

Technical Article

Calculating Friction Loss

Darcy-Weisbach Formula vs. Hazen-Williams: Why Darcy is the Appropriate Selection in Large Volume Sprinkler Systems That Use Propylene Glycol

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Introduction

Propylene glycol has been widely accepted and utilized in fire sprinkler systems for many years. Until recently it has been restricted to antifreeze loops on wet pipe sprinkler systems. Innovative advances in the design of sprinkler systems and full-scale fire testing of class 2 commodities in rack storage configurations have demonstrated that sprinkler systems pre-primed with a water and propylene glycol solution utilizing K 25.2 sprinklers are a viable option for the protection of cold storage occupancies under certain conditions.

Full-scale burn testing has been conducted utilizing specific types of sprinkler systems; propylene glycol solutions and K 25.2 ESFR sprinklers that have been specifically tested for the application. The listings and manufacturer's installation instructions for these propylene glycol systems are very specific with regards to the type of system, the system volume and the piping configuration. If a system is selected to protect a cold storage occupancy using a propylene glycol solution, the fire protection designer must verify the appropriate product listings. In addition, the manufacturer's technical literature must be reviewed to ensure that the system design is in compliance with the listings and that all of the required components have been installed.

Application

There are currently two sprinkler system configurations utilized for installation in cold storage applications that utilize piping pre-primed with the propylene glycol solution. The early versions of these systems were wet pipe sprinkler systems. However through improvements and modifications implemented to enhance system performance in cold storage environments, the optimal system has evolved into a single interlock preaction system pre-primed with propylene glycol solution rather than pressurized air. In both cases these systems are used in conjunction with K 25.2 sprinklers that have been specifically tested for the application. K 25.2 sprinklers allow the designer more flexibility in the design and may allow the in-rack sprinklers required for the rack storage to be removed. In either case, a 50 % or 35% propylene glycol and water solution will be used depending on what the minimum temperature is expected to be in the cold storage environment.

In addition to evaluating manufacturer's recommendations and the specific equipment required for these special sprinkler systems, the designer must approach the hydraulic calculation with the understanding that a liquid other than water will initially be moving through the piping network. Traditionally, when the fire protection designer is performing the hydraulic calculation for a sprinkler system in accordance with NFPA 13, the Hazen-Williams formula for determining the friction loss is adequate. However, because the propylene glycol solution is a much more viscous liquid than water, the system volumes are much larger than a traditional antifreeze loop, and the cold storage environment may experience sustained temperatures as low as -20 degrees Fahrenheit, the Darcy-Weisbach formula must be used in one of the two required hydraulic calculations for systems utilizing a propylene glycol solution.

The Darcy-Weisbach formula for calculating friction loss is more accurate than Hazen-Williams for determining friction loss in piping in several situations encountered in sprinkler system design including the calculations for foam concentrate (not solution) piping, high water velocities above 40 ft/sec such as those in water mist systems and the friction loss calculations for antifreeze systems especially when these systems have a large volume and are in areas with very low temperatures such as cold storage areas. The primary reason for this is that the Hazen-Williams formula does not allow the user to take into account a change in the viscosity of a liquid being calculated. The Darcy-Weisbach formula does allow the user to modify the viscosity of liquid being calculated when determining a part of the equation called the Reynolds Number, which we will define later in the article.

Viscosity

Crane's Technical Paper No. 410 Flow of Fluids Through Valves, Fittings and Pipe states that the viscosity of a liquid can be expressed as the readiness with which a fluid flows when acted upon by an external force or shear stress. It only stands to reason that the more viscous propylene glycol will interact with the piping wall differently than the less viscous water at room temperature. In the freezer environment, where the temperature can be maintained well below zero, the already high viscosity of propylene glycol solution will increase dramatically, underscoring the need for the more accurate Darcy-Weisbach calculation where changes in viscosity can be taken into account.

The viscosity units for a fluid can be expressed as either the dynamic (absolute) viscosity or the kinematic viscosity. The unit for the absolute (dynamic) viscosity of a fluid is the poise, which is equal to 100 centipoise. For example, the viscosity of water at 60 degrees Fahrenheit is approximately 1.02 centipoise where as the viscosity of a 50% propylene glycol solution at the same temperature is 8.13 centipoise. Kinematic viscosity is the ratio of the absolute viscosity to the mass density and is expressed as:

$$\kappa = \mu/s$$

Where

κ = kinematic viscosity

μ = dynamic viscosity

s= specific gravity of the liquid

The unit for Kinematic viscosity is called a stoke where one stoke is equal to 100 centistokes. The designer of the system must determine which way the viscosity units (dynamic or kinematic) have been provided by the antifreeze manufacturer to ensure the Darcy-Weisbach formula is performed properly. The example provided below will use the poise dynamic viscosity units.

Formula History

To gain an understanding of exactly where the differences lie between Hazen-Williams and Darcy Weisbach it is important to understand the history of each formula and the factors each takes into consideration when calculating friction loss. As described by Harold Wass in Sprinkler Hydraulics each formula was derived from and uses the fundamental concepts developed by the French engineer Antoine de Chezy. In Chezy's formula, friction loss is calculated by using a coefficient reflecting the roughness of the pipe, the internal hydraulic radius of the pipe and the hydraulic slope, which is the friction loss per unit length of pipe. The formula is expressed as:

$$v = c\sqrt{rs}$$

where

c= coefficient for pipe roughness

r= internal hydraulic radius

s = the hydraulic slope or friction loss per length unit

This formula was refined further by several engineers including Henri Darcy and Julius Weisbach into what is referred to today as the Darcy-Weisbach formula. The Darcy-Weisbach formula expands on the concept of the friction factor first utilized by Chezy and modifies the formula into:

$$h = f L/D \times V^2/2g$$

h= friction loss (ft of head)

f= friction loss factor (from Moody Diagram)

L=length of pipe or tube (ft)

V= velocity of flow in tube (ft/sec)

D= diameter of pipe (ft)

g= gravitational constant = 32.2 ft/sec

To the experienced fire protection designer, most of the information required to complete the calculation in the Darcy-Weisbach formula is familiar and self-explanatory. However, as we stated above the formula has expanded on the concept of the friction factor (f). The friction factor is determined by using what is called the "Moody Diagram". As of the time of the writing of this article, the "Moody Diagram" is only found in two locations readily available to the fire protection designer. NFPA 750, the standard for Water Mist Systems, and the Fire Protection Handbook both provide copies for reference and several hydraulic calculation programs have options for Darcy-Weisbach calculations. Because the calculation of the friction factor is complicated and time consuming, this formula was later modified again into the simpler Hazen-Williams formula.

Reynolds Number

The "Moody Diagram" requires the fire protection designer to calculate what is called the Reynolds Number and to identify the average protuberance of the piping material. The Reynolds Number can be defined as the ratio of the dynamic forces of mass flow to the shear stress due to viscosity. The protuberance or roughness of the piping is identified by the Greek symbol epsilon (ϵ) and can

be supplied by the pipe manufacturer. When the Reynolds Number and the relative roughness have been determined, the Moody Diagram is used to determine (the friction factor) for use in the calculation in the Darcy-Weisbach formula. It is during the calculation of the Reynolds Number that the viscosity of liquid is used in the formula. Depending on whether the propylene glycol solution manufacturer has supplied the kinematic or dynamic viscosity units the Reynolds Number can be calculated in several ways.

If the dynamic (absolute) viscosity is provided the Reynolds number may be determined using either:

$$RE = 50.6Q\rho/d\mu$$

Where

Q= flow (gpm)

d= internal pipe diameter (in.)

ρ = weight density of fluid

μ = dynamic (absolute) viscosity

Or by using

$$RE = \rho vd/\mu$$

Where

ρ = density

v= velocity

d= internal pipe diameter (feet)

μ = dynamic (absolute) viscosity

If the kinematic viscosity is provided, the Reynolds number may be determined by using:

$$RE = vd/\kappa$$

Or

$$50.6Q/d\kappa$$

Where

v= velocity

d= internal pipe diameter (feet)

κ = kinematic viscosity

When using any of the above methods for determining the Reynolds Number the viscosity of liquid is used. Depending on the temperature of the cold storage environment the viscosity of the propylene glycol solution is going to change. The dynamic (absolute) viscosity of propylene glycol solution at 60 degrees Fahrenheit is 8.13 Centipoise and 180 Centipoise at -20 degrees Fahrenheit. Given the large change in viscosity it can be anticipated that the friction factor determined on the "Moody Diagram" will be completely different at the two temperatures.

Example

If we use the Darcy-Weisbach Formula to calculate the friction loss for 400 gallons of propylene glycol with a 50% solution flowing through 30 feet of 2.5 inch schedule 40 steel pipe at 60 degrees Fahrenheit and then again at -20 degrees Fahrenheit we see the following. To ensure a proper calculation designers must ensure they are using the roughness (ϵ) for older pipe not new pipe. For example the roughness (ϵ) for new steel pipe is .00015 (ft); this equates to a C factor of 140 in Hazen Williams. So the roughness

factor must be adjusted to account for age and corrosion like the C factors in Hazen Williams. In this case the roughness (ϵ) used will be .00033 (ft), which equates to a C factor of 120 in Hazen Williams.

Using the above parameters at 60 degrees the friction loss is calculated at approximately 16 psi over the 30 feet of pipe. Using the exact parameters above by adjusting the viscosity units for the decrease in temperature to -20 degrees the friction loss is calculated at approximately 35 psi for the 30 feet of pipe. As you can see there is a 19-psi difference. If the fire protection designer did not account for the difference in the liquids viscosity the calculation of friction loss would have been corrupted.

Hazen-Williams

In the early 1900's Gardner Williams and Allan Hazen again modified the Chezy formula into the Hazen-Williams formula, as we know it today. As with the Darcy-Weisbach formula the internal roughness of the piping, flow of water, velocity and hydraulic slope are taken into consideration during the calculation of friction loss. However, the Hazen-Williams formula was not revised to take into consideration different viscosities of liquids like the Darcy-Weisbach formula does during the calculation of the Reynolds Number. Instead the Hazen-Williams formula uses a pipe roughness coefficient called the "C" factor only. The "C" factor is a measure of the roughness of the pipe internal wall. The "C" factor can be compared to the epsilon value used in Darcy-Weisbach calculation; however, as we discussed before there are more variables taken into consideration to determine the "f" factor.

The "C" factors described in NFPA 13 for pipe are:

Unlined Cast or Ductile Iron	100
Black Steel (Dry Systems)	100
Black Steel (Wet Systems)	120
Galvanized	120
Cement Lined Cast or Ductile Iron	140
Plastic (listed)	150
Copper Tube	150
Stainless Steel	150

A calculation using Hazen-Williams and Darcy-Weisbach to calculate the friction loss over 30 feet of schedule steel pipe using the same parameters we used earlier in the Darcy calculation provides a useful comparison. At room temperature the friction loss would be calculated at approximately 15.5 psi using Hazen-Williams. These results are almost identical to Darcy-Weisbach at the same temperature. Again the change occurs when there is a decrease in temperature and the viscosity of the propylene glycol solution changes dramatically.

Conclusion

Regardless of which formula is being used the purpose of applying a friction loss formula is to ensure that sprinkler system design has properly accounted for the loss of pressure within the flowing water or water antifreeze solution due to friction with the internal pipe wall. Because fire protection hydraulics is only concerned with a few basic elements in the flow computations, additional steps must be taken for a fluid other than water.

Historically, as Harry Hickey describes in Hydraulics for Fire calculation; however, evaluating flow in sprinkler systems we have been able to make the following assumptions. The fluid being calculated is water. The weight of water is 62.4 pounds per cubic foot. The water temperature range is between 45 and 75 degrees F. The Flow velocities will typically range between 5 to 18 feet per second. Finally, we will have a known pipe roughness coefficient. Given the differences in these values that can be seen when using a propylene glycol solution it is not prudent for the fire protection designer to make these same assumptions. Although the Darcy-Weisbach formula can be more complicated than Hazen-Williams, when designing the piping network for these special fire protection systems with propylene glycol solution it is imperative that the designer use it to ensure an accurate calculation of friction loss.

References

Crane Technical Paper No. 410, Flow of Fluids Through Valves, Fittings, and Pipe. Crane Co., Signal Hill CA, 1988.

Hickey Harry E., Hydraulics for Fire Protection, National Fire Protection Association, Quincy MA, 1980.

Wass Harold S., Sprinkler Hydraulics and What it's all about, 2nd edition, Society of Fire Protection Engineers, Bethesda MD, April 2000.