a single path from the supply to the operating sprinkler(s).

Velocity Pressure: The pressure to move water through a tube or pipe.

Hydraulic Calculations

When NFPA 13 introduced hydraulic calculations as an option to the pipe schedules all computations were performed manually. The formulas were written and solved with pencil and paper. Slide rules, which were the "calculators" before the computer age, were used extensively. Slide rules, designed specifically for hydraulics, were utilized by the very adept designers and engineers.

As a result of the arduous nature of solving equations by hand, volumes of data were maintained in paper form for such needed information as friction loss factors for different diameters of pipe, c-values, and different flows. Because it was literally impossible to have every data for each variable, interpolation between known quantities was used and added extensively to the time involved and increased the chance for mistakes.

We have the advantage of inexpensive programmable handheld calculators, in which an individual with limited knowledge can input the basic formulas that are needed to perform calculations. In this module, the calculation process utilizes the Hazen-Williams formula to determine friction loss caused by flowing water through pipe. To complete this module, a calculator with basic scientific functions (algebra/trigonometry) is required.

A programmable calculator is very helpful and will allow the student to process the problems much more quickly. There is virtually an unlimited variety of calculators on the market making it impossible to provide instructions for all, but the following instructions for the Texas Instruments TI-85 calculator should provide sufficient guidance to enter the formula in most programmable handheld scientific calculators.

Hazen-Williams Calc for TI-85 Calculator

The following program should work for all TI calculators.

```
Disp “Q”
Input Q
Disp “C”
Input C
Disp “d”
Input d
P=4.52*Q^1.85/d^4.87/C^1.85
Disp “P=”
Disp P
```

Basically, while running the program, when prompted for Q enter the flow, hit return. Continue like that for C (C-factor) and d (internal pipe diameter). The calculator will then display the Hazen-Williams factor (friction loss in psi per foot of pipe).

Elevation Pressure (Head)

Pressure is a form of energy. In the context of the study of hydraulic calculations, pressure may be exerted by water or applied to water. For example, a column of water one foot high will exert a pressure at the base of the column of .433 psi. Conversely, to lift a column of water one foot will require a pressure of .433 psi to be applied at its base. The term “head” is often used to describe this pressure and will often be found in hydraulic texts. Many manufacturers use “head” in describing the pressure rating for fire pumps.

The relationship between head and pressure is expressed in the following formulas:

Head (ft) = psi x 2.31 ft/psi **psi = Head (ft) x .433 psi/ft**

Example:

What is equivalent head for a standpipe with a pressure at the bottom of 66 psi?

Head = psi x 2.31 ft/psi
Head = 66 psi x 2.31 ft/psi
Head = 152.5 ft

Water in an elevated component, such as a tank or standpipe, represents stored energy and is expressed in the terms of **head** or **psi**. If the water is released, it loses some of this energy. The energy of the stored water is referred to as *static pressure* or *head* since the water is at rest (not flowing). If water is discharged, it commences to flow and the remaining energy is called *residual pressure* or *head*. In the standards and codes dealing with sprinkler systems, the term **psi** is most commonly used when discussing hydraulic calculations and will be used in this module.

Example:

What pressure is needed to lift the water into an elevated tank 150 ft high?

psi = Head (ft) x .433 psi/ft
psi = 150 ft x .433 psi/ft
psi = 65

Friction Loss

Friction loss was briefly discussed in Part 1 of this series. When water flows through pipe, there is always a loss in pressure. The loss is caused primarily by the friction between the flowing water and the wall of the pipe but to a lesser extent it is also caused by the friction between the water molecules such as when a change of direction takes place or a rapid change in the size of the tube or pipe.

Friction loss is expressed in terms of pressure. For the purposes of hydraulic calculations, the friction loss psi is defined as the loss of pressure through one foot of pipe.

$$p = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

p = frictional resistance in psi per foot of pipe
Q = flow in gpm
C = friction loss coefficient
d = actual internal diameter of pipe in inches

NFPA 13 designates that the Hazen-Williams formula be used to determine pipe friction losses.

With the Hazen-Williams formula, the system layout technician can determine the friction loss for any type and size of pipe and for any volume of flow through the pipe. The friction loss coefficient (C-value), which is related to the smoothness of the pipe, has a dramatic impact on friction loss. NFPA 13 includes a table giving the friction loss coefficients for various types of pipe. It is important to note that the table includes coefficients for steel pipe used in wet or dry type systems. Also not all pipe that is listed for fire protection use is included on the table. When a type of pipe is used that is not on the table, the manufacturer of the pipe must be consulted.

Table 22.4.4.7 Hazen–Williams *C* Values

Pipe or Tube	*C* Value*
Unlined cast or ductile iron	100
Black steel (dry systems including preaction)	100
Black steel (wet systems including deluge)	120
Galvanized (all)	120
Plastic (listed) all	150
Cement-lined cast or ductile iron	140
Copper tube or stainless steel	150
Asbestos cement	140
Concrete	140

*The authority having jurisdiction is permitted to consider other *C* values.

The Hazen-Williams formula uses the actual internal diameter of pipe. Consider, for instance, that the external diameter for all schedules (5, 7,10, 40, etc.) of steel pipe is virtually the same, but there are significant differences in the internal diameters depending on the wall thickness. Just as it is with the friction loss coefficient, different internal diameters (though seemingly small) have a significant impact on the friction loss. The following tables have the internal diameters for some common pipe utilized in sprinkler systems. Remember though, that the technician should consult the manufacturer data for all special sprinkler pipe.

You may want to flag these tables in your NFPA 13 for the exercises later in this program.

Table A.6.3.2 Steel Pipe Dimensions

Nominal Pipe Size		Outside Diameter		Schedule 5 Inside Diameter		Schedule 5 Wall Thickness		Schedule 10[a] Inside Diameter		Schedule 10[a] Wall Thickness		Schedule 30 Inside Diameter		Schedule 30 Wall Thickness		Schedule 40 Inside Diameter		Schedule 40 Wall Thickness	
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
½[b]	15	0.840	21.3	—	—	—	—	0.674	17.0	0.083	2.1	—	—	—	—	0.622	15.8	0.109	2.8
¾[b]	20	1.050	26.7	—	—	—	—	0.884	22.4	0.083	2.1	—	—	—	—	0.824	21.0	0.113	2.9
1	25	1.315	33.4	1.185	30.1	0.065	1.7	1.097	27.9	0.109	2.8	—	—	—	—	1.049	26.6	0.133	3.4
1¼	32	1.660	42.2	1.530	38.9	0.065	1.7	1.442	36.6	0.109	2.8	—	—	—	—	1.380	35.1	0.140	3.6
1½	40	1.900	48.3	1.770	45.0	0.065	1.7	1.682	42.7	0.109	2.8	—	—	—	—	1.610	40.9	0.145	3.7
2	50	2.375	60.3	2.245	57.0	0.065	1.7	2.157	54.8	0.109	2.8	—	—	—	—	2.067	52.5	0.154	3.9
2½	65	2.875	73.0	2.709	68.8	0.083	2.1	2.635	66.9	0.120	3.0	—	—	—	—	2.469	62.7	0.203	5.2
3	80	3.500	88.9	3.334	84.7	0.083	2.1	3.260	82.8	0.120	3.0	—	—	—	—	3.068	77.9	0.216	5.5
3½	90	4.000	101.6	3.834	97.4	0.083	2.1	3.760	95.5	0.120	3.0	—	—	—	—	3.548	90.1	0.226	5.7
4	100	4.500	114.3	4.334	110.1	0.083	2.1	4.260	108.2	0.120	3.0	—	—	—	—	4.026	102.3	0.237	6.0
5	125	5.563	141.3	—	—	—	—	5.295	134.5	0.134	3.4	—	—	—	—	5.047	128.2	0.258	6.6
6	150	6.625	168.3	6.407	162.7	0.109	2.8	6.357	161.5	0.134[c]	3.4	—	—	—	—	6.065	154.1	0.280	7.1
8	200	8.625	219.1	—	—	—	—	8.249	209.5	0.188[c]	4.8	8.071	205.0	0.277[d]	7.0	7.981	—	0.322	—
10	250	10.750	273.1	—	—	—	—	10.370	263.4	0.188[c]	4.8	10.140	257.6	0.307[d]	7.8	10.020	—	0.365	—
12	300	12.750	—	—	—	—	—	—	—	—	—	12.090	—	0.330[c]	—	11.938	—	0.406	—

[a] Schedule 10 defined to 5 in. (127 mm) nominal pipe size by ASTM A 135, *Standard Specification for Electric-Resistance-Welded Steel Pipe.*
[b] These values applicable when used in conjunction with 8.14.19.3 and 8.14.19.4.
[c] Wall thickness specified in 6.3.2.
[d] Wall thickness specified in 6.3.3.

Table A.6.3.5 Copper Tube Dimensions

Nominal Tube Size		Outside Diameter		Type K Inside Diameter		Type K Wall Thickness		Type L Inside Diameter		Type L Wall Thickness		Type M Inside Diameter		Type M Wall Thickness	
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
¾	20	0.875	22.2	0.745	18.9	0.065	1.7	0.785	19.9	0.045	1.1	0.811	20.6	0.032	0.8
1	25	1.125	28.6	0.995	25.3	0.065	1.7	1.025	26.0	0.050	1.3	1.055	26.8	0.035	0.9
1¼	32	1.375	34.9	1.245	31.6	0.065	1.7	1.265	32.1	0.055	1.4	1.291	32.8	0.042	1.1
1½	40	1.625	41.3	1.481	37.6	0.072	1.8	1.505	38.2	0.060	1.5	1.527	38.8	0.049	1.2
2	50	2.125	54.0	1.959	49.8	0.083	2.1	1.985	50.4	0.070	1.8	2.009	51.0	0.058	1.5
2½	65	2.625	66.7	2.435	61.8	0.095	2.4	2.465	62.6	0.080	2.0	2.495	63.4	0.065	1.7
3	80	3.125	79.4	2.907	73.8	0.109	2.8	2.945	74.8	0.090	2.3	2.981	75.7	0.072	1.8
3½	90	3.625	92.1	3.385	86.0	0.120	3.0	3.425	87.0	0.100	2.5	3.459	87.9	0.083	2.1
4	100	4.125	104.8	3.857	98.0	0.134	3.4	3.905	99.2	0.110	2.8	3.935	99.9	0.095	2.4
5	125	5.125	130.2	4.805	122.0	0.160	4.1	4.875	123.8	0.125	3.2	4.907	124.6	0.109	2.8
6	150	6.125	155.6	5.741	145.8	0.192	4.9	5.845	148.5	0.140	3.6	5.881	149.4	0.122	3.1
8	200	8.125	206.4	7.583	192.6	0.271	6.9	7.725	196.2	0.200	5.1	7.785	197.7	0.170	4.3
10	250	10.130	257.3	9.449	240.0	0.338	8.6	9.625	244.5	0.250	6.4	9.701	246.4	0.212	5.4

Calculate the friction loss per foot for 25 gpm of water flowing under the following condition:

A) 1 inch diameter Schedule 40 steel pipe in a wet sprinkler system

  a. Using our tables we find that internal pipe diameter is 1.049 and the friction loss coefficient is 120.

  b. Now insert the following data in the Hazen-Williams formula.

$$p = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$p = \frac{4.52 \times 25^{1.85}}{120^{1.85} \times 1.049^{4.87}}$$

$$p = \frac{1743.12}{8864.66}$$

***p* = .197 psi/ft**

Calculate the friction loss per foot for 25 gpm of water flowing under the following condition:

B) 1 inch diameter Schedule 40 steel pipe in a dry sprinkler system
   a. Using our tables we note that the friction loss coefficient is now 100.
   b. Now insert the following data in the Hazen-Williams formula.

$$p = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$p = \frac{4.52 \times 25^{1.85}}{100^{1.85} \times 1.049^{4.87}}$$

$$p = \frac{1743.12}{6326.7}$$

***p* = . 276 psi/ft**

Equivalent Lengths

When performing hydraulic calculations the friction loss is based on linear footage of pipe or, in other words, water that is flowing in a straight line. However, when we change the direction of the water flow it results in turbulence which requires additional pressure to push the water through the fitting that is creating the change. This additional pressure loss is described by equating the additional pressure needs with an equivalent length of straight pipe. For example, in a wet system utilizing steel pipe, the pressure loss caused by water flowing through a 2-inch 90° elbow is the equivalent of the pressure loss that occurs from water flowing through 5 feet of straight 2-inch pipe. Flow through fittings (such as couplings) that does not change the direction are typically negligible and normally ignored. However, the internal configuration of valves and other devices can create resistance to water flow and usually require an equivalent footage conversion.

Table 22.4.3.1.1 in NFPA 13 provides the equivalent footages for standard fittings and common valves. The table is based for Schedule 40 steel pipe with a C-value of 120 (wet system). Click on the image below to open a larger version in a new window.

Table 22.4.3.1.1 Equivalent Schedule 40 Steel Pipe Length Chart

Fittings and Valves	Fittings and Valves Expressed in Equivalent Feet (Meters) of Pipe														
	½ in. (15 mm)	¾ in. (20 mm)	1 in. (25 mm)	1¼ in. (32 mm)	1½ in. (40 mm)	2 in. (50 mm)	2½ in. (65 mm)	3 in. (80 mm)	3½ in. (90 mm)	4 in. (100 mm)	5 in. (125 mm)	6 in. (150 mm)	8 in. (200 mm)	10 in. (250 mm)	12 in. (300 mm)
45° elbow	—	1 (0.3)	1 (0.3)	1 (0.3)	2 (0.6)	2 (0.6)	3 (0.9)	3 (0.9)	3 (0.9)	4 (1.2)	5 (1.5)	7 (2.1)	9 (2.7)	11 (3.4)	13 (4)
90° standard elbow	1 (0.3)	2 (0.6)	2 (0.6)	3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)	7 (2.1)	8 (2.4)	10 (3)	12 (3.7)	14 (4.3)	18 (5.5)	22 (6.7)	27 (8.2)
90° long-turn elbow	0.5 (0.2)	1 (0.3)	2 (0.6)	2 (0.6)	2 (0.6)	3 (0.9)	4 (1.2)	5 (1.5)	5 (1.5)	6 (1.8)	8 (2.4)	9 (2.7)	13 (4)	16 (4.9)	18 (5.5)
Tee or cross (flow turned 90°)	3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)	8 (2.4)	10 (3)	12 (3.7)	15 (4.6)	17 (5.2)	20 (6.1)	25 (7.6)	30 (9.1)	35 (10.7)	50 (15.2)	60 (18.3)
Butterfly valve	—	—	—	—	—	6 (1.8)	7 (2.1)	10 (3)	—	12 (3.7)	9 (2.7)	10 (3)	12 (3.7)	19 (5.8)	21 (6.4)
Gate valve	—	—	—	—	—	1 (0.3)	1 (0.3)	1 (0.3)	1 (0.3)	2 (0.6)	2 (0.6)	3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)
Swing check*	—	—	5 (1.5)	7 (2.1)	9 (2.7)	11 (3.4)	14 (4.3)	16 (4.9)	19 (5.8)	22 (6.7)	27 (8.2)	32 (9.3)	45 (13.7)	55 (16.8)	65 (20)

For SI units, 1 in. = 25.4 mm; 1 ft = 0.3048 m.
Note: Information on ½ in. pipe is included in this table only because it is allowed under 8.15.19.4 and 8.15.19.5.
*Due to the variation in design of swing check valves, the pipe equivalents indicated in this table are considered average.

NPFA 13 requires modifiers be utilized for different C-values and/or internal pipe diameters.

The modifier for pipe diameter is a factor derived from the following formula:

$$\textbf{\textit{Factor}} = \left\{\frac{\textit{Actual Inside Diameter}}{\textit{Schedule 40 Steel Inside Diameter}}\right\}^{4.87}$$

The modifiers for C-Values other than 120 are found in Table 22.4.3.2.

Table 22.4.3.2 *C* Value Multiplier

Value of *C*	100	130	140	150
Multiplying factor	0.713	1.16	1.33	1.51

Note: These factors are based upon the friction loss through the fitting being independent of the *C* factor available to the piping.

Example:

Determine the equivalent footage for a 3 inch 90° long-turn elbow in a dry system using Schedule 10 steel pipe.

a. The inside diameter of 3-inch Schedule 40 pipe from Table A.6.3.2

is 3.068.

b. The actual inside diameter of 3-inch Schedule 10 pipe is 3.26.

Factor = $\left\{\frac{Actual\ Inside\ Diameter}{Schedule\ 40\ Steel\ Inside\ Diameter}\right\}^{4.87}$

Factor = $\left\{\frac{3.26}{3.068}\right\}^{4.87}$

Factor = **.134**

We modify the equivalent footage of 5 ft. found in Table 22.4.3.1.1 by the factor of 1.34 giving a footage of 6.7 ft. However we must further modify our result (6.7 ft) with the factor for a C-value of 100 because it is a dry system. This factor from Table 22.4.3.2 is 0.713 and gives a final result of 4.8 (4.77) ft.

Since equivalent footages are used in all hydraulic calculations, numerous tables showing these footages for nearly all types of pipes and fittings are available which make performing these computations unnecessary in most cases. In addition, manufacturer's data should always be consulted for all fittings, valves, and devices to make certain that the proper equivalent footages are utilized.

Sprinkler Flow

In Part 1 of this series, we were introduced to the formula to solve for calculating sprinkler pressure.

$$P = \left(\frac{Q}{K}\right)^2$$

We can also set up the formula to solve for flow.

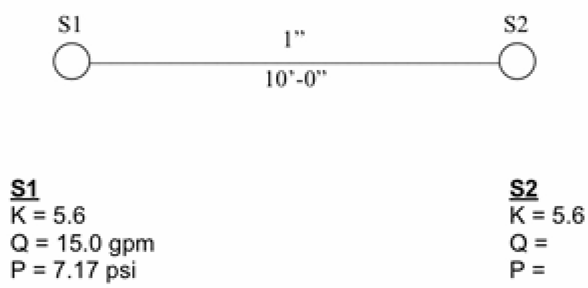
$$Q = K\sqrt{P}$$

Do not confuse this with the formula for determining minimum flow from Part 1. Hydraulic calculations are based on the premise that we can never flow less than the minimum amount of water needed to deliver the design criteria (density/area). However, because of friction loss, we will always have more pressure than needed at the majority of our sprinklers. This added pressure causes more water to discharge from successive sprinklers. This has the compound effect of requiring more pressure to push more water through the pipe, thus increasing the flow in the next sprinkler.

Therefore, a major objective in performing hydraulic calculations is to ensure that our system delivers no less than the minimum amount of water needed, while at the same time endeavoring to keep any overage (or unnecessary water) to a minimum.

Let's examine this concept:

Figure 2.0



Sprinkler S1 has a K-factor of 5.6, is flowing 15 gpm, and requires a pressure of 7.17 psi. The friction loss per foot is .075 psi. As a result, .75 psi is needed for friction loss to move the 15 gpm from sprinkler S2 to S1. Therefore the total pressure at sprinkler S2 is 7.92 psi (7.17 + .75). By utilizing the formula Q = K √ P we can solve for how much water will be discharged from sprinkler S2.

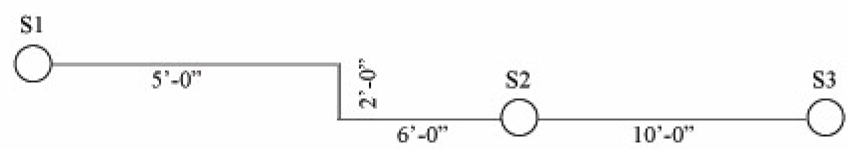
$$Q = K \sqrt{P}$$

$$Q = 5.6\sqrt{7.92}$$

$$Q = 15.8 \text{ gpm}$$

It is time to bring together some of the concepts we have examined thus far. This exercise takes us through steps that we have learned including minimum sprinkler flow, sprinkler pressure, equivalent footage, and friction loss. Using these concepts we can perform a simple calculation. Using the information found in Figure 2.1, consider the following examples:

Figure 2.1



Pipe Size:	1 inch
Pipe Type:	Schedule 5 steel
Sprinkler Type:	K5.6
Area of Coverage:	S1 = 120 sq. ft. S2 = 120 sq. ft. S3 = 120 sq. ft.
Density:	.15
System Type:	Wet pipe

1. **What is the minimum sprinkler flow required for S1 and S2?**

   Q = A x D

   Q = 120 x .15

   Q = 18 gpm

2. **What is the required pressure at S1?**

   P = $\left(\frac{Q}{K}\right)^2$

   P = $\left(\frac{18.0}{5.6}\right)^2$

   P = 3.21^2

   P = 10.3 psi

3. **What is the equivalent length for the (2) 90° standard elbows?**
   a. Using Table 22.4.3.1.1, the equivalent length for (2) 1-inch standard 90° elbows is 4 ft.
   b. However, we must modify for Schedule 5 steel pipe.

***Factor* =** $\left\{\dfrac{\textit{Actual Inside Diameter}}{\textit{Schedule 40 Steel Inside Diameter}}\right\}^{4.87}$

***Factor* =** $\left\{\dfrac{1.185}{1.049}\right\}^{4.87}$

***Factor* =** $1.13^{4.87}$

***Factor* =** 1.81

4 ft x 1.81 = 7.2 ft

4. **What is the total equivalent length from S1 to S2?**

$L_T = L + L_E$

L_T = 13 ft + 7.2 ft

L_T = **20.2 ft**

5. **What is the friction loss per foot of pipe?**

***P* =** $\dfrac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$

***P* =** $\dfrac{4.52 \times 18.0^{1.85}}{120^{1.85} \times 1.185^{4.87}}$

***P* =** $\dfrac{949.3}{16050.7}$

***P* = .059 psi/ft**

6. **What is the total friction loss from S1 to S2?**

P_T **=** L_T x P

P_T **=** 20.2 ft x .059 psi/ft

P_T = 1.19 psi

7. **What is the pressure at S2?**

P_{S2} **=** $P_{S1} + F_T$

P_{S2} **=** 10.3 psi + 1.19 psi

P_{S2} **= 11.49 psi**

8. What flow will sprinkler S2 discharge?

Q = $K \sqrt{P}$

Q = $5.6 \times \sqrt{11.49}$ psi

Q = 5.6 x 3.39 psi

Q = 19.0 gpm

9. What is the total flow required and what pressure is needed to supply both sprinklers and S1 and S2?

Pressure required:

P_T **= 11.49 psi**

Total flow required:

$Q_T = Q_{S1} + Q_{S2}$

Q_T = 18.0 gpm + 19.0 gpm

Q_T **= 37.0 gpm**

Since 37.0 gpm is needed to supply the needs for both S1 and S2, the pipe from S2 to S3 must carry this volume of water. As we are continuing to use 1-inch diameter pipe, this combined volume will result in greater friction loss.

10. What is the friction loss per foot between S2 and S3?

$$P = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$P = \frac{4.52 \times 37.0^{1.85}}{120^{1.85} \times 1.185^{4.87}}$$

$$P = \frac{3600.1}{16050.7}$$

P **= .224 psi/ft**

11. What is the total friction loss between S2 and S3?

$F_T = L_T \times P$

$\boldsymbol{F_T}$ **=** 10.0 ft x .224 psi/ft

$\boldsymbol{F_T}$ **= 2.24 ps**

12. What is the pressure at sprinkler S3?

$\boldsymbol{P_{S3}}$ **=** $P_{S2} + F_T$

$\boldsymbol{P_{S3}}$ **=** 11.49 psi + 2.24 psi

$\boldsymbol{P_{S3}}$ **= 13.73 psi**

13. What flow will sprinkler S3 discharge?

Q = $K \sqrt{P}$

Q = 5.6 x $\sqrt{13.73}$ psi

Q = 5.6 x 3.71 psi

Q = 20.8 gpm

14. What is the total flow required and what pressure is needed to supply sprinklers S1, S2 and S3?

Pressure required:

$\boldsymbol{P_T}$ **= 13.73 psi**

Total flow required:

$\boldsymbol{Q_T}$ **=** $Q_{S1} + Q_{S2} + Q_{S3}$

$\boldsymbol{Q_T}$ **=** 18.0 gpm + 19.0 gpm + 20.8 gpm

$\boldsymbol{Q_T}$ **= 57.8 gpm**

Note that, as we account for friction loss, each sprinkler upstream flows more water as a result of the higher pressures. This excess water is referred to as overage and we can control the overage by keeping the pressure increases from friction loss to a minimum. The simplest method to keeping friction loss down is by increasing our pipe size as our flow increases from adding sprinklers.

Referring to Figure 2.0, if we utilize K5.6 sprinklers and 1-inch Schedule 5 steel pipe, we will need to have a minimum of 57.8 gpm of water and 13.73 psi available at S3 to deliver the density of .15 for the 3 sprinklers. We just completed a simple hydraulic calculation!

Conclusion

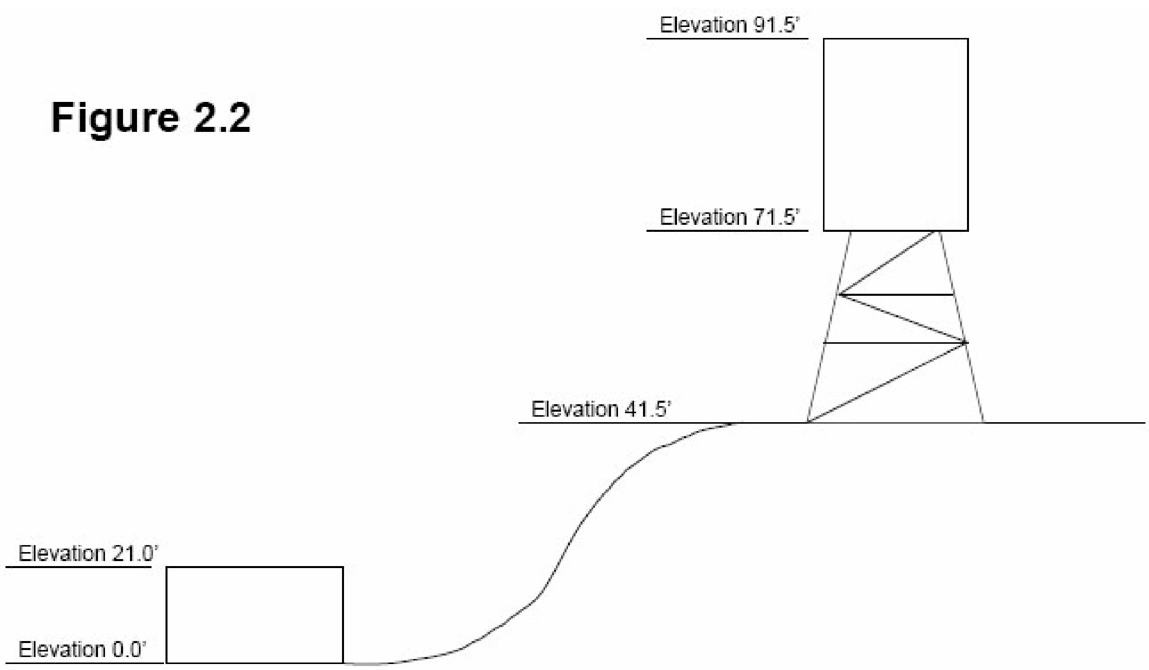
We have built upon the basic concepts that were covered in Part 1 with the principles of elevation, friction loss, and sprinkler flow. We have examined the impact of C-values, pipe sizes, and K-factors on pressure and flow. Using these concepts and principles, we can perform simple line calculations to determine the total flow and pressure needed to supply the desired densities for multiple sprinklers. With this knowledge, we have a foundation for designing systems that provide the desired design criteria at the best possible value.

Use these concepts and principles to complete the following exercises.

Exercises

Exercise Number 1

Use Figure 2.2 to complete the following questions.



Question 1: Use Figure 2.2 for the following questions.

What is the highest static pressure available at grade if the storage tank is filled to the top?

a. 39.6psi
b. 31.0 psi
c. 30.5 psi
d. 30.3 psi

Question 2: Use Figure 2.2 for the following questions.

What is the available static pressure at grade if the tank is three quarters full?

a. 29.7 psi
b. 37.5 psi
c. 28.4 psi
d. 9.9 psi

Exercise Number 2

Question 1

Using the Hazen-Williams formula, what is the friction loss per foot in a 3-inch diameter type k copper tube with 265.0 gpm flowing?

a. .093 psi/ft
b. .072 psi/ft
c. .061 psi/ft
d. .112 psi/ft

Question 2

Using the Hazen-Williams formula, what is the friction loss per foot in a 3-inch diameter Schedule 40 steel pipe (wet) flowing 265.0 gpm?

a. .062 psi/ft
b. .083 psi/ft
c. .058 psi/ft
d. .065 psi/ft

Exercise Number 3

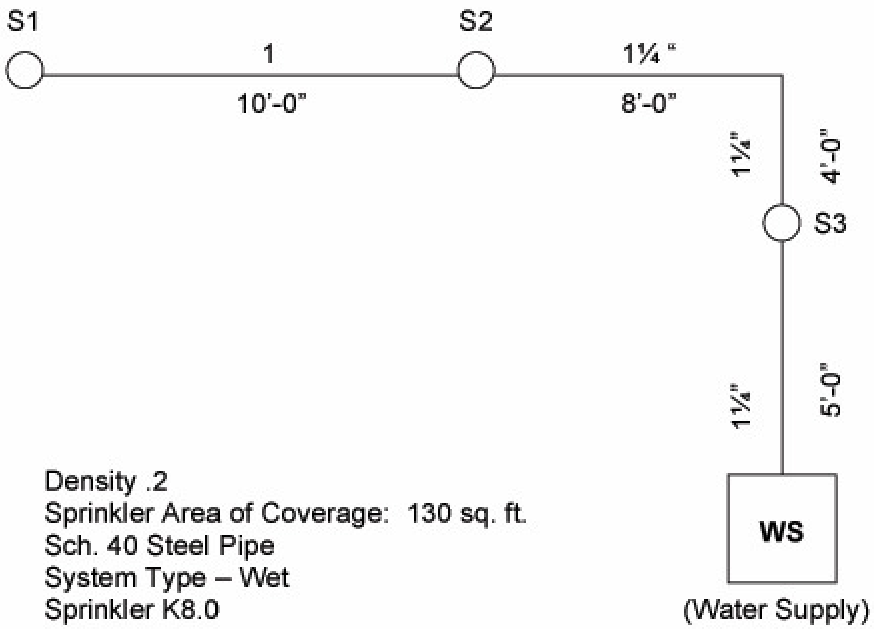
Question 1

What is the total equivalent footage for a dry system with 224 ft. Schedule 10 2.5-inch steel pipe, (2) Tees, (8) 90° long-turn elbows and (1) Butterfly valve?

a. 278 ft
b. 269.9 ft
c. 311.3 ft
d. 285.5 ft

Use Figure 2.3 to complete the following questions.

Figure 2.3



Density .2
Sprinkler Area of Coverage: 130 sq. ft.
Sch. 40 Steel Pipe
System Type – Wet
Sprinkler K8.0
Standard Fittings

Exercise Number 4

What is the minimum needed flow and pressure for sprinkler S_1?

a. 20.5 gpm and 6.7 psi
b. 24.5 gpm and 8.7 psi
c. 26.0 gpm and 10.6 psi
d. 28.5 gpm and 12.6 psi

What is the minimum needed flow and pressure for sprinkler S_2?

a. 26.0 gpm and 10.6 psi
b. 28.0 gpm and 11.6 psi
c. 30.0 gpm and 12.6 psi
d. 32.0 gpm and 14.6 psi

What is the minimum needed flow and pressure for sprinkler S_3?

a. 25.0 gpm and 9.6 psi
b. 26.0 gpm and 10.6 psi
c. 27.0 gpm and 11.6 psi
d. 28.0 gpm and 12.6 psi

What is the actual flow and pressure for sprinkler S_1?

a. 20.0 gpm and 7.6 psi
b. 22.0 gpm and 8.6 psi

c. 24.0 gpm and 9.6 psi
d. 26.0 gpm and 10.6 psi

What is the actual flow and pressure for sprinkler S_2?

a. 28.5 gpm and 12.7 psi
b. 26.5 gpm and 13.7 psi
c. 24.5 gpm and 14.7 psi
d. 22.5 gpm and 15.7 psi

What is the actual flow and pressure for sprinkler S_3?

a. 26.0 gpm and 13.0 psi
b. 28.0 gpm and 14.0 psi
c. 30.0 gpm and 15.0 psi
d. 32.0 gpm and 16.0 psi

What is the total flow and pressure required at the Water Supply?

a. 76.5 gpm and 15.6 psi
b. 86.5 gpm and 18.6 psi
c. 96.5 gpm and 21.6 psi
d. 106.5 gpm and 24.5 psi

What is the total flow and pressure required at the Water Supply if the pipe from S_3 to Water Supply was increased to 1.5 inches?

a. 66.5 gpm and 19.2 psi
b. 76.5 gpm and 18.2 psi
c. 86.5 gpm and 17.2 psi
d. 96.5 gpm and 16.2 psi

Final Exam

1. What is the total equivalent footage for 235 ft of dry 2 inch Schedule 10 steel pipe with four (4) 45° elbows, ten (10) 90° long turn elbows, and two (2) tees?

   A. 313 ft
   B. 290.6 ft
   C. 331 ft
   D. 285.9 ft

2. What is the difference in friction loss per foot of pipe for 885.6 gpm flowing through 5 inch galvanized Schedule 40 steel pipe and 5 inch galvanized Schedule 10 steel pipe? (round to nearest hundredth)

   A. .018 psi/ft
   B. .017 psi/ft
   C. .014 psi/ft
   D. .03 psi/ft

3. Determine the total friction loss for 95.5 gpm flowing through 120 ft of 1.5 inch Schedule 5 galvanized steel pipe with four (4) 45° elbows and two (2) 90° standard elbows.

   A. 26.7 psi
   B. 42.3 psi
   C. 24.9 psi
   D. 39.6 psi

4. Using the following data, determine the minimum flow and pressure required for sprinkler S_1.

   Sprinklers are K8.0
   Area of coverage for sprinkler S_1 is 100 ft^2
   Area of coverage for sprinkler S_2 is 125 ft^2
   Density is .2 gpm/ft^2

   A. 20 gpm @ 7.0 psi
   B. 20 gpm @ 6.25 psi
   C. 21.2 gpm @ 6.25 psi
   D. 21.2 gpm @ 7.0 psi

5. Using the following data, determine the minimum flow and pressure required for sprinkler S_2.

   Sprinklers are K8.0
   Area of coverage for sprinkler S_1 is 100 ft^2
   Area of coverage for sprinkler S_2 is 125 ft^2
   Density is .2 gpm/ft^2

   A. 25 gpm @ 7.0 psi
   B. 21.2 gpm @ 9.8 psi
   C. 21.2 gpm @ 7.0 psi
   D. 25 gpm @ 9.8 psi

6. Using Figure 2.4 and the following data, calculate the flow and pressure for sprinkler S_3 with all sprinklers flowing.

   A. 24.2 gpm @ 18.7 psi
   B. 12.0 gpm @ 4.6 psi
   C. 14.8 gpm @ 7.0 psi
   D. 25.6 gpm @ 12.5 psi