

Head Losses in Pipes

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Nomenclature

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|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| d | inside diameter of a pipe or “device” |
| f | Darcy friction factor, as on the Moody chart or from the Colebrook equation |
| g | gravitational constant (9.81 m/s ²) |
| h | head, i.e. elevation of a fluid column |
| h_{major} | major head loss (height of water column) due to friction in a pipe |
| h_{minor} | minor head loss (height of water column) due to a “device” in the pipe system |
| $\Delta h_{L, \text{total}}$ | total irreversible head loss, including major and minor losses: $\Delta h_{L, \text{total}} = \sum h_{\text{major}} + \sum h_{\text{minor}}$ |
| K | nondimensional minor loss coefficient |
| L | length of pipe section |
| L_e | Entrance length required for fully developed flow in a pipe |
| \dot{m} | mass flow rate through the pipe |
| P | static pressure |
| Re_d | Reynolds number based on length scale d : $Re_d = Vd/\nu$ |
| V | mean velocity in a pipe |
| \forall | volume |
| $\dot{\forall}$ or Q | volume flow rate |
| \dot{W}_{pump} | work done <i>to</i> the control volume by a pump |
| \dot{W}_{turbine} | work done <i>by</i> the control volume on a turbine |
| \dot{W}_{viscous} | viscous work done <i>on</i> the control volume by a moving wall |
| α | kinetic energy correction factor in energy equation for a control volume |
| ε | average roughness height in a pipe |
| ν | kinematic viscosity of the fluid (for water, $\nu \approx 1.0 \times 10^{-6}$ m ² /s) |
| ρ | density of the fluid (for water, $\rho \approx 998$ kg/m ³ at room temperature) |

Educational Objectives

1. Learn how to measure the volume flow rate of water through a pipe.
2. Reinforce concepts of the Moody chart, and of major and minor head losses in pipes.
3. Measure the friction factor for pipes of various diameters and roughnesses.
4. Compare the experimental results to the published Moody chart (or Colebrook equation).

Equipment

1. pipe flow rig, consisting of a flow loop powered by a flow pump, a control valve, and various test specimens with static pressure taps
2. tape measure
3. micrometer
4. stopwatch
5. graduated cylinders of various volumes and sizes
6. Validyne pressure transducer with display unit and analog DC voltage output to measure the head difference along a length of pipe section
7. calibration stand with water manometer tubes to calibrate the pressure transducer
8. long sections of pipe, with static pressure taps:
 - nominal 1/2-inch and nominal 3/4-inch copper pipes
 - nominal 1/2-inch, nominal 1-inch, and nominal 1 1/2-inch PVC pipes (hydrodynamically smooth)
 - nominal 3/4-inch galvanized iron pipe
9. personal computer with digital data acquisition software
10. magnetic resonance flow meter (Rosemount – reads volume flow rate in liters per minute)

Background

When water (or any other fluid) flows through a pipe, the pressure continuously drops in the streamwise direction because of friction along the walls of the pipe. It is common to express this pressure drop in terms of an irreversible **head loss**. **Head** is defined as the vertical height of a column of fluid connected to the flow by a static pressure tap. A fluid column that is at rest has a hydrostatic pressure difference from top to bottom of the column given by $\Delta P = \rho g |\Delta z| = \rho g h$, where $h = |\Delta z|$ is the difference in “head” or elevation of the column from top to bottom. In flow through piping systems, there are two types of irreversible head losses. **Major losses**, denoted by h_{major} (sometimes h_f), are those due to frictional losses through sections of constant diameter pipe, in which the flow is fully developed. Major losses are expressed in reference books in terms of a nondimensional **friction factor**, f , defined as

$$f = \frac{h_{\text{major}}}{\frac{L}{d} \frac{V^2}{2g}} \quad (1)$$

The **Moody chart**, or its corresponding equation, the **Colebrook equation**, is useful for obtaining friction factor as a function of Reynolds number and pipe roughness coefficient.

Minor losses, denoted by h_{minor} , are those due to any other “devices” in the piping system other than constant-diameter pipe sections. These include entrances, valves, couplings which change the diameter of the pipe, elbows, etc. Minor losses are listed in reference books in terms of a nondimensional **minor loss coefficient**, K , defined as

$$K = \frac{h_{\text{minor}}}{\frac{V^2}{2g}} \quad (2)$$

In a system with both major and minor losses, it is important to recognize that a minor loss is defined as the **additional** loss due to the presence of the valve, elbow, etc. For example, the minor loss through an elbow does *not* include the frictional (Moody chart) loss through the length of the elbow. Thus, when measuring a minor loss coefficient, it is necessary to measure the length of the elbow, and to incorporate this length into the total length, L , of the pipe system.

For a piping system where the pipe diameter remains constant, Equations (1) and (2) can be combined as follows:

$$\Delta h_{L, \text{total}} = \sum h_{\text{major}} + \sum h_{\text{minor}} = \frac{V^2}{2g} \left(\frac{fL}{d} + \sum K \right) \quad (3)$$

where $\Delta h_{L, \text{total}}$ is the sum of all the major and minor losses. In keeping with the above convention, length L represents the total length of pipe, including the centerline length through each elbow or other minor loss device.

References

1. Çengel, Y. A. and Cimbala, J. M., *Fluid Mechanics – Fundamentals and Applications*, McGraw-Hill, NY, 2006.
2. White, F. M., *Fluid Mechanics*, Ed. 5, McGraw-Hill, NY, 2003.