AFSA
American Fire Sprinkler Association

Applied Sprinkler Technology 201: Hydraulic Calculations, Part 1

Course Description

This one hour online course is the first in a 4 part series covering the topic of hydraulic calculations for automatic sprinkler systems. The course is designed to assist designers 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 this course the student will:

- Understand basic terminology
- Understand basic hydraulic concepts including pressure, density, area of coverage, friction loss.
- Be familiar with standard formulas for calculation area of operation (or coverage), minimum flow, sprinkler operating pressure, and K-factors.
- Lay foundation for study of friction loss formulas and simple single line calculations.

Introduction

Hydraulics is the foundation of fire sprinkler system performance. Fire sprinkler systems utilize the concept of removing “heat” to control and extinguish fire. The most basic concept is that sufficient water must be directed on and around the fire to keep combustible materials from reaching their ignition point. Most sprinkler systems are designed to wet the areas around the initial fire area to sufficiently keep the fire contained within the area of origination. In addition, there are system design criteria that are intended to suppress the fire by discharging large volumes of water directly on the fire in its early stages of development. For many years, fire sprinkler design used “pipe schedules” to determine the number of sprinklers and the size of the pipes for different types of hazards. The schedules were a “one size fits all” criteria that was utilized as long as the water supplies supplied a minimum volume and pressure.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, is the most widely used standard for the layout and installation of sprinkler systems. The first edition was published in 1896 and the piping schedules were found in the standard. The 1966 edition of NFPA 13 was the first to include a chapter that addressed hydraulic calculations. The 1975 edition was the first to reference “gridded” systems. Computers made the calculations of these types of systems (gridded) practical. Fire sprinkler systems utilizing NFPA standards are calculated virtually 100 percent of the time.

The first known automatic fire sprinkler system was patented in England in 1723. It consisted of a wooden cask of water, powder charges, and a series of fuses. Its design principles are amazingly similar to today’s systems. It was activated only with heat and its operation was automatic. Systems utilizing perforated pipe were first installed in the United States in the early 1850s. Henry S. Parmelee patented the first practical automatic sprinkler in 1874.

A consolidated set of rules for designing and installing fire sprinkler systems was published in 1896 and led to the formation of the National Fire Protection Association (NFPA) and publication of NFPA 13. NFPA 13 hydraulic design criteria specified pipe schedules for the protection of different hazards. Pipe schedules were based on hydraulic principles and were conservative in nature. However, the schedules did not provide the engineer or layout technician with the opportunity to take advantage of various piping configurations such as loops to boost the efficiency of the system.

The 1966 edition of NFPA 13 was the first to address hydraulic calculations. By the late 1970s, most systems were hydraulically calculated. An interesting phenomenon took place though, in that the pipe schedules were often utilized when the calculations showed that water supply was insufficient for the hazard. The use of pipe schedules was severely restricted, and today’s standards require all systems to be hydraulically calculated with just a few exceptions.

Hydraulic calculations affect virtually all aspects of system design. The basic principles of system design include the following:

- Selection of correct occupancy (hazard) classification
- Proper evaluation of water supplies
- Determination of design criteria
- Selection of most efficient sprinkler(s)
- Selection of most efficient sprinkler spacing and area of coverage
- Selection of most efficient density
- Selection of the most efficient system configuration

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)**

- Basic scientific calculator

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

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.

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

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.

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

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.

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

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

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.

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

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).

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).

Occupancy (Hazard) Classification

The selection of the correct hazard and the evaluation of the water supply are at the very foundation of hydraulic calculations. If either of these two items is incorrect, the rest of the process is flawed. If the engineer or technician selects the incorrect hazard, no matter how well the actual calculation process is performed, the result will be unsatisfactory. The system will either be economically inefficient or will underperform when operating.

The 2007 edition of NFPA 13 addresses Occupancy Classification in Chapter 5. It is important to note that the occupancy classifications found in NFPA 13 are not intended to parallel those found in the building codes. They relate only to fire sprinkler design and installation. The classifications referenced in NFPA 13 include:

- Light Hazard
- Ordinary Hazard Group 1
- Ordinary Hazard Group 2
- Extra Hazard Group 1
- Extra Hazard Group 2
- Special Occupancies (refer to Chapter 21 of 2007 edition of NFPA 13)
- Commodity (storage) Classifications

The classifications are defined, and it should be noted that care should be taken in examining the building or area where protection is contemplated to determine which classification is most proper. The annex of NFPA 13 contains examples of classifications, but ultimately the proper selection must be acceptable to the Authority Having Jurisdiction (AHJ).

Several factors to keep in mind when selecting hazards:

1. Most buildings contain multiple Occupancy Classifications.

2. System Design must protect the building for highest classification or for specific hazards where located.

3. Special Occupancies require expertise in application.

4. The increased use of plastics has had a significant impact on occupancy and commodity classification.

Water Supply

The best designed and installed sprinkler system will not perform to the level intended if the water supply does not satisfy the design criteria. NFPA 13 lists the following as acceptable water supplies:

- A reliable water works
- Gravity tank
- Pressure tank
- Fire pump

Water supplies consist of two components: 1) Volume and 2) Pressure. Water works, gravity tanks, and pressure tanks must supply a quantity of water as well as the pressure to deliver the water to the sprinklers.

Fire pumps are not a water supply on their own. A fire pump takes water that is unusable and provides pressure to allow the available water to satisfy the system needs. Water for fire pumps can come from water works, storage tanks, reservoirs, ponds, rivers, or any source of water that is sufficient to meet the system needs.

Water supplies must be sufficient to meet the system demand at all times. This requires a number of factors to be considered when evaluating water supplies. Some of the factors include:

- Seasonal and daily fluctuations
- Drought
- Future uses and demands (development)

A comprehensive examination of the water supplies is paramount to successful sprinkler design and operation. AHJs (including the owner) are required by NFPA 13 to approve the water supply information and give consideration to the factors listed on the previous page. Do not gloss over this. There is an important formula that must not be ignored:

P(u) = $(s)
[Pressure Unused equals Dollars Spent]

Once the water supply for the sprinkler system has been determined and agreed upon, a major purpose of the hydraulic calculations is to provide a system that provides the necessary protection in the most cost efficient manner. The engineer and technician will use as much as needed (all if necessary) of the available pressure (after the evaluation) to design the system utilizing the fewest number of sprinklers, least amount of pipe, and smallest piping sizes possible.

Design Criteria

Chapter 11 of NFPA 13 addresses Design Approaches. The selection of the design approach is at the discretion of the designer/layout technician. The most widely used approaches are Occupancy Hazard Fire Control and Density/Area. Density/Area is the most commonly used design method and will be the basis for our examination of design criteria.

The Density/Area method is based on the sprinklers delivering a specified density over a corresponding area of sprinkler operation. The criteria were determined by fire tests and years of actual fire experience. The theory is simple: Lower densities on the curve require a larger area of operation before fire control is achieved.

The minimum water supply needed for fire sprinkler design using Density/Area is determined by using Figure 11.2.3.1.1 and Table 11.2.3.1.2, found in the 2007 edition of NFPA 13.

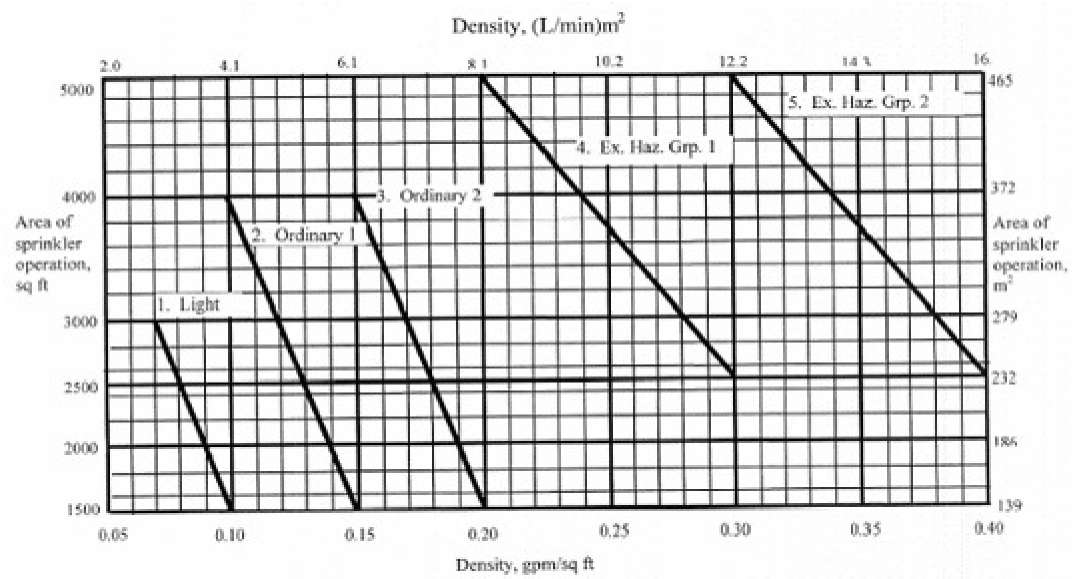

Figure 11.2.3.1.1 reprinted with permission from NFPA 13-2007, Installation of Sprinkler Systems, Copyright © 2007. National Fire Protection Association, Quincy, MA 02169. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

Minimum sprinkler flow is determined by the following formula:

Q = A x D

Q = flow (gpm)
A = Area of Operation
D = density (gpm/ft2)

It should be noted that only one point on the design curve must be satisfied and the point can be selected at the designer/layout technician's discretion.

Design Criteria Examples

A) Utilizing the Light Hazard curve a density of .1 gpm/ft^2 is selected. The corresponding area of operation is 1500 ft^2.

Q = 1500 ft^2 x .1 gpm/ft^2
Q = 150 gpm

B) Utilizing the Light Hazard curve a density of .07 gpm/ft^2 is selected. The corresponding area of operation is 3000 ft^2.

Q = 3000 ft^2 x .07 gpm/ft^2
Q = 210 gpm

In addition to the water needed for the sprinklers, an additional quantity of water is anticipated to be needed for manual fire fighting. This is referred to as Hose Allowance.

Hazard Classification	Inside Hose (gpm)	Total Combined Inside & Outside Hose (gpm)	Duration in Minutes
Light	0, 50 or 100	100	30
Ordinary	0, 50 or 100	250	60-90
Extra Hazard	0, 50 or 100	500	90-120

Table 11.2.3.1.2 reprinted with permission from NFPA 13-2007, Installation of Sprinkler Systems,

The hose allowance is selected from the **Total Combined Inside and Outside Hose** column for the selected Occupancy.

The total minimum demand is determined by adding the sprinkler flow to the hose allowance. Recalling Examples A and B from page 5, the total demand for each would be:

A. 150 gpm plus a hose allowance of 100 gpm equals a total demand of 250 gpm

B. 210 gpm plus a hose allowance of 100 gpm equals a total demand of 310 gpm

In addition to the demand (gpm) we must also determine the total supply needed (gal). Table 11.2.3.1.2 on page 6 has a column labeled **Duration**. The Duration is the length of time that our water supply must deliver the demand. For Light Hazard it is 30 minutes. Note that the Duration for Ordinary and Extra Hazards have two choices. The lower Duration is for systems where the flow of water is monitored 24 hours per day at a constantly attended location. The supply needed for our two examples includes:

A. 250 gpm x 30 min = 7500 gal

B. 310 gpm x 30 min = 9300 gal

Sprinkler Selection

The selection of the most efficient sprinkler to meet the design criteria is the single most important decision in the hydraulic calculation process. The types and sizes of sprinklers available to the engineer and technician have exploded over the last 20 years. However, there are some basic hydraulic principles that apply to all sprinklers:

- The minimum pressure that any sprinkler may operate is 7 psi.
- The larger the orifice the less pressure required to flow an equal amount of water.
- Temperature rating of sprinkler has no impact on the *procedure* of calculations.
- Speed of operation (RTI) has no impact on the *procedure* of calculations.

Using the Density/Area design method, the minimum flow for a sprinkler uses the same formula as that for the total system demand:

Q = A x D

Spacing requirements of the maximum areas of coverage for an individual sprinkler are found in chapter 8 of NFPA 13. The method for determining the area of coverage on a sprinkler is found in 8.5.2. The formula is:

A = S x L

A = Area of coverage (ft^2)
S = Dimension along the branch line*
L = Dimension between the branch lines**

S = Dimension along the branch line

***S Dimension**—Determine the distance between sprinklers along the branch line (or to the wall or obstruction in the case of the end sprinkler) upstream and downstream and choose the larger of either twice the distance to the wall or obstruction or the distance to the next sprinkler.

L = Dimension between the branch lines

****L Dimension**— Determine the perpendicular distance to the sprinkler on the adjacent branch line (or to a wall or obstruction in the case of the last branch line) on each side of the branch line and choose the larger of either twice the distance to the wall or obstruction or the distance to the next branch line.

With area of coverage for the sprinkler calculated, we can now complete the formula for determining the minimum flow required for the sprinkler.

Once we have determined the minimum flow, we can calculate the operating pressure of a sprinkler. The formula consists of 3 variables:

Q = Flow (gpm)
K = K-Factor
P = Pressure (psi)

The K-factor of a sprinkler is based on the size of the orifice and is assigned by the manufacturer. Chapter 6 of NFPA 13 mandates that sprinklers be classified by their discharge characteristics which include nominal orifice sizes and referenced by the corresponding nominal K-factor.

The formula for calculating sprinkler pressure is:

$P = (Q/K)^2$

A. **A K-5.6 sprinkler requires a minimum flow of 16 gpm. What is the sprinkler operating pressure?**

$P = (16.0\ gpm/5.6)^2$
$P = (2.86)^2$
$P = 8.2\ psi$

B. The minimum flow required for a sprinkler is 25 gpm. What is the sprinkler operating pressure when using:

a K-8.0 sprinkler?

$P = (25.0\ gpm/8.0)^2$
$P = (3.13)^2$
$P = 9.8\ psi$

a K-5.6 sprinkler?

$P = (25.0\ gpm/5.6)^2$
$P = (4.46)^2$
$P = 19.9\ psi$

Example B illustrates the significant pressure savings by using a K- 8.0 sprinkler.

Using differing K-factor sprinklers is one way of reducing (or increasing) the operating pressure of the sprinkler. The other option is to lower the flow variable. This can be accomplished by reducing the operating area of the sprinkler or using a lower density.

A. What is the operating pressure of a K-5.6 sprinkler delivering a density of .1 gpm/ft^2 with a:

200 ft^2 area of coverage?

$Q = A \times D$
$Q = 200\ ft^2 \times .1\ gpm/ft^2$
$Q = 20.0\ gpm$

$P = (Q/K)^2$
$P = (20.0\ gpm/5.6)^2$
$P = (3.57)^2$
$P = 12.8\ psi$

A. What is the operating pressure of a K-5.6 sprinkler delivering a density of .1 gpm/ft^2 with a:

150 ft^2 area of coverage?

$Q = 150\ ft^2 \times .1\ gpm/ft^2$
$Q = 15.0\ gpm$

$P = (15.0\ gpm/\ 5.6)^2$
$P = (2.68)^2$

P = 7.2 psi

Friction Loss

Friction loss describes the pressure (force) that is used to move the water between two points. Friction is the resistance that the surface of the pipe creates against the movement of water. Several factors increase or decrease the resistance and thus the amount of force (pressure) needed to overcome the resistance. The factors include:

- Smoothness of the pipe
- Diameter of the pipe
- Volume of water

The smoothness of pipe is designated by C-Factor. The larger the C-Factor, the smoother the surface. Different types of materials have different C-Factors. For instance, black steel is designated to have a C-Factor of 120. Plastic, such as CPVC, has a C-Factor of 150. Pipe use also affects the C-Factor. For instance, black steel used in a dry sprinkler system is given a C-Factor of 100.

The diameter of pipe impacts the friction loss. The greater the surface area between the water and the pipe, the less force required to overcome friction. Thus larger pipe moving the same volume of water will have less friction loss. Conversely, more or less water moving through the same diameter pipe will create greater or lesser friction and therefore use more or less pressure to move the water.

Conclusion

We have examined a number of basic concepts pertaining to the hydraulic calculation of sprinkler systems. The foundation of all system design is the identification of the correct hazard and the proper evaluation of the water supply. We focused on the use of the Density/Area curves and the relationship between the two variables.

We have explored the basic formulas for determining the area of coverage, sprinkler flow, and sprinkler pressure and how each is related in selecting the most efficient design components.

Use this information to complete the following exercises and questions.

Exercises

Use the two images below to complete the following questions and exercises.

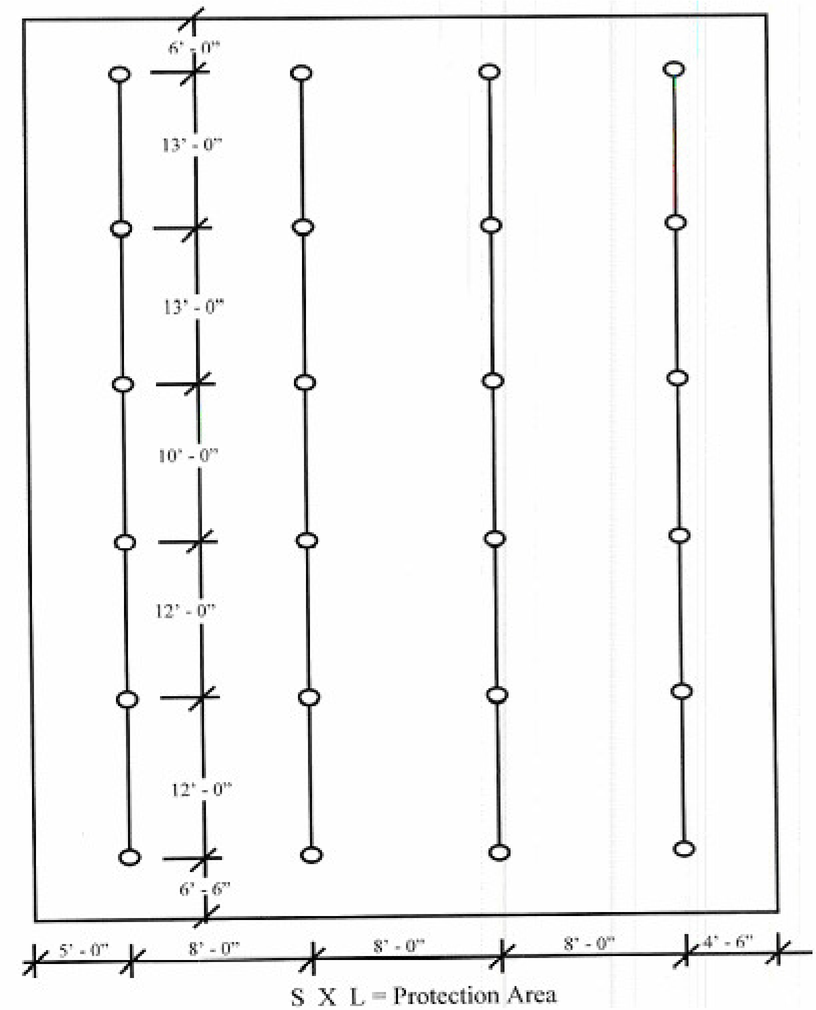

Figure 1.0

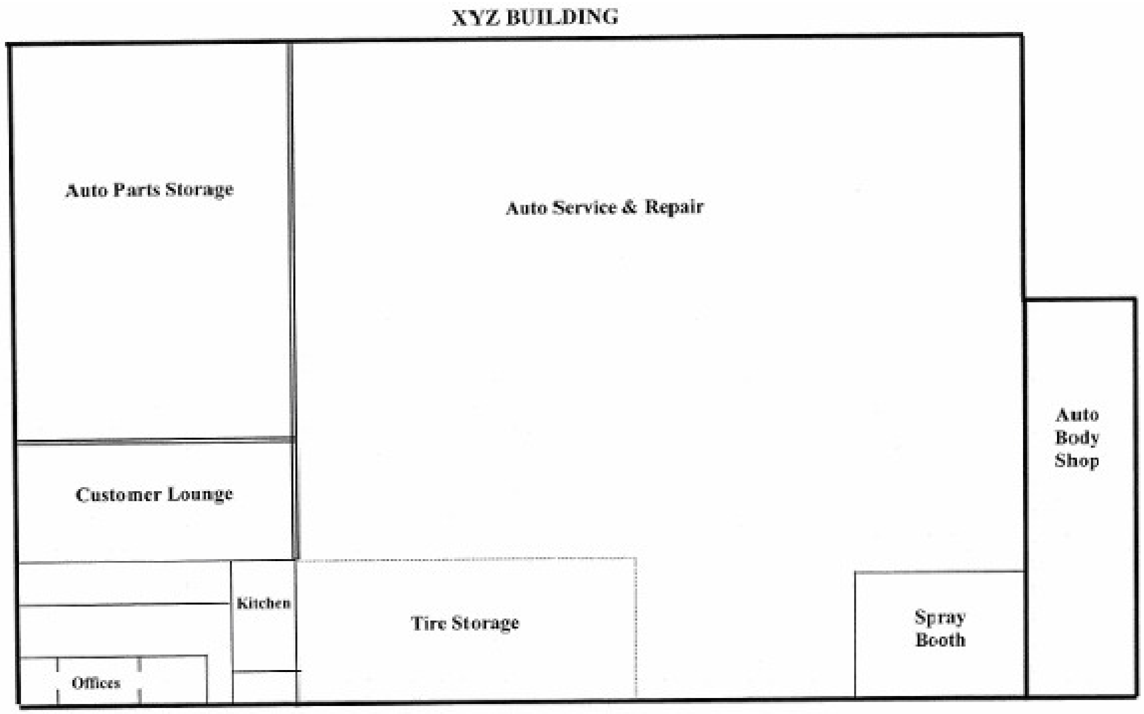

Figure 1.1

Exercise Number 1: Occupancy Classifications

1. Using Figure 1.1, identify the Occupancy classification for the following areas.

   The office is a(n):

   a. light hazard
   b. ordinary hazard group 2
   c. extra hazard group 1
   d. commodity classification

   The customer lounge is a(n):

   a. light hazard
   b. ordinary hazard group 2
   c. extra hazard group 1
   d. commodity classification

   The Auto Service and Repair area is a(n):

   a. light hazard
   b. ordinary hazard group 2
   c. extra hazard group 1
   d. commodity classification

Exercise Number 2: Water Supply

1. A building is identified as a light hazard occupancy. The selected area of operation is 3000 ft^2. Click here to open Figure 11.2.3.1.1 in a new window. You'll need it in order to answer the following question.

   What is the minimum flow required for this sprinkler system?

   a. 210 gallons per minute
   b. 122 gallons per minute
   c. 55 gallons per minute
   d. 400 gallons per minute

   What is the total water supply needed?

   a. 7300 gallons
   b. 8300 gallons
   c. 9300 gallons
   d. 10,300 gallons

2. A full service medical center (hospital) is being developed. Upon considering all of the possible occupancy classifications:

   What is the highest likely occupancy classification?

   a. Ordinary Hazard Group 3
   b. Ordinary Hazard Group 2
   c. Light Hazard
   d. None of the above

   What is the greatest possible required sprinkler flow?

   a. 200 gallons per minute
   b. 350 gallons per minute
   c. 425 gallons per minute
   d. 600 gallons per minute

   What is the highest likely water supply needed?

   a. 76,500 gallons
   b. 96,500 gallons
   c. 126,500 gallons
   d. 146,500 gallons

Exercise Number 3: Area of Coverage

For the following question, please either print this page or use a separate sheet of paper to write down your answers. The answer key for this exercise is located at the end of the chapter.

Using Figure 1.0, what is the area of coverage for the following?

A. _______________

B. _______________

C. _______________

D. _______________

E. _______________

Exercise Number 4: Minimum Sprinkler Flow

Using Figure 1.0, if the hazard classification is Ordinary Group 2, what is the minimum flow required for:

A. _______________

B. _______________

E. _______________

Exercise Number 5: Sprinkler Pressure

Using Figure 1.0 and the minimum flows from Exercise number 4, what is the sprinkler operating pressure for a K-5.6 Sprinkler?

A. _______________

C. _______________

E. _______________

Using Figure 1.0 and the minimum flows from Exercise number 4, what is the sprinkler operating pressure for a K-8.0 Sprinkler?

A. _______________

B. _______________

E. _______________

Exercise Number 3: Area of Coverage

Answer Key

Using Figure 1.0, what is the area of coverage for the following?

A. 130 ft^2

B. 120 ft^2

C. 120 ft^2

D. 130 ft^2

E. 117 ft^2

Exercise Number 4: Minimum Sprinkler Flow

Answer Key

Using Figure 1.0, if the hazard classification is Ordinary Group 2, what is the minimum flow required for:

A. 26 gallons per minute

B. 24 gallons per minute

E. 23.4 gallons per minute

Exercise Number 5: Sprinkler Pressure

Answer Key

Using Figure 1.0 and the minimum flows from Exercise number 4, what is the sprinkler operating pressure for a K-5.6 Sprinkler?

A. 21.6 psi

C. 18.4 psi

E. 17.5 psi

Using Figure 1.0 and the minimum flows from Exercise number 4, what is the sprinkler operating pressure for a K-8.0 Sprinkler?

A. 10.6 psi

B. 9.0 psi

E. 8.6 psi

Final Exam

1. Which of the following is true when choosing the design criteria for a fire sprinkler system?

A. Each area of the building must be designed independently.
B. A single occupancy must be chosen for the entire building the system is protecting.

C. The system may be designed to protect the entire building for the highest hazard found.
D. The design criteria must be determined by the building architect.

2. Which of the following must be considered when evaluating the water supply for a sprinkler system?

A. Seasonal fluctuations
B. Future development plans
C. Volume of stored water
D. All of the above
E. None of the above

3. Sprinkler orifice sizes are designated by K-factor. Using NFPA 13 as your guide, which of the following is not a recognized K-factor?

A. 1.4
B. 14.0
C. 5.6
D. 21.0
E. 28.0

4. Using NFPA 13, what is the C-factor (Value) for all Galvanized steel pipe?

A. 100
B. 120
C. 140
D. 150
E. None of the above

5. Which of the following is the formula for determining area of coverage of a sprinkler?

A. A = S x L
B. A = Q x D
C. A = S/L
D. A = L/S