# Chapter 2

## Factors Affecting Water Pressure

**Chapter 2 discusses five factors affecting water pressure:**

1. Velocity
2. Temperature and viscosity
3. Friction losses in pipes
4. Friction losses in fittings
5. Friction losses in valves

Pipe sizing tables, charts and graphs are considered a reliable source of information for their intended purpose. They do not provide optimum pipe sizes in all cases, as it is too difficult to take into account all the factors that simultaneously affect the pipe size for a given situation. Only one of these factors needs to vary and the overall calculations for the project will be affected.

Computer software technology is available to take into account a range of variables in one process, including velocity, temperature, pressure and head losses due to friction. The complex formulas that need to be applied for each individual calculation are almost impossible to process manually and it is certainly uneconomical and impractical for a designer to spend valuable time deliberating over every tee, bend, valve and individual length of pipe.

## Velocity

The speed at which water flows through a pipe is referred to as ***'velocity'*** and it has a significant effect on the calculations for optimum pipe sizes. Water moving through pipes can be likened to wind blowing between buildings or through a tunnel; the greater the velocity, the greater the turbulence.

Water passing through pipes and fittings at high speed will create turbulence and cause friction on the walls of the pipes and fittings, resulting in a drop in pressure at the outlet. The degree of pressure loss will depend on the direction of flow through the fitting and the roughness of the internal surface of the pipe. The greater the velocity in a pipe, the more friction there will be, with a corresponding loss of pressure. High velocities can cause noise within the pipe, water hammer and erosion of the internal surface, which are covered in Chapter 8. Increasing the diameter of a pipe for the same flow demand reduces velocity.

Building standards specify a maximum design velocity of 3 m/s for potable water. This standard does not apply to fire services, which may have a higher design velocity. Good design practices indicate that 3 m/s is very high for potable water services. Most building specifications require the design velocity to be between 1.2 and 2.2 m/s.

Pipe manufacturers provide technical data recommending maximum velocities for their pipes and fittings, which take into consideration the optimum performance of these products. In most cases the recommended velocities will be below those stated by the relevant standards.

The optimum velocity can vary depending on the type of building, the application and the necessity to reduce noise within the pipes.

## Case Study

An upstairs water closet in a residence was designed with the minimum 15mm pipe in accordance with most standards. It was 15mm diameter x 3 metres in length before increasing to a 20mm diameter pipe. The pipe passed through the ceiling of the ground floor dining room.

A dinner party was in progress and the guests were seated enjoying their meal. The water closet was flushed and the noise in the pipe, which was caused by the water flowing at high velocity and the cistern filling quickly, was offensive. In this case, the pipe size needed to be increased to 20mm diameter for most of its length and only reduced to 15mm within 500mm of the cistern. Velocity can also be slowed by partially closing the cistern valve, which will eliminate the noise.

Table 2-1 provides a range for good design parameters in line with regulations and manufacturers' recommendations.

| ***Pipe Material*** | ***L/s*** | ***L/s*** |
|---|---|---|
| Copper | 1.2 | 2.2 |
| Steel | 1.2 | 2.2 |
| PVC | 1.8 | 2.6 |
| HDPE | 1.8 | 3.0 |
| Ductile Iron | 2.0 | 3.0 |

*Table 2-1 Recommended Design Range for Velocities of Potable Water*

# Flow of Water Through Pipes

**Calculating the velocity**

**Formula**

$$V = \frac{Q}{A}$$

The quantity of water that will pass through a pipe over a set period of time is determined by:

**Calculating the actual flow**

$$Q = A \times V$$

Where:

$Q$ = flow in cubic metres per second ($m^3/s$)

$A$ = area of the internal cross section of the pipe ($m^2$)

$\frac{\pi}{4} \times (D^2)$ *or* $\pi R^2$

$V$ = velocity in metres per second (m/s)

## Exercise 2-1

What is the flow through a 100mm copper pipe with an internal diameter of 98.34mm?

The flow is 1.8 m/s.

**Step 1** Internal cross sectional area of the pipe

$$= \frac{\pi}{4} \times (D^2) \times V \quad \textit{or} \quad \pi R^2 \times V$$

$$= \frac{3.1416}{4} \times (0.09834^2) \times 1.8$$

$$= 0.7854 \times 0.00967 \times 1.8$$

$$= 0.01367\ m^3/s$$

**Step 2** To convert $m^3/s$ to L/s multiply by 1000

= 0.01367 x 1000

= 13.67 L/s

## Temperature and Viscosity

Viscosity is that property which determines the amount of a fluid's resistance to a shearing force. Viscosity is due primarily to interaction between fluid molecules, particularly as it relates to the fluid's ability to flow. The less viscous a fluid is, the 'thinner' it is and the more easily it flows. Viscosity of liquids decreases as temperature increases. Thus, cold water is more viscous than hot water. Therefore, cold water flowing through a pipe will result in a greater pressure drop, when comparing flows of differential temperature with equal velocity through pipes of the same diameter.

Potable water from the local authority's main usually has an ambient temperature of 15 to 20°C. Depending on the geographical location it may be higher or lower. The colder months will see water temperatures as low as 4°C and hotter months could result in temperatures of up to 25°C.

The Kinematic viscosity of water is as follows:

4°C = $1.568 \times 10^{-6}$

15°C = $1.14 \times 10^{-6}$

60°C = $4.76 \times 10^{-7}$

82°C = $3.55 \times 10^{-7}$

When considering this in detail, it becomes apparent why tables, charts and graphs, along with most design engineers, do not consider temperature to any great degree when sizing pipes.

## Friction Losses in Pipes

Friction within pipes is a major contributor to pressure losses in piping systems. It should be noted that the velocity in the pipe has a direct bearing on the pressure loss. The internal roughness of the pipe is expressed in a 'K' value and taken into account when determining the head loss.

K = Coefficient value for the roughness of the internal surface of the pipe, or an equivalent that measures the friction loss through bends, tees and valves. Manufacturers' technical data provides the 'K' value for each of their products.

Pressure drop due to friction losses in pipes is expressed as a number of metres per 100 lineal metres of pipe, which is easily converted to a percentage per metre.

Chapter 5 addresses the friction losses for pipes and fittings in more detail and also provides exercises for calculating and applying friction losses.

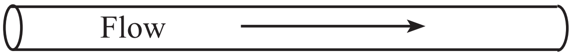


*Figure 2-1 Flow Through a 15mm Copper Pipe*

The water in the above 15mm pipe over a 3.0 metre length with a flow rate of 0.3 L/s, has a velocity of 3.23 m/s. The friction loss for the 3 metre length is 3.47 m/h, 34 kPa or 0.34 bar. Both the velocity and head loss are unacceptable for good design practice.

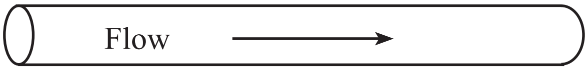


*Figure 2-2 Flow Through a 20mm Copper Pipe*

The water in the above 20mm pipe over a 3 metre length with the same flow rate of 0.3 L/s, will have a velocity of 1.32 m/s. The friction loss for the 3 metre length is 0.41 m/h, 4.0 kPa or 0.04 bar, which is a very good result.

## The Darcy - Weisbach Equation

The Darcy - Weisbach equation takes into account the fact that pipe friction is dependant on the pipe's internal surface, its internal diameter as well as the velocity of the liquid passing through it. The equation is as follows:

$$h_f = f \frac{L}{D} \frac{v^2}{2g}$$

Where $h_f$ = head loss (m)

$L$ = pipe length (m)

$D$ = average internal diameter of pipe (m)

$v$ = average fluid velocity (m/s)

$g$ = acceleration, due to gravity (9.8 $m^2$/s)

$f$ = friction factor - a dimensionless number which has been determined experimentally and is dependant on the Reynolds Number (Re).

The Reynolds Number (Re) is a dimensionless parameter which relates the inertial forces within the fluid to the viscous forces. The relationship is given by the expression:

$$Re = \frac{\mathrm{v}\, D}{\nu}$$

Where:

$D$ = actual internal diameter of pipe
v = average fluid velocity (m/s)
$\nu$ = Kinematic viscosity ($m^2$/s)

Depending on the nature of the flow within the pipe, the friction factor is determined as follows:

## Transition or Turbulent Zone (Re > 4000)

Where the Reynolds Number (Re) is greater than 4000 the friction factor is affected by the Reynolds Number and the internal surface roughness of the pipe. The friction factor is determined by the formula developed by Colebrook-White and is given by the expression:

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left[ \frac{2.51}{Re\sqrt{f}} + \frac{k}{3.7d} \right]$$

Where:

$d$ = actual internal diameter of pipe (mm)
$Re$ = Reynolds Number (pure number)
$f$ = friction factor (pure number)
$k$ = absolute roughness of the internal pipe surface (mm)

Beyond the transition zone the value of $f$ tends to be constant.

## The Hazen and Williams Equation

An easier formula to use for pipe friction  is that developed by Hazen and Williams:

$$h_L = \left[\frac{3.3 \times 10^6\, Q}{d^{2.63} C}\right]^{1.825}$$

Where:

$h_L$ = head loss (m/h per 100m)
$Q$ = flow rate (L/s)
$d$ = actual internal diameter of pipe (mm)
$C$ = Hazen and Williams roughness factor (pure number)

The Hazen and Williams formula does not take into account viscosity and may not be entirely suitable for diameters less than 50mm or velocities greater than 3 m/s. It should also be noted that the formula is not entirely accurate for values of C which are less than 100. Care should be taken when using this equation.

## Friction Losses in Fittings

Turbulence caused in fittings will significantly increase with an increase in demand at the fixture outlet. As the flow demand increases, the velocity through the fitting also increases, with a corresponding increase in turbulence.

Water flowing through a bend behaves in a similar manner to a racing car driver who goes to great lengths to achieve a smooth line as he/she guides their car through a bend on the racetrack. Water passing through fittings is looking for the smoothest line. If the velocity is too high the water hits the bend and pushes back against itself, causing turbulence with the water following, thus creating excessive turbulence and a loss of pressure. The extent of friction loss will depend on the type of fitting and the direction of flow through the fitting.

Each of the fittings illustrated in Figures 2-3 to 2-8 will be affected to a greater or lesser degree by friction loss due to the direction of flow of the water.

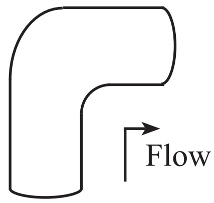


*Figure 2-3 Elbow*

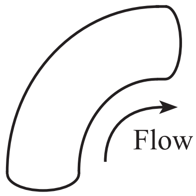


*Figure 2-4 Long Radius Bend*

Assuming the same diameter pipe and flow rate in Figures 2-3 and 2-4, the elbow will create more friction and a higher head loss. Bends are a better design option.

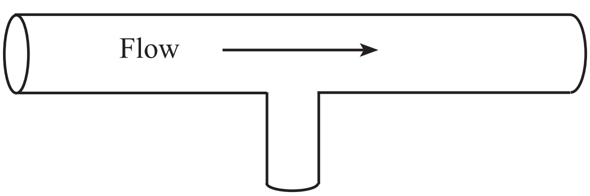


*Figure 2-5 Straight-Through Tee*

A different degree of friction loss applies for each tee in Figures 2-5 and 2-6. Figure 2-5 shows the main flow as being directly through the tee as if it were a straight pipe. However, when the demand becomes greater the tee may act similarly to a bend.

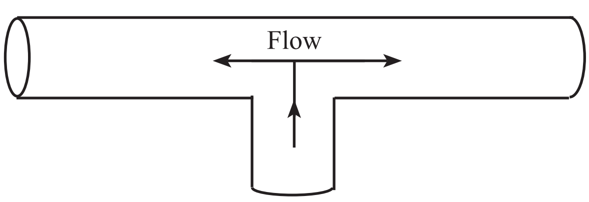


*Figure 2-6 Right Angle Tee*

A right angle tee, Figure 2-6 creates a greater friction loss due to the water hitting the back of the tee before it is distributed to the right and left. Where the degree of pressure drop is critical, tees can be fabricated using a separate take-off for each direction, with a 45° slope and a 45° bend to achieve the 90° change in direction similar to those used for sanitary plumbing.

The configuration shown in Figure 2-7 could be used to reduce head losses where it becomes critical.

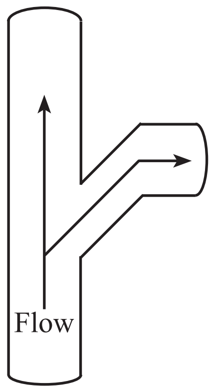


*Figure 2-7 Alternative Method for a Change in Direction*

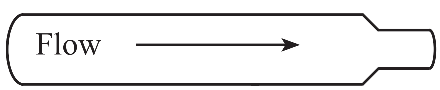


*Figure 2-8  Reducer*

## Friction Losses in Valves

The friction loss through any valve is determined by the diameter of the valve, the flow passing through the valve and the 'K' value for the valve.

The technical data for valves available from valve manufacturers, includes charts indicating the pressure drop through each available diameter at various flows. These charts also provide a good cross-check for the designer to confirm his/her choice of pipe size. If the pipe is undersized, the pressure drop through the valve will indicate an unacceptable result. Should the pressure drop be insignificant, a smaller pipe may be appropriate.

It is recommended that the design engineer obtain technical charts for all the common valves he or she is likely to specify. Refer also to Chapter 5, Table 5-2 on page 61.