PIPE SYSTEM LOSSES

DR TERRY LUCKE EXPLAINS PIPE SYSTEM LOSSES, THE REASONS WHY THEY OCCUR AND HOW TO AVOID THEM.

In the last edition I discussed the fundamentals of pressure and related it back to pipe system design using some everyday examples. You may remember I used the term "maximum theoretical pressure" in some of my examples in the last article because there are a number of other factors that will cause pressure losses in pipework systems such as pipe friction and form losses.

Pipe system pressure losses are very important and they can significantly affect expected pipework flowrates and velocities, as well as system performance.

In this issue I will provide a simple explanation of some of the fundamental causes of pressure losses in fluid systems.

There are generally two types of pipe flow: pressurised pipe flow (i.e. water supply systems - Fig. 1a) and open channel pipe flow (e.g. stormwater drainage pipes - Fig. 1b).

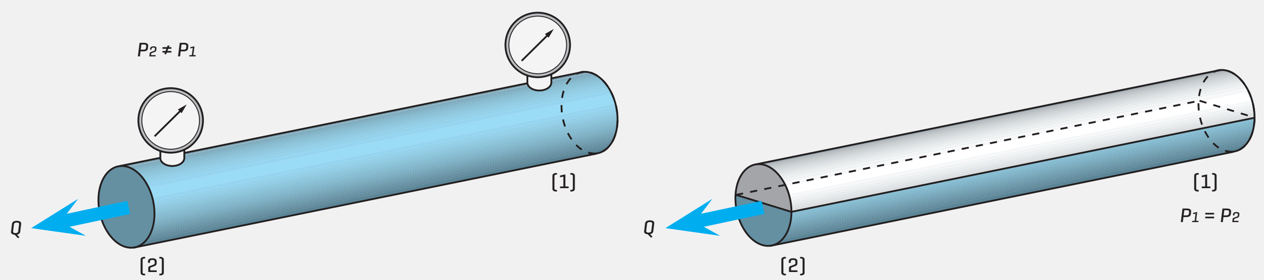
The difference between pressurised pipe flow and open-channel flow is in the fundamental mechanism that drives the flow. For open-channel flow, gravity is the only driving force acting on the fluid, i.e. water flows downhill. However, for the flow in pressurised (full-pipe) systems, while gravity may also play a role, the main driving force is likely to be a pressure gradient along the pipe (i.e. the fluid can flow uphill in a pressurised full-pipe system). For example, in Figure 1a, when the pressure at point (1) is greater than the pressure at point (2), a positive pressure gradient exists which drives the fluid along the pipe from point (1) to point (2). Importantly, if the pipe is not full (Fig. 1b), it is not possible to maintain this pressure difference (P1= P2) so the fluid does not flow (unless it is affected by gravity).

Before we get into pipe pressure losses, I think it is a good time to explain the concepts of hydraulic grade line (HGL) and energy grade line (EGL). The HGL is a line that can be drawn along a pipe to indicate the elevation to which the fluid would rise if open to atmospheric pressure. This is shown in by the piezometer tubes in Figure 2. It is also the same height that the fountain of water would theoretically raise if you punched a hole in the top of the pipe.

The HGL is an indicator of static pressure and is not affected by the velocity of the fluid. The HGL is also often called the Pressure Head and the units are usually measured in metres height of fluid (m). In an open-channel, or a partially full pipe, the HGL follows the water surface. The HGL is the most important indicator for designers of stormwater drainage systems because it indicates the water surface levels (and potential overflows) in any of the system components open to the atmosphere (i.e. in gutters or drainage pits). It also identifies locations of any potentially excessive system pressures.

The energy grade line (EGL) is a line that can be drawn along a pipe indicating the total energy at any point in the pipe. The EGL values generally include the Potential Head, ➤

FIGURE 1 – DIFFERENT PIPE FLOWS



(A) PRESSURISED PIPE FLOW

(B) OPEN-CHANNEL PIPE FLOW

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FIGURE 2 – HGL AND EGL IN AN IDEAL PIPE SYSTEM

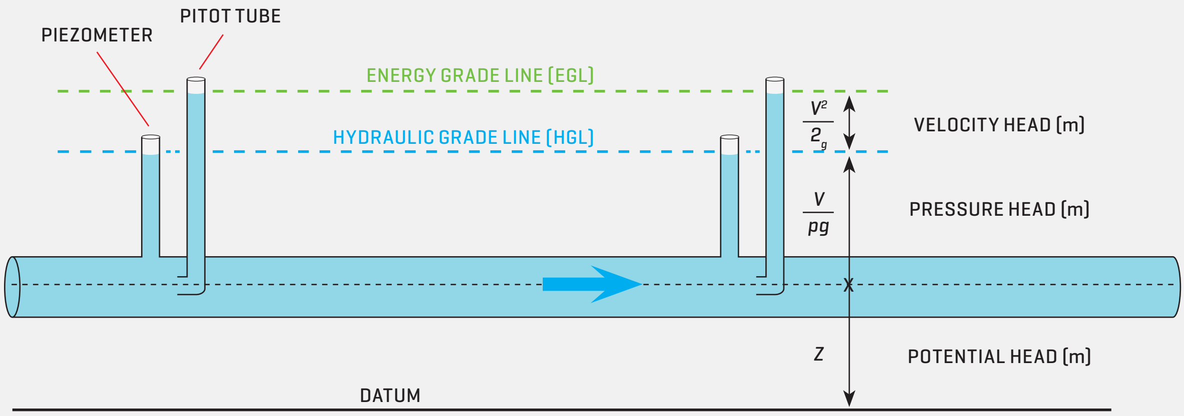
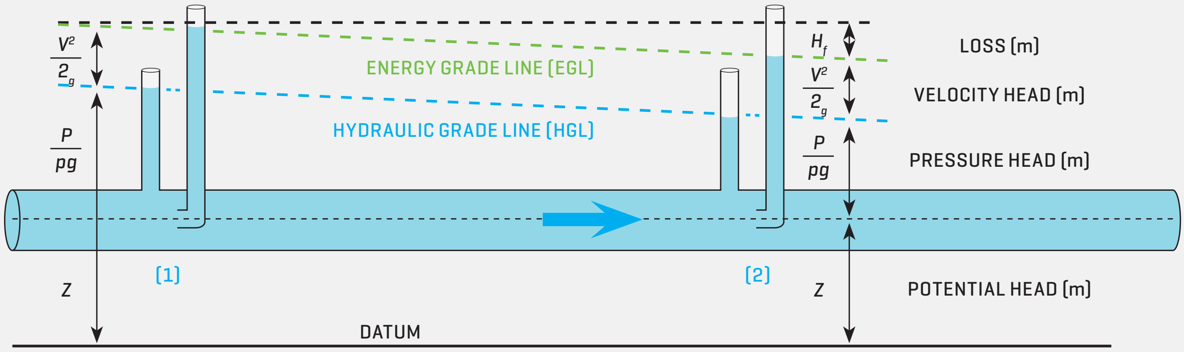


FIGURE 3 – HGL AND EGL IN A REAL PIPE SYSTEM INCLUDING FRICTION LOSS



the Pressure Head and the Velocity Head as shown in Figure 2. Please note that the pipe shown in Figure 2 is an "ideal pipe" which means there are no losses shown in this system (this is impossible in real systems).

FRICTION LOSSES

In real pipe systems, fluids lose energy as they move through the pipes. This energy loss (or pressure loss) is caused by a variety of reasons including friction, turbulence through fittings, change of flow direction, heat and noise. When designing common pipe systems, we are usually concerned with two main pressure losses: Friction Losses and Form Losses.

Friction Losses, as the name implies, are caused by friction that is generated between the fluid and the pipe (or channel) walls due to the fluid's viscosity. While pipes may look and feel smooth, at a microscopic scale pipe walls are actually quite rough and they generate a lot of turbulence and friction in the flow. In order to overcome these frictional forces along the walls, the fluid loses significant pressure energy as it moves through the pipe system.

Friction losses are often referred to as "Major Losses" as they generally account for the majority of losses in a typical pipework system. Major losses (usually expressed as H_f) for a steady flowrate, in a straight pipe of constant cross-sectional area are generally quite straightforward to calculate. H_f is usually expressed as a certain value of pressure (or head) loss per metre, i.e. a set proportion of the total flow energy is lost along every metre of pipe. Figure 3 shows how friction losses (H_f) reduce both the HGL and the EGL in a straight pipe between points (1) upstream and (2) downstream.

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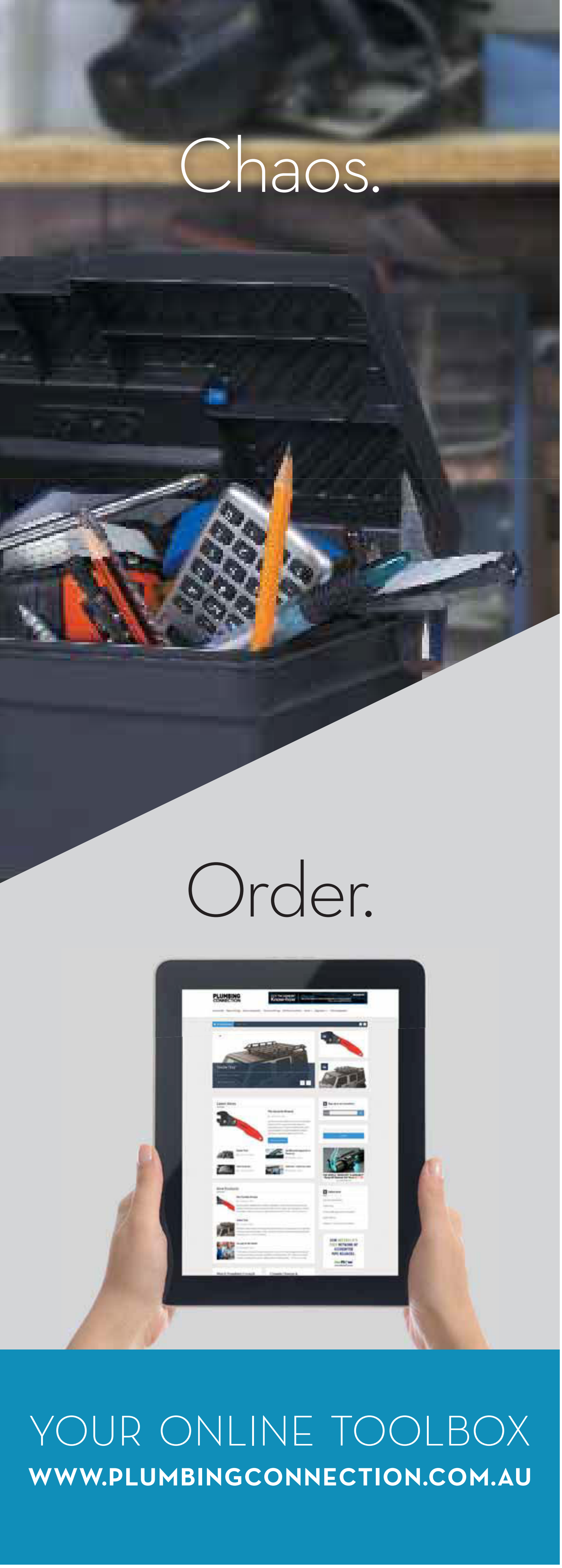

The pressure loss per metre length of pipe is directly proportional to the roughness of the pipe. We use a dimensionless friction factor (f), to calculate pipe pressure losses along the pipe due to friction. The f value is variable and depends on the roughness of the pipe material, the pipe diameter, the density and viscosity of the fluid, and the velocity of flow.

Typical f values for most practical applications range between about 0.012 and 0.030. Major Losses are not affected by gravity so it doesn't matter how much slope a pipe has, or even if it is vertical.

The main thing affecting Major Losses is the velocity of the flow in the pipe. Major losses are applied to the velocity head of the pipe flow. The velocity head is directly proportion to the velocity squared, so small changes in velocity can result in large increases in pressure loss. The major (friction) loss (H_f) in a pipe is calculated using (the Darcy-Wiesbach) Equation 1.

EQUATION 1

$$H_f = f \frac{L}{D} \frac{V^2}{2g}$$

where:

- H_f = Major (friction) loss (m)
- f = Pipe friction factor (dimensionless)
- L = Pipe length (m)
- D = Pipe diameter (m)
- V = average pipe flow velocity (m/s)
- g = gravitational force on earth (9.81m/s^2)

Example 1

Calculate the major headloss (m) in the pipe shown in Figure 3 if it is a Ø150mm, PVC (f = 0.015) pipe, the flowrate (Q) is 65L/s, and the distance between points (1) and (2) is 4.6m.

Solution:

1. First we need to calculate the velocity in the pipe. Velocity equals flowrate divided by pipe area (V = Q/A).
2. To calculate velocity, we need the pipe's area:
3. Area = $\pi D^2/4 = \pi \times 0.15^2 / 4 = \underline{0.0177 m^2}$
4. V = Q/A: Velocity = Q (0.065 m^3/s) / Area (0.0177 m^2) = $\underline{3.68 m/s}$
5. Now insert values into Eq. 1:

$$H_f = f \frac{L}{D} \frac{V^2}{2g} = 0.015 \frac{4.6}{0.15} \frac{3.68^2}{2*9.81} = 0.317 \text{ m (317mm)}$$

So the major (friction) head loss in the pipe between points (1) and (2) is 0.317m (ans).


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FORM LOSSES

The other type of pressure losses in pipe systems are Form Losses. These are often referred to as Minor Losses because in a typical system, these losses are usually much less than friction (Major) losses. Form Losses are caused by the excessive turbulence generated in the fluid when it has to travel through pipe fittings and other components. For example, when a fluid has to travel through a valve, or around a bend, this causes significant turbulence which makes it more difficult for the fluid to flow. This results in the fluid losing pressure (energy).

Fittings and components that cause pressure losses in pipework are generally allocated a form loss coefficient designated as a K factor (Table 1). To estimate the pressure loss (H_L) due to a component or fitting, the K factor is also simply applied to the velocity head as shown in Equation 2.

EQUATION 2

$$H_L = K \frac{V^2}{2g}$$

where:
H_L = Minor (form) loss (m)
K = Form loss factor (dimensionless)
V = average pipe flow velocity (m/s)
g = gravitational force on earth (9.81m/s2)

<u>Example 2</u>

Calculate the headloss (m) through the Ø80mm, 45° PVC bend shown in Figure 4 when the flowrate (Q) is 15 L/s. The K factor for the bend is 0.3.

Solution:

- First we need to calculate the velocity in the pipe (V = Q/A).

TABLE 1 – TYPICAL K FACTORS OF COMMON VALVE AND FITTINGS

Valve or Fitting	K factor
Globe Valve – Wide open	10
Globe Valve – ½ open	12.5
Gate Valve – Wide Open	0.2
Gate Valve – ¾ Open	0.9
Gate Valve – ½ Open	4.5
Gate Valve – ¼ Open	24
Return bend	2.2
Standard Tee	1.8
45° elbow	0.3
90° elbow	0.9
Ball check valve	4.0

FIGURE 4 – Ø80MM, 45° PVC BEND

- Area = $\pi D^2/4 = \pi \times 0.08^2 / 4 = \underline{0.005\ m^2}$
- V = Q/A: Velocity = Q (0.015 m^3/s) / Area (0.005 m^2) = <u>3.0 m/s</u>
- Now insert values into Eq. 2:

$$H_L = K \frac{V^2}{2g} = 0.3 \frac{3.0^2}{2*9.81} = 0.138 \text{ m (138mm)}$$

So the minor head loss in the elbow = <u>0.138m</u> (ans).

To calculate the total pressure losses in a pipe system, we simply go through and sum the individual Major and Minor losses in each section. As long as the total pressure driving the system is greater than the total losses, we have flow. If not, we need to either increase system pressure (bigger pump or potential head), reduce Major and Minor losses (better design or larger pipes), or a combination of both.

I hope this article has helped to improve your understanding of pressure losses in pipe systems due to friction and form losses. I have purposely tried to simplify the article as much as possible to make it easier to understand. The underlying fluid mechanics principles are obviously a bit more complicated than this, but not that much. ■

Please feel free to email me any comments, questions or suggestions at tlucke@usc.edu.au.

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