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Technical Article

Hydraulic Calculations: One Method for Adjusting Flows for Liquids Other Than Water

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When conducting hydraulic calculations of automatic sprinkler systems it's a valid assumption that the fluid is clear water with a weight density of 62.4 lbs/ft³ in all but a few situations . Applications where antifreeze ssolutions or foam water solutions are required change the weight density of the fluid medium being calculated, and in some cases may require a conversion of the standard flow formula Q = K√P to calculate accurate sprinkler flow. Various NFPA standards address these situations in different ways and provide the system designer with guidance as to whether or not a flow conversion should be considered.

Density and Specific Gravity

Before addressing the specific situations it is important to review the fundamental principles used in fire protection hydraulics and where the standard flow formulas come from. We know as previously stated that one cubic foot of clear water weighs 62.4 lbs. If we assume that the vessel holding this water measures one foot on either side the total weight of 62.4 lbs is exerted on the bottom area of 1 ft² or 144 in². The pressure is then 62.4 lbs/ft² or .433 lbs/in². The pressure per square inch is calculated simply by dividing 62.4 by 144. This means that for every elevated foot of water the pressure at the bottom of a water column will be increased by .433psi. For example if a water column stood 30 ft tall the pressure at the bottom would be 30ft x .433psi = 13psi.

The converse relationship uses these fundamental principles to determine the feet of potential head. Head is a term that is generally describes how many feet the water column extends above the base of the column. Using the reciprocal of .433 or 1÷.433 = 2.31 we can determine that the potential head (h) by using the formula h = 2.31p where (p) is equal to pounds per square inch (psi). For example; if a gauge reads 43.3psi at the base of a water storage tank, multiplying 43.3psi x 2.31= 100 ft. The water column is 100 ft tall.

Another important relative measurement is specific gravity. The specific gravity (Sg) of a substance may be defined as the ratio of the weight density of a substance to the weight density of another substance, typically water at 39.2° F which has a specific gravity of 1.0 .

Sg = Wa÷Wb

Where

Sg= specific gravity
Wa = weight of substance lbs/ft³
Wb= weight of water 62.4 lbs/ft³

For example, if the density of a propylene glycol and water solution is 64.96 lbs/ft³ at 60°F we can determine the specific gravity as follows:

64.96 ÷ 62.4 = 1.041 Sg at 60°F

Understanding the concept of specific gravity becomes particularly useful when dealing with flammable and combustible liquids. Liquids with a specific gravity less than water (1.0) will float on the surface of the water and liquids with a higher specific gravity than water will sink below the surface of the water. The specific gravity will also be an essential piece of information for modifying flow formulas.

Theoretical Flow from an Orifice

The foundation formula for flow through an orifice is Q = av where :

Q= flow in cubic feet per second
a= the cross sectional area in square feet
v= velocity in feet per second

The formula for area in square feet is:

$a = \pi D^2 \div 4$

Converting the formula to find the area in square inches the formula is modified to:

$A= \pi d^2 \div 576$

Velocity can be expressed as:

$v= \sqrt{2gh}$ where:

v= velocity
g= acceleration due to gravity (32.2 ft/sec)
h= the head in feet (2.31P)

The theoretical flow from an orifice formula can be written as :

$Q = \pi d^2 \div 576 \sqrt{2gh}$

Understanding that we will have to convert Q to gallons per minute the formula needs to be modified further to insert 7.48 gallon per cubic foot and 60 seconds in one minute:

$Q = 60 \times 7.48 \times \pi d^2 \div 576 \sqrt{2gh}$

When simplified, and the discharge coefficient (c) is added for the orifice, the formula is written as:

$Q = 29.84cd^2\sqrt{P}$

This formula should be familiar to anyone who has evaluated a water supply by measuring velocity pressure from a fire hydrant.

The formula can be reduced further to a single constant "K" for a given sprinkler:

$Q = K\sqrt{P}$

It is important to remember that a fundamental part of this formula was derived based on the weight density of water. From our earlier examples we know that our potential head was calculated using 2.31P. This was calculated using a weight density of clear water of 62.4 lbs/ft^3. Part of our equation for flow from an orifice ($v= \sqrt{2gh}$) also written as ($v= \sqrt{(2) (32.2) (2.31) (P)}$) uses the assumption that it is the weight density of water 62.4 lbs/ft^3 in the calculation of velocity. If the fluid medium is different than water than the weight density will be different which may require a conversion in the formulas for accurate flow measurement.

Flow conversions: When are they appropriate?
As stated earlier, there are a limited number of cases when the fluid medium within the sprinkler system is not solely clear water. These can include applications where foam water solutions or antifreeze solutions are required. NFPA 16 Standard for the Installation of Foam-Water Sprinkler and Foam Water Spray Systems has address the procedure for the hydraulic calculation of piping carrying foam water solution by stating that the piping shall be sized as if carrying plain water. In this case no flow conversion is required for the system to ensure an accurate measurement.

However, new language has been added to the 2007 edition of NFPA 13 Standard for the Installation of Sprinkler Systems in section 22.4.4.5.1 and A. 22.4.4.5.1 which states "For antifreeze solutions greater than 40 gal in size, the friction loss shall also be calculated using the Darcy Weisbach equation shown in 22.4.2.1.3 using the Moody diagram, ε-factors that are represented for aged pipe, and adjusted K-factors for fluid properties."
A.22.4.4.5.1 goes on to state: "Published K factors are based upon water at ambient conditions and need to be modified to address different fluid properties".

This makes perfect sense for sprinklers that are not listed with an antifreeze solution. Sprinklers such as the Viking K 25.2 ESFR have been through extensive fire tests with propylene glycol solution and this listing of this sprinkler describes the concentrations of propylene glycol allowed at specific starting pressures, so no adjustment is required. However, when using sprinklers that have not been through testing with an antifreeze solution NFPA 13 now requires a K factor adjustment to the selected sprinkler because the density of antifreeze solution can increases dramatically, especially at temperatures below freezing, and we know from the information earlier that the formulas used in standard hydraulic calculations assume the fluid medium is water between 40°F and 100°F. The purpose of adjusting the sprinkler K factor is ultimately to achieve a higher starting pressure for the sprinkler. A higher starting pressure will result in higher flow rates. It is important to keep in mind that the actual K factor does not change. The adjustment is a change in the formulas only which results in the higher starting pressure.

The critical piece of information needed to make the adjustment is the specific gravity of the antifreeze solution being used. This varies with temperature so it is important to contact the antifreeze manfuacturer for specific information about the type of antifreeze being used, concentration of antifreeze in the solution, minimum temperature expected in the area where the sprinkler system is being used and finally the weight density or specific gravity of the antifreeze solution. It is important to keep in mind that "solution" refers to when the antifreeze is mixed with water.

Once the specific gravity for the antifreeze solution has been determined the flow conversion can begin with our formula:

The standard formula is $Q = K\sqrt{P}$

Adjusting the formula with the specific gravity of the antifreeze solution the formula becomes $Q = K\sqrt{P \div Sg}$.

For example, if the antifreeze loop was greater than 40 gallons as described in NFPA 13 in an area with sustained temperatures at -20°F and a 50% propylene glycol and water solution is being used, the specific gravity of the solution is 1.085. The project is OH-2 with sprinkler spaced at 130 ft² and a density requirement of .2 gpm/ft². K factor 8.0 sprinklers have been selected.

Flow required is:

130 x .2 = 26 gpm.

Using the standard formula without conversion the required starting pressure is:

$P = (Q \div K)^2$

$P = (26 \div 8)^2$

P = 10.56psi

When using the adjusted formula to calculate flow when considering the antifreeze and the starting pressure of 10.56psi ÷ 1.085 we can see what the actual flow would be with a propylene glycol solution.

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

$Q = 8.0 \sqrt{10.56 \div 1.085}$

Q= 24 gpm

We see that there is a 2 gpm difference between the water calculation and the antifreeze calculation. The initial sprinkler flow will be at approximately a .185 gpm/ft² instead of the required .2 gpm/ft². When the heavier liquid is not taken into consideration the actual flow will be less than expected.

To account for the different density of the fluid and ensure the proper hydraulic calculations are completed with accurate flows, the sprinkler K factor can be mathematically adjusted prior to the actual calculation to obtain a new starting pressure which

should be used in the actual hydraulic calculations.

Adjusting the starting pressure prior to the calculation provides the higher flow rate. When using this method there is no reason to continue using the adjusted K factor during the actual hydraulic calculation. The changes have occurred prior to the actual calculation and will carry through mathematically. Using this method allows the designer to continue to use the manufacturesr's published technical information and helps avoid confusion during the engineering and AHJ review process. The reasons and adjustments made should be noted on the hydraulic calculation to provide the AHJ with the purpose of the higher flow rate.

Step 1. Calculate the required flow and pressure for the sprinkler selected using the standard formula $Q= K\sqrt{P}$.

From the previous example: The sprinkler selected is a K of 8.0.

First determine the required flow and starting pressure under normal clear water condition.

The flow required from the previous example is:

130 x .2 = 26 gpm.

Using the standard formula without conversion, the required starting pressure is:

$P = (Q \div K)^2$

$P = (26 \div 8)^2$

P = 10.56psi

Step 2. Use the adjusted formula to determine the adjusted K factor. For the previous example we used a specific gravity of 1.085 for propylene glycol at -20°F for 50 % solution.

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

$K = 26 \div \sqrt{10.56 \div 1.085}$

The adjusted K- factor needed to determine the adjusted starting pressure is= 8.33.
Note: The adjusted K factor is not used in the actual hydraulic calculations. Only the adjusted starting pressure and flow rate are used.

Step 3. Insert the adjusted K factor into the standard flow formula using the actual required pressure.

$Q = K\sqrt{P}$

$Q = 8.33\sqrt{10.56}$

The adjusted flow = 27 gpm

Step 4. Recalculate using the adjusted flow and the actual K factor selected to get the new required starting pressure for use in the standard flow formula.

$P = (Q \div K)^2$

$P = (27 \div 8)^2$

The starting pressure that should be used to start our calculation = 11.39psi.

Step 5. Start the calculation using the actual K factors selected for the system with the adjusted starting pressure and flow rates. Mathematically this will carry through the entire calculation.

The designer can use the adjusted starting pressure with the K 8.0 sprinkler to run the actual calculation, verify the adequacy of the water supply and prove the effectiveness of the system using the standard flow formula. Using the higher starting pressure to increase the required flow actually ensures the minimum flow is achieved when the heavier antifreeze is being discharged. Section 22.4.4.5.1 of NFPA 13 also requires that the calculation be done using the Darcy-Weisbach equation for determining friction loss when the antifreeze system is over 40 gallons in size. In this example the adjusted calculation will actually provide a density of a .207 gpm/ft^2 when the antifreeze has been discharged and 100% water is flowing from the sprinklers.

Conclusion

Basic hydraulic principles are the foundation of automatic sprinkler design. It is critically important to understand where the formulas come from and how to convert the formulas if necessary. Adequate flow in accordance with the required design is essential for fire control. It should be noted that The NFPA 13 Handbook also offers commentary on this subject.

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