FIRE PROTECTION HYDRAULICS

INTRODUCTION

Fluid mechanics is concerned with the forces and motions associated with gases and liquids. Hydraulics, a distinct branch of fluid mechanics, concerns itself with the study of the flow of water. Many of the particulars that are essential to accurate fluid mechanics measurements are unnecessary for the accuracy of fire protection measuring devices.

There are many equations that deal with pressure loss in piping systems. This section will concentrate the theories and methods from the work of Bernoulli and Hazen/Williams. Equations derived or used, will contain variables that can easily be read from tables, or measured with conventional, portable, water testing equipment such as pressure gauges and pitot tubes. Sprinkler system hydraulic calculations are covered in PRC.12.1.0.1.1.

This guide will:

- Discuss basic hydraulic theory.
- Derive pertinent equations.
- Present applicable charts and tables.

Physical Properties Of Water

The properties of water are often used as the basis for comparing other liquids.

Density of water (ρ) is defined as mass per unit volume.

$$\rho = \frac{Mass}{Volume} \tag{1}$$

At atmospheric conditions the density of water is 62.4 lbs mass/ft^3 (1000 kg/m^3) and is considered a constant for fire hydraulics purposes.

Specific gravity (s) is the ratio of the density of a liquid to the density of water at a specific temperature and pressure, usually 60°F (16°C) at one atmosphere pressure (1 bar).

$$s = \frac{\rho_{liquid}}{\rho_{water}} \tag{2}$$

Specific gravity varies with temperature; however, for liquids this change is only slight.

Viscosity is a measure of resistance to flow. The viscosity of water decreases with an increase in temperature, however, the changes experienced in fire protection systems are so slight they are ignored in fire protection hydraulics.

The specific weight (ω) is defined as weight per unit volume.

$$\omega = \frac{Weight}{Volume} \tag{3}$$

Since force is expressed as:

$$F = ma \tag{4}$$

Where:

$m =$ lb mass (lbm)

$a =$ acceleration = 32.2 ft/s^2

Then:

1 lbf = (1 lbm) (32.2 ft/s^2)

Equation (1) (3) and (4) can be used to derive the following:

$$\omega = \rho\, g \tag{5}$$

Where:

$\omega =$ 62.4 lbf/ft^3 (9810 N/m^3)

Pressure, expressed in terms of a column of liquid, is the force per unit area at the base of the column. Absolute pressure is usually expressed with reference to local atmospheric pressure. Gauge pressure is the difference between a value and local atmospheric pressure.

$$P_{Absolute} = P_{Gage} + P_{Atmospheric\ at\ gage} \tag{6}$$

Unless otherwise indicated, all pressures discussed will be gauge pressure.

A conversion factor can be derived from the density, which is quite useful in determining pressure changes that are due to corresponding differences in elevation, such as pressures developed by gravity fed water sources.

$$P = \omega\, s\, Z \tag{7}$$

Where:

$P =$ Pressure

$\omega =$ Specific weight

$s =$ Specific gravity (1.0 for water)

$Z =$ Elevation

The pressure developed per unit of elevation of water can be expressed as follows:

English Units:

$$P = 0.433\ Z \tag{7E}$$

Where P is expressed in psi and Z is expressed in feet.

SI Units:

$$P = 9810\ Z\ \text{(Pa) or} \quad (7S)$$

$$P = 0.0981\ Z$$

Where P is expressed in bar and Z is expressed in meters.

Flow In Pipes

The flow of water in a fire protection piping system can normally be characterized as steady, one-dimensional, and incompressible. This makes the application of the basic physical principles of conservation of energy and conservation of mass easier to apply to flow conditions along a pipe. The effects of various obstructions to flow can then be determined.

If water was not confined by pipes and was elevated above an established datum, the maximum potential energy stored would depend on the weight of the water and the height to which it was elevated. If allowed to fall freely, the potential energy released would be converted to kinetic energy and would depend on the velocity attained by the water, which is a function of the height. However, if a pipe was used to convey the water, some of the stored energy would appear as friction in the piping system.

The law of conservation of mass states that matter can neither be created nor destroyed. In a single entrance — single exit system, the mass that enters at one point should be the same as the mass that exits at the other. Flow is mass per unit time, which can be expressed in terms of three variables: the density of the liquid, cross sectional area of the conduit, and the velocity of the liquid.

Referring to Figure 1, the conservation of mass can be expressed mathematically as constant flow at two points along the same pipe segment.

$$Q = \rho_a\ A_a\ V_a = \rho_b\ A_b\ V_b \quad (8)$$

Because of incompressibility, the density of water does not change appreciably; therefore, density can be cancelled out of each side of the equation. As a result, at any point in a water system the flow can be expressed in terms of its cross sectional area and its velocity:

$$Q = A\,V \quad (9)$$

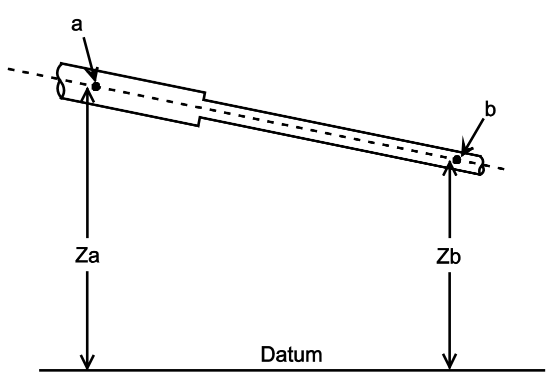


Figure 1. Typical Pipe Between Two Points.

Where:

Q = flow (usually ft³/s [m³/s])

V = velocity (usually ft/s [m/s])

A = flow area (usually ft² [m²])

For the sake of simplicity, most of the remaining equations will be shown without units until reduced to a usable form.

The law of conservation of energy states that energy can neither be created nor destroyed. Therefore, the total energy at one point in a system is equal to that of another.

In 1738, Bernoulli formulated his theorem of conservation of energy. It can be applied to a simple pipe system by taking into account the various forms of energy that exist in an ideal frictionless model. Applying Bernoulli's Theorem to the piping system shown in Figure 1 results in the following:

$$\frac{V_a^{\,2}}{2g} + \frac{P_a}{\omega} + Z_a = \frac{V_b^2}{2g} + \frac{P_b}{\omega} + Z_b \qquad (10)$$

Where:

$V =$ Velocity

$g =$ Gravitational acceleration

$P =$ Pressure

$\omega =$ Specific weight

$Z =$ Elevation

Rearranging and combining like terms:

$$\left[\frac{V_a^2 - V_b^2}{2g}\right] + \left[\frac{P_a - P_b}{\omega}\right] + \left[Z_a - Z_b\right] = 0$$

Each term of this equation is expressed as an elevation. Multiplying each term by ω results in each term being expressed as pressure:

$$\left[\omega\,\frac{V_a^2 - V_b^2}{2g}\right] + \left[P_a - P_b\right] + \left[\,\omega\,(Z_a - Z_b)\right] = 0$$

The first term of the equation is the change in kinetic energy, which is due to the change in velocity that results from the change in the cross sectional area. This term is referred to as the change in Velocity Head or ΔP_v.

In a uniform diameter pipe with steady flow, there is no change in the velocity between entrance and exit points, so the P_v term reduces to zero.

Velocity pressure is usually not considered, since:

- The effect of one pipe size difference in diameter is usually negligible.
- The procedure adds a significant amount of complexity to hydraulic calculations.
- The overall effect of velocity pressure reduces the anticipated hydraulic demand and, therefore, is less conservative.

The second term of the equation is the change in potential energy. This is the normal pressure exerted against the side of the confining vessel with or without water movement. This term is referred to as the change in Pressure Head or ΔP_n.

The third term of the equation is the potential energy that is due to change in elevation. This term is referred to as the change in Elevation Head or ΔP_e.

Since the real world is not frictionless, the friction is added to the algebraic sum of the other energy terms:

$$\Delta P_v + \Delta P_n + \Delta P_e + P_f = \Delta P_t \tag{11}$$

Where:

P_f = Pressure due to friction losses.

ΔP_t = The total pressure change.

In most discussions and writings on hydraulics, the system losses in a piping system are referred to as either major losses or minor losses. The major losses involve friction loss along a pipe system. The minor losses include the losses through fittings that are due to changes in direction, and losses which are due to sudden enlargement and contractions, usually found at discharge devices. These losses are addressed later in the section on friction loss.

Flow Through An Orifice

The equation for flow through an orifice can also be determined by applying Bernoulli's Theorem, equation (10). Refer to Figure 2 showing an open top container with a hole located at the datum that passes through reference point b .

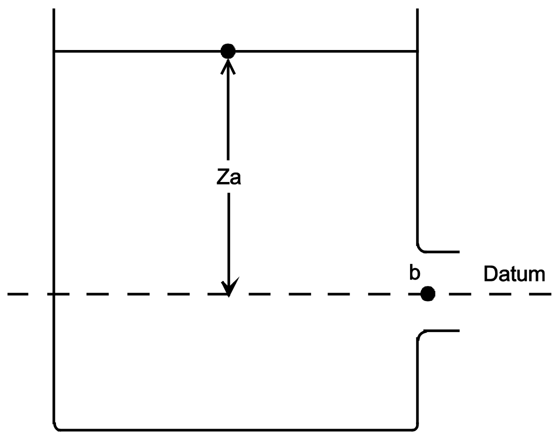


Figure 2. Flow From An Orifice.

$$\frac{V_a^2}{2g} + \frac{P_a}{w} + Z_a = \frac{V_b^2}{2g} + \frac{P_b}{w} = Z_b$$

Since the velocity at a is approximately zero and since there is no external pressure other than atmospheric acting on a, the first two terms on the left side of the equation can be eliminated. There is no external pressure other than atmospheric acting on b and, since Z_b is zero, the second and third terms on the right side of the equation can be eliminated. There is no piping and, thus, no friction losses between reference point a and reference point b. The equation can be simplified to:

$$Z_a = \frac{V_b^2}{2g}$$

Solving for V_b:

$$V_b = \sqrt{2g\, Z_a}$$

Velocity at the orifice is shown in terms of elevation and the gravitational constant. See equation (7). The elevation can be converted to pressure by dividing by w. Resulting in:

$$V = \left(\frac{2g\ P}{w}\right)^{0.5} \tag{12}$$

By applying conservation of mass, a modified equation (9) can be used which expresses the flow in terms of velocity. The modification consists of applying a discharge coefficient C_d to compensate for non-ideal flow conditions at the orifice:

$$Q = C_d\ A V \tag{13}$$

The cross-sectional area of the orifice can be expressed as:

$$A = \frac{\pi\ D^2}{4} \tag{14}$$

Where:

$D =$ internal orifice diameter

Substituting all of the variables in equation (13):

$$Q = C_d\ \pi \frac{D^2}{4}\left(\frac{2g\ P}{w}\right)^{0.5} \tag{15}$$

All of the constants can be replaced with a single diameter dependent constant K:

Where:

$$K = C_d\ \pi \frac{D^2}{4}\left(\frac{2g}{w}\right)^{0.5}$$

Substituting with the new constant results in a simplified equation based on pressure and a known K-factor:

$$Q = K\sqrt{P} \tag{16}$$

Where:

Q = flow

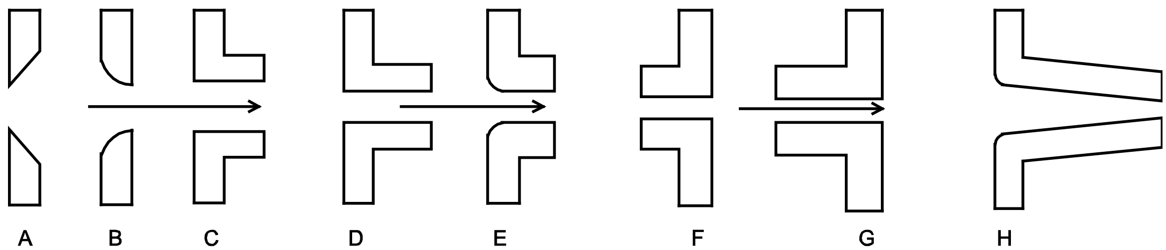
P = pressure

K = orifice coefficient flow/pressure$^{0.5}$

This equation is valid for flow through an orifice such as a hose nozzle, a hydrant, or a sprinkler head. It is also valid for an equivalent orifice at any point in a pipe system where the flow (Q) is assumed to be flowing out of an orifice and where the pressure (P) is the total pressure of all sources of energy applied at the assumed orifice. This could apply for a portion of the system such as a branch line, the entire sprinkler system at the base of riser, or an entire water supply being discharged from a reservoir.

A piping arrangement with a single flow outlet can also be analyzed using a fictitious nozzle having an orifice K-factor based on the actual flow and pressure. Identical piping configurations will result in the same K-factor, therefore, a given K-factor can be used to represent piping configurations with similar flow characteristics.

If two or more flows are combined or split, then the K-factor will change downstream of the branch point.



Description	C_d	C_c	C_v
A Sharp edge	0.62	0.63	0.98
B Round edge	0.98	1.00	0.98
C Very short tube	0.61	1.00	0.61
D Short tube	0.82	1.00	0.82
E Short tube (rounded)	0.97	0.99	0.98
F Reentrant tube (thin)	0.54	0.55	0.99
G Reentrant tube	0.72	1.00	0.72
H Underwriter's play pipe	0.98	0.99	0.99

Figure 3.Typical Nozzle Coefficients

The K-factor for a particular flow device, such as a sprinkler head or a nozzle, can be determined by taking pressure and flow measurements at the device in question. A sprinkler head must be held in a pipe fitting; thus, its specified K-factor includes a nominal 1 in. (25 mm) tee by convention.

Another version of equation (15) that is useful when performing water tests is shown below. By knowing the discharge coefficient of the discharge device (see Figure 3), the center of stream pressure (pitot tube pressure reading), and the diameter of the flow opening, the resulting flow can easily be determined.

English Units:

$$Q = 29.85\, C_d\, D^2 \sqrt{P} \tag{17E}$$

Where:

$Q =$ flow (gpm)

$D =$ internal orifice diameter (in.)

$P =$ pitot pressure (psi)

SI Units:

$$Q = 0.0666\, C_d\, D^2 \sqrt{P} \tag{17S}$$

Where:

$Q =$ flow (L/min)

$D =$ internal orifice diameter (mm)

$P =$ pitot pressure (bar)

When conducting water measurement tests, the pitot pressure reading is taken at the center of the stream where maximum velocity is present. By using a nozzle with a known discharge coefficient, the maximum pressure reading at the center of the stream, and equation (17) (flow from an orifice), the discharged flow can be fairly accurately determined.

Flow results of this type are occasionally put into tables where the flow can be read as a function of pressure readings. The AXA XL Risk Consulting Hydraulic Calculator is an example of such a device. The equation is helpful in determining flow at pressures not included on the AXA XL Risk Consulting Hydraulic Calculator.

The discharge coefficient C_d is applied to account for minor losses at the discharge device. The significance of this factor increases as the disruption to the flow condition increases. The coefficient is normally between 0.54 and 0.98. Ideal flow conditions are achieved if the coefficient reaches unity.

The discharge coefficient is a result of two minor losses acting on the flow. C_c is the coefficient of contraction which corrects for the reduction in flow diameter which occurs when water passes through the orifice. C_v is the coefficient of velocity and is caused when water flows through a free discharge opening. The coefficient of discharge is the product or result of both of these coefficients acting on the flow.

$$C_d = C_c C_v \tag{18}$$

The values of these necessary coefficients can be found in Figure 3.

Velocity Pressure

As stated earlier, velocity pressure is usually omitted from most sprinkler calculations because of loss of conservatism and the complexity of calculation method. However, when very accurate results are required, such as fire pump acceptance testing or performing hydraulic gradients, it is necessary to determine these quantities. Equations for flow velocity and velocity pressure can be determined from previously derived equations.

Using equation (12), the velocity pressure P_v can be solved for by rearranging the equation as follows:

$$P_v = \frac{wV^2}{2g}$$

English Units:

$$P_v = 0.00673\,V^2 \tag{19E}$$

Where:

$V =$ Velocity (ft/s)

$P =$ Pressure (psi)

SI Units:

$$P_v = 0.005\,V^2 \tag{19S}$$

Where:

$V =$ Velocity (m/s)

$P =$ Pressure (bar)

Using equation (10) and substituting for flow area in term of pipe diameter, it is also possible to solve for velocity in terms of flow and diameter.

English Units:

$$V = \frac{0.4085\,Q}{D^2} \tag{20E}$$

Where:

$V =$ Velocity (ft/s)

$Q =$ Flow (gpm)

$D =$ Internal pipe diameter (in.)

SI Units:

$$V = \frac{21.21\,Q}{D^2} \tag{20S}$$

Where:

$V =$ Velocity (m/sec)

$Q =$ Flow (L/min)

$D =$ Internal pipe diameter (mm)

Taking this one step further, the velocity pressure P_v can be shown in terms of flow and internal pipe diameter using equations (19) and (20):

English Units:

$$P_v = \frac{0.001123\,Q^2}{D^4} \tag{21E}$$

Where:

$P_v =$ Velocity pressure (psi)

$Q =$ Flow (gpm)

$D =$ Diameter (in.)

SI Units:

$$P_v = \frac{2.25\,Q^2}{D^4} \tag{21E}$$

Where:

$P_v =$ Velocity pressure (bar)

$Q =$ Flow (L/min)

$D =$ Diameter (mm)

Friction Loss

Losses which are due to friction are a result of shear forces acting on the individual water molecules within the pipe. At the pipe wall, shear forces also act between the water molecules and the wall of the pipe. There is more resistance near the wall than near the center of the stream. This results in faster moving particles of water at the center of the stream as shown in Figure 4. The rougher the pipe surface the more resistance to flow.

When very slow flow in a piping segment or water channel occurs, it is termed laminar flow. As velocity increases, a brief transition stage occurs before reaching turbulent flow. Most fire protection flow occurs in the turbulent range.

The pressure loss (P_f), contains the losses caused by friction in pipe, valves, fittings and enlargement or contraction devices. The greatest part of this loss is attributed to friction in the pipe.

The Darcy-Weisbach friction loss equation is commonly used in hydraulics. It is suitable for all liquids where the viscosity is constant. It is rather difficult to use in that it involves a complex set of variables that must be known or estimated.

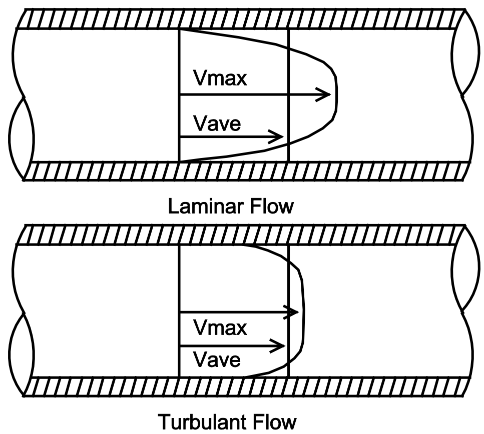


Figure 4. Typical Pipe Velocity Profile.

The most commonly used friction loss equation in fire protection hydraulics is that empirically derived by Allen Hazen and Gardner S. Williams in 1905. It is based on data collected over many years of water measurement. It involves variables that can easily be measured or estimated. The Hazen-Williams equation is arranged as follows:

English Units:

$$F_p = \frac{4.52\ Q^{1.85}}{C^{1.85}\ D^{4.87}} \qquad (22E)$$

Where:

F_p = friction loss factor (psi/ft)

Q = flow (gpm)

D = internal diameter (in.)

C = roughness coefficient

SI Units:

$$F_p = \frac{6.06 \times 10^5\ Q^{1.85}}{C^{1.85}\ D^{4.87}} \qquad (22S)$$

Where:

F_p = friction loss (bar/m)

Q = flow (L/min)

D = internal diameter (mm)

C = roughness coefficient

It can be seen from the previous equations that the amount of friction loss in a segment of pipe depends on:

- The inside diameter of the pipe.
- The length of the pipe.
- The amount of flow through the pipe.
- The roughness coefficient, C.
- The number and type of fittings.

The inside diameter of the pipe is the external diameter minus twice the wall thickness. The larger the internal diameter, the less resistance to flow and, thus, less friction loss. Pipe lengths are usually measured from the center of one fitting to the center of the next. The longer the pipe the greater the friction loss.

The C-factor or coefficient of friction is dependent on the condition of the pipe. If the pipe's internal surface is rough when manufactured or if it becomes rough with age, there is increased resistance to flow at the wall. C-factors become smaller as the flow condition worsens. Table 1 shows the average C-factor for different pipe types and ages.

These factors can be used to correct friction loss table figures from a C-factor of 100 to the C-factor in question (refer to Table 3).

The correction factors in Table 1 are simply the ratio:

$$\left[\frac{C_{Factor\ for\ Friction\ Loss\ Table}}{C_{Factor\ Actual}}\right]^{1.85} \qquad (23)$$

The losses in a piping system also depend on the number and type of pipe fittings used in the system. The fittings and other devices in the pipe system can be expressed in terms of an equivalent length of pipe of the same diameter, even though most of the pressure drop across a fitting is attributed to the turbulence caused by a change in the direction of the flowing water. This is a very simplistic approach but has gained much support over the years and is now ingrained as the "accepted norm." The average equivalent length of fittings is established by laboratory testing. The total equivalent length in a segment of piping is the actual length plus the sum of the equivalent lengths of the fittings.

The loss due to friction can be expressed by multiplying the equivalent length of pipe (L_{eq}) between two points by the friction loss factor per foot of pipe (F_p)

$$P_f = F_p\ (L_{eq}) \qquad (24)$$

Table 2 shows equivalent length factors for various size fittings.

TABLE 1
Typical *C*-factors

Pipe type	*C*-factor	Correction Factor
New steel pipe unlined	120	0.7
10 years old unlined	110	0.8
15 years old unlined	100	1.0
20 years old unlined	90	1.2
30 years old unlined	80	1.5
50 years old unlined	70	1.9
75 years old unlined	60	2.6
Riveted steel	110	0.84
Enamel-lined	140	0.55
Brass copper	140	0.53
Cement-lined	140	0.61
Cement asbestos	140	0.53
Rubber lined hose	140	0.55
Unlined linen hose	90	1.20

TABLE 2
Equivalent Lengths in Feet Based on *C* = 120

FITTING / SIZE	.75	1	1.25	1.5	2	2.5	3	3.5	4	5	6	8	10	12
90° Elbow	2	2	3	4	5	6	7	8	10	12	14	18	22	27
90° Long Turn	1	2	2	2	3	4	5	5	6	8	9	13	16	18
45° Elbow	1	1	1	2	2	3	3	3	4	5	7	9	11	13
Side Tee	4	5	6	8	10	12	15	17	20	25	30	35	50	60
Gate Valve	-	-	-	-	1	1	1	1	2	2	3	4	5	6
Swing Check	4	5	7	9	11	14	16	19	22	27	32	45	55	65
Alarm Valve	-	-	-	-	-	-	-	-	28	-	37	41	-	-
Dry Pipe Valve	-	-	-	-	28	-	29	-	30	-	53	-	-	-

SI Units: 1 ft = 0.305 m

The loss through a fitting is independent of C-factor and pipe schedule. Therefore, it is necessary to alter the figures in Table 2 so that when the friction loss per foot is applied to the fitting equivalent length, the net loss through the fitting does not change. The Fitting Length Correction Factor can be calculated by the following ratios:

$$\left[\frac{C_{Factor\,Table}}{C_{Factor\,Actual}}\right]^{1.85} \tag{25}$$

and

$$\left[\frac{D_{Table\,Schedule}}{D_{Actual\,Pipe\,Schedule}}\right]^{4.87} \tag{26}$$

A convenient way to use friction loss factors is by selecting them from tables based on flow, pipe size and C-factor. There are many such published tables. They are nothing more than the result of friction loss/ft as calculated using the Hazen/Williams equation. An example of calculated results is shown in Table 3.

Table 4 shows actual inside pipe diameters in inches for common pipe types used in sprinkler systems.

Table 5 shows actual inside pipe diameter for common pipe types made in France, Germany, and England.

Examining the Hazen-Williams equation, we can see that friction loss can be simplified to a three variable equation:

$$P_f = Constant\ Q^{1.85}$$

The constant may as well be expressed in terms of K.

Rearranging the equation to solve for Q results in the following:

$$Q = K\, P_f^{\ 0.54} \qquad (27)$$

This equation is valid when the resulting pressure is dependent on friction loss rather than flow through an orifice.

It is important to emphasize that the K-factors in equations (16) and (27) are **not** equivalent.

TABLE 3

Friction Loss Tables in psi/ft Based on *C* = 100

	Size									
gpm	**-0.5-**	**-0.75-**	**-1-**	**-1.25-**	**-1.5-**	**-2-**	**-2.5-**	**-3-**	**-3.5-**	**-4-**
5	0.1793	0.0454	0.0140	0.0036	0.0017	0.0005	0.0002	0.0001	0.0000	0.0000
10	0.6463	0.1637	0.0506	0.0128	0.0061	0.0018	0.0008	0.0003	0.0001	0.0001
15		0.3466	0.1071	0.0271	0.0128	0.0038	0.0016	0.0006	0.0003	0.0001
20	**5**	0.5901	0.1823	0.0462	0.0218	0.0065	0.0027	0.0009	0.0005	0.0003
30		1.2494	0.3860	0.0979	0.0462	0.0137	0.0058	0.0020	0.0010	0.0005
40	0.0003		0.6573	0.1666	0.0787	0.0233	0.0098	0.0034	0.0017	0.0009
50	0.0005	**6**	0.9932	0.2518	0.1188	0.0352	0.0148	0.0051	0.0025	0.0014
60	0.0006		1.3917	0.3528	0.1665	0.0493	0.0208	0.0072	0.0036	0.0019
70	0.0008	0.0003	1.8509	0.4692	0.2215	0.0656	0.0276	0.0096	0.0047	0.0026
80	0.0011	0.0004		0.6007	0.2835	0.0840	0.0353	0.0123	0.0060	0.0033
90	0.0014	0.0006	**8**	0.7469	0.3526	0.1044	0.0439	0.0153	0.0075	0.0041
100	0.0016	0.0007		0.9077	0.4284	0.1269	0.0534	0.0185	0.0091	0.0049
120	0.0023	0.0009	0.0002	1.2718	0.6003	0.1778	0.0748	0.0260	0.0128	0.0069
140	0.0031	0.0013	0.0003	1.6915	0.7984	0.2365	0.0995	0.0346	0.0170	0.0092
160	0.0039	0.0016	0.0004		1.0222	0.3027	0.1274	0.0442	0.0218	0.0118
180	0.0049	0.0020	0.0005	**10**	1.2710	0.3764	0.1584	0.0550	0.0271	0.0146
200	0.0059	0.0024	0.0006		1.5445	0.4574	0.1925	0.0668	0.0329	0.0178
220	0.0071	0.0029	0.0007	0.0002	1.8424	0.5456	0.2296	0.0797	0.0393	0.0212
240	0.0083	0.0034	0.0008	0.0003		0.6409	0.2697	0.0937	0.0461	0.0249
260	0.0096	0.0039	0.0010	0.0003	**12**	0.7432	0.3128	0.1086	0.0535	0.0289
280	0.0110	0.0045	0.0011	0.0004		0.8525	0.3588	0.1246	0.0614	0.0332
300	0.0125	0.0051	0.0013	0.0004	0.0002	0.9685	0.4076	0.1415	0.0697	0.0377
350	0.0167	0.0068	0.0017	0.0006	0.0002	1.2881	0.5421	0.1882	0.0927	0.0501
400	0.0213	0.0087	0.0022	0.0007	0.0003	1.6491	0.6940	0.2410	0.1187	0.0642
450	0.0265	0.0108	0.0027	0.0009	0.0004		0.8630	0.2996	0.1476	0.0798
500	0.0322	0.0132	0.0033	0.0011	0.0005		1.0487	0.3641	0.1794	0.0969
550	0.0385	0.0157	0.0039	0.0013	0.0005		1.2509	0.4343	0.2140	0.1156
600	0.0452	0.0185	0.0046	0.0015	0.0006		1.4694	0.5102	0.2514	0.1358
650	0.0524	0.0214	0.0053	0.0018	0.0007		1.7039	0.5916	0.2915	0.1575
700	0.0601	0.0246	0.0061	0.0020	0.0009		1.9543	0.6786	0.3343	0.1806
750	0.0683	0.0279	0.0069	0.0023	0.0010			0.7709	0.3798	0.2052
800	0.0769	0.0314	0.0078	0.0026	0.0011			0.8687	0.4280	0.2313
850	0.0861	0.0352	0.0087	0.0029	0.0012			0.9718	0.4788	0.2587
900	0.0957	0.0391	0.0097	0.0032	0.0014			1.0802	0.5322	0.2876
950	0.1057	0.0432	0.0107	0.0035	0.0015			1.1938	0.5882	0.3178
1000	0.1162	0.0475	0.0118	0.0039	0.0017			1.3127	0.6467	0.3495
1250	0.1757	0.0718	0.0179	0.0059	0.0025			1.9835	0.9772	0.5281
1500	0.2461	0.1006	0.0250	0.0082	0.0035				1.3693	0.7399
1750	0.3273	0.1338	0.0333	0.0110	0.0046				1.8211	0.9841
2000	0.4191	0.1713	0.0426	0.0140	0.0060					1.2598
2250	0.5211	0.2130	0.0530	0.0175	0.0074					1.5665
2500	0.6332	0.2588	0.0644	0.0212	0.0090					1.9037
2750	0.7553	0.3087	0.0768	0.0253	0.0107					
3000	0.8872	0.3626	0.0902	0.0297	0.0126					
4000	1.5107	0.6174	0.1535	0.0506	0.0215					
5000	2.2828	0.9329	0.2320	0.0765	0.0324					

SI Units: 1 psi/ft = 0.2261 bar/m;1 gpm = 3.74 L/min

TABLE 4
Internal Diameter In in. For Nominal Pipe Sizes In in.

Size	Cu L	Steel	Thin	Cu K	Cu M	XL	Berger	CTS	IPS	Poly-B
0.75	0.785	0.824	0.884	0.745	0.811	0.864	0.750	0.705	0.839	0.884
1	1.025	1.049	1.097	0.995	1.055	1.104	1.185	0.911	1.051	1.109
1.25	1.265	1.380	1.442	1.245	1.291	1.452	1.530	1.112	1.332	1.400
1.5	1.505	1.610	1.682	1.481	1.527	1.687	1.770	1.314	1.528	1.602
2	1.985	2.067	2.157	1.959	2.009	2.154	2.245	1.720	1.917	2.003
2.5	2.465	2.469	2.639	2.435	2.495	2.581	2.709	--	--	2.423
3	2.945	3.068	3.260	2.907	2.981	3.200	3.344	--	--	2.951
3.5	3.425	3.548	3.760	--	--	--	3.834	--	--	--
4	3.905	4.026	4.260	3.857	3.935	--	4.334	--	--	--
5	4.875	5.047	5.295	--	--	--	5.345	--	--	--
6	5.845	6.065	6.357	--	--	--	--	--	--	--
8	7.725	8.071	8.249	--	--	--	8.250	--	--	--
10	9.625	10.136	10.374	--	--	--	--	--	--	--
12	11.565	12.090	12.374	--	--	--	--	--	--	--

SI Units: 1 in. = 25.4 mm

TABLE 5
Internal Diameter in mm for Nominal Metric Pipe Sizes in mm

Size	France	Germany	England
20	0.851	0.850	0.837
25	1.073	1.071	1.063
30	1.415	1.413	1.407
32	1.415	1.413	1.407
35	1.415	1.413	1.407
40	1.648	1.646	1.624
50	2.084	2.087	2.067
65	2.703	2.500	2.677
75	3.175	3.248	3.159
80	3.175	3.248	3.159
90	3.665	3.500	3.642
100	4.137	3.968	4.134
125	5.115	4.921	5.118
150	6.119	5.906	6.122
200	8.126	8.161	8.071
250	10.172	--	10.192
300	12.250	--	12.090

SI Units: 1 in. = 25.4 mm

Use Of Semi-Log Graph Paper

Since pressure loss because of friction varies directly with flow raised to the 1.85 power, flow and pressure can easily be plotted on special graph paper where the vertical axis is pressure and the horizontal axis is flow raised to the exponent 1.85. The unique thing about the obtained curves is that the plotted results are straight lines allowing for results to be extrapolated beyond the values examined. In order to achieve the best accuracy in line drawing, the flow capacity should be as far out on the horizontal axis as practicable. Generally, the higher the flow capacity the more accurate the results.

Semi-log graph paper is quite useful for plotting water supply results, showing friction loss curves for a particular sized pipe, plotting sprinkler system demand curves, and plotting the head pressure at the most remote sprinkler head in the system.

Water supply curves can be plotted from water test data by knowing two points. The static pressure is the pressure available with no water flowing. The residual pressure is the resulting pressure with a known quantity of water flowing. These two points are plotted; then they are connected to form a straight line. This line is called the supply curve for the particular water supply.

Friction loss curves are determined by first assuming a flow and calculating the friction loss for a given length of pipe. Then the friction loss curve is drawn by plotting the pressure which is due to friction at zero flow and zero pressure, and the calculated pressure which is due to friction at the assumed flow. For any flow along the horizontal axis, the corresponding pressure loss can be found from the curve. Friction loss curves can also be drawn for complex looped piping systems. See PRC.14.1.2.3.

Sprinkler system demand curves for a specific area of application can be plotted in the same manner. First, the demand at the base of the sprinkler riser is calculated. At zero flow, a certain amount of pressure is required because of the elevation of the most remote area. The total elevation change from the most remote sprinkler to the base of the riser is determined and multiplied by 0.433 psi/ft. The resulting pressure is plotted at zero flow to form one point and the system demand pressure and flow is plotted to form the other point. The points are then connected to form a straight line called the demand curve. This curve represents changes in demand for a variety of densities along the curve for a specific area of application.

SUMMARY

The two main equations used in fire protection hydraulics are the orifice equation (16) and the Hazen/Williams equation (27). Hydraulics is further simplified by putting these equations into accessible tables and graphs.

By using equations with variables that can be measured by simple devices, such as pressure gauges and pitot tubes, fire protection hydraulics have been reduced to simple procedures. These procedures can be used to predict the acceptability of water based fire protection, analyze present and future water demands, analyze water tests, confirm the design of sprinklers, and a multitude of other functions.

This subject is further expanded in other PRC Guidelines. Section 12 deals with water-based protection. In particular, PRC.12.1.1.1 deals exclusively with sprinkler system hydraulic calculations. Section 14 involves water supplies. The entire PRC.14.1.2 grouping is concerned with the hydraulic analysis of fire protection water supplies.