Fluid Mechanics: Fundamentals of Fluid Mechanics, 7th Edition,
Bruce R. Munson. Theodore H. Okiishi. Alric P. Rothmayer
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Lecture- 14
Internal Flows
(Minor Losses)

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Learning Objectives

- After completing this Lecture, you should be able to:

1. identify and understand various characteristics of the flow in pipes.
2. discuss the main properties of Minor Losses of laminar and turbulent pipe flow and appreciate their differences.
3. calculate losses in various pipe system components.
4. apply appropriate equations and principles to analyze a variety of pipe flow situations.

Outline

- Overview of Viscous Pipe Flow
- Minor Losses
- Loss Coefficients for pipe components
- Piping Networks and Pump Selection

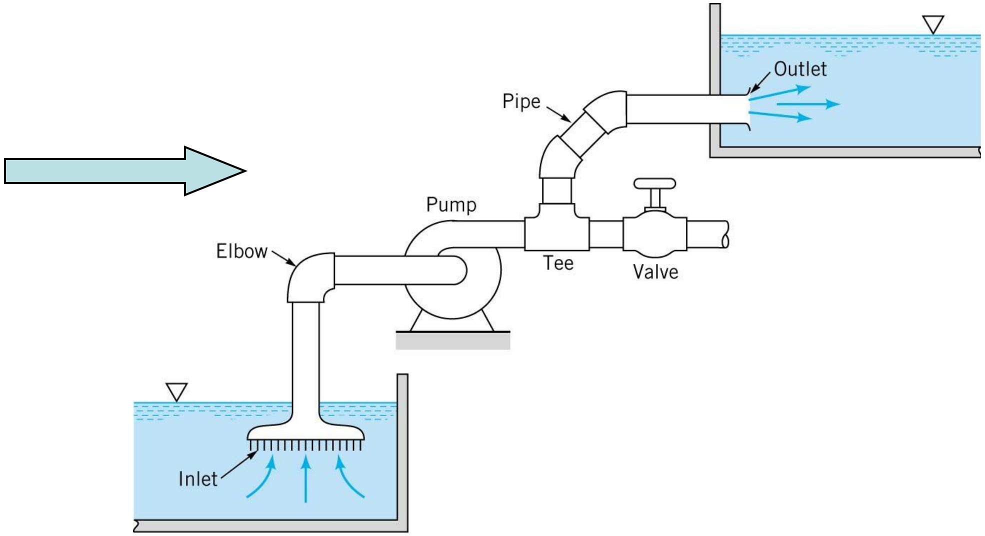
Viscous Pipe Flow: Overview

Pipe Flow is important in daily operations and is described in general as flow in a closed conduit (pipes and ducts). It is also known as an internal flow.

Some common examples are oil and water pipelines, flow in blood vessels, and HVAC ducts.

When real world effects such as viscous effects are considered, it is often difficult to use only theoretical methods. Often theoretical, experimental data, and dimensional analysis is used,

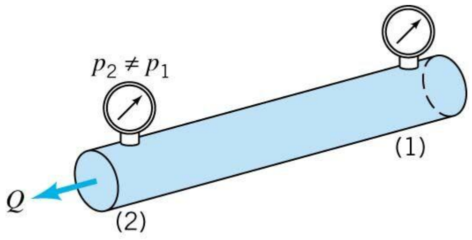
Some common pipe flow components are shown:



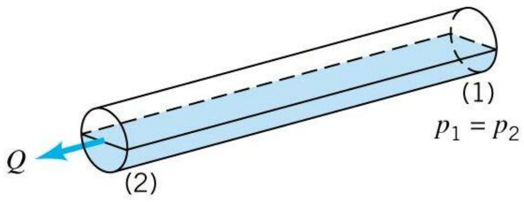
Viscous Pipe Flow: Overview

Pipe flow versus Open-channel flow:

Pipe Flow:



Open-Channel Flow:



- Pipe is completely filled with fluid
- Pressure Gradients drive the flow
- Gravity can also be important

- Pipe is not full of fluids
- Pressure gradient is constant
- Gravity is the driving force

i.e., flow down a concrete spill way.

Minor Losses

- Piping systems include fittings, valves, bends, elbows, tees, inlets, exits, enlargements, and contractions.
- These components interrupt the smooth flow of fluid and cause additional losses because of flow separation and mixing
- We introduce a relation for the minor losses associated with these components

$$\boxed{h_L = K_L \frac{V^2}{2g}}$$

- K_L is the loss coefficient.
- Is different for each component.
- Is assumed to be independent of Re.
- Typically provided by manufacturer or generic table (e.g., Table 8-4 in text).

Minor Losses

- Total head loss in a system is comprised of major losses (in the pipe sections) and the minor losses (in the components)

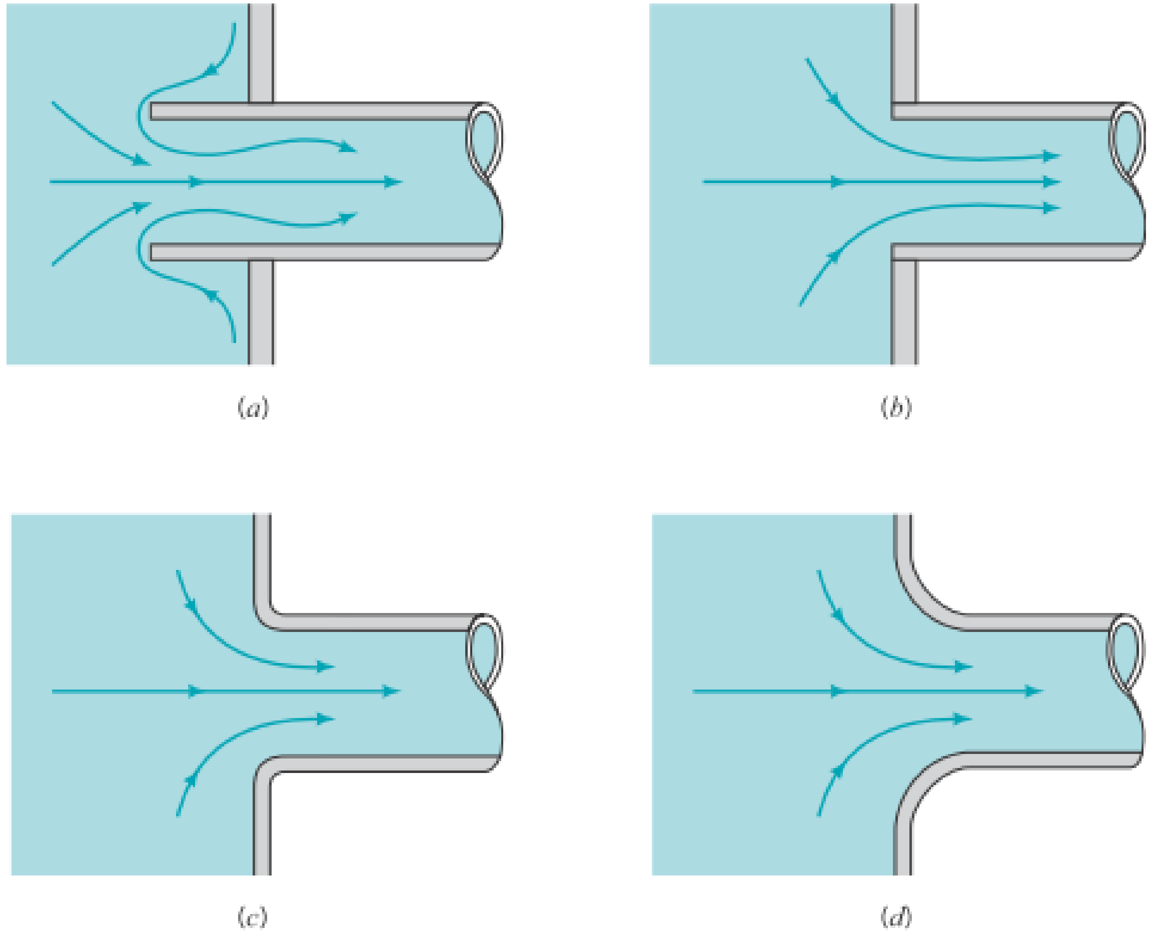
$$h_L = h_{L,major} + h_{L,minor}$$

$$h_L = \underbrace{\sum_i f_i \frac{L_i}{D_i} \frac{V_i^2}{2g}}_{\text{i pipe sections}} + \underbrace{\sum_j K_{L,j} \frac{V_j^2}{2g}}_{\text{j components}}$$

- If the piping system has constant diameter

$$h_L = \left(f \frac{L}{D} + \sum K_L \right) \frac{V^2}{2g}$$

Minor Losses



■ FIGURE 8.22 Entrance flow conditions and loss coefficient (Refs. 28, 29). (*a*) Reentrant, $K_L = 0.8$, (*b*) sharp-edged, $K_L = 0.5$, (*c*) slightly rounded, $K_L = 0.2$ (see Fig. 8.24), (*d*) well-rounded, $K_L = 0.04$ (see Fig. 8.24).

Minor Losses

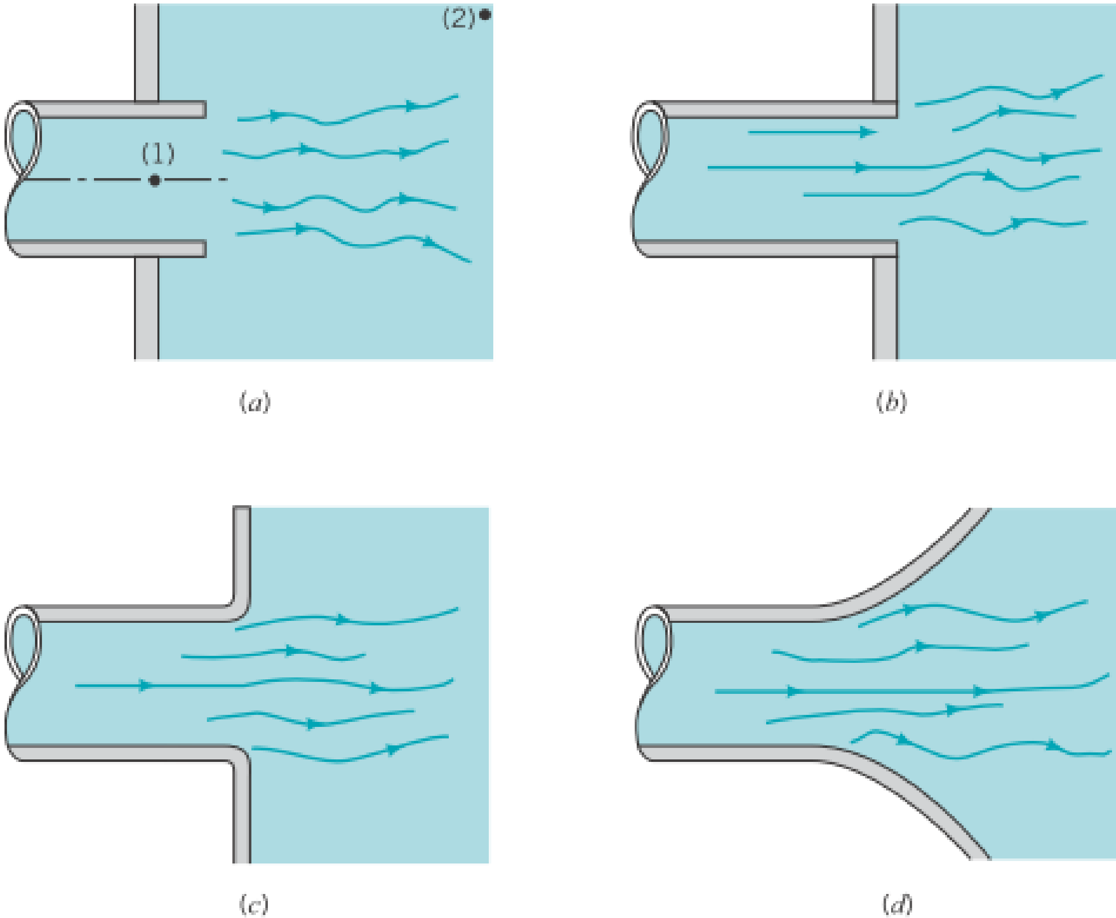
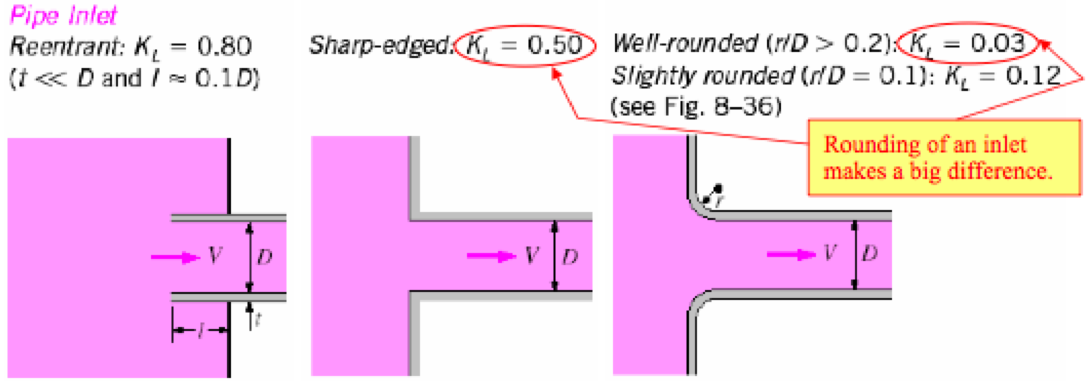
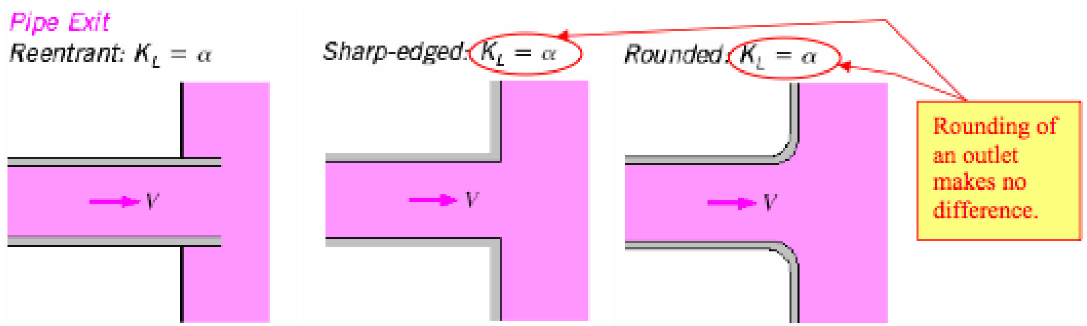


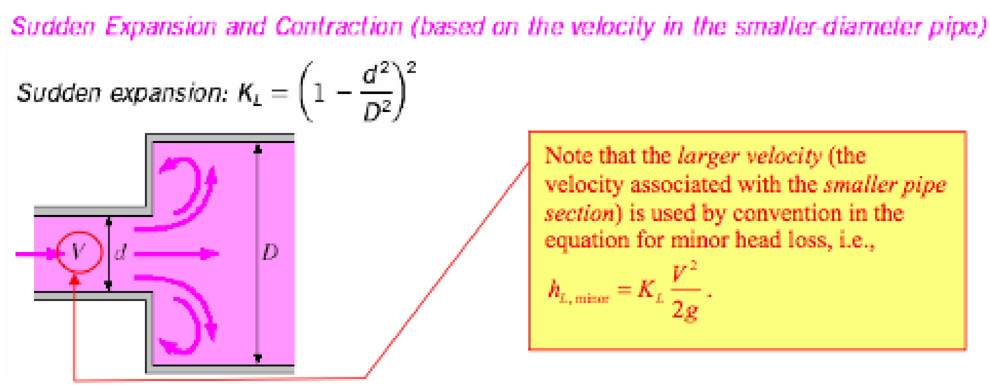
FIGURE 8.25 Exit flow conditions and loss coefficient. (*a*) Reentrant, $K_L = 1.0$, (*b*) sharp-edged, $K_L = 1.0$, (*c*) slightly rounded, $K_L = 1.0$, (*d*) well-rounded, $K_L = 1.0$.

Minor Losses

Here are some sample loss coefficients for various minor loss components. More values are listed in Table 8-4, page 350 of the Çengel-Cimbala textbook:





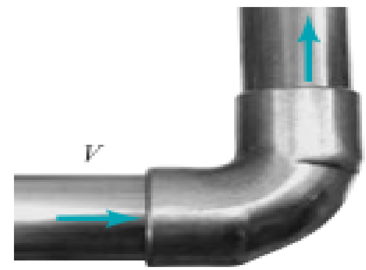


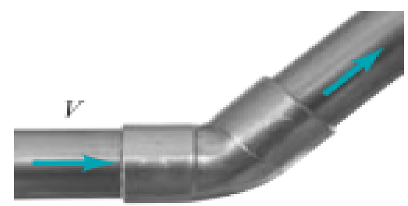
Loss Coefficients for pipe components

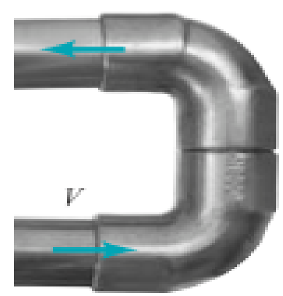
TABLE 8.2

Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$ **(Data from Refs. 5, 10, 27)**

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0





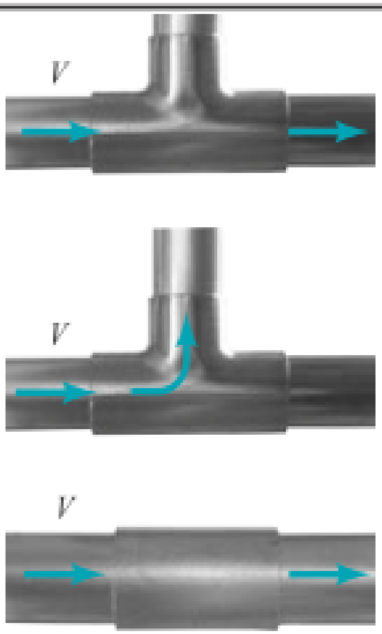


Loss Coefficients for pipe components

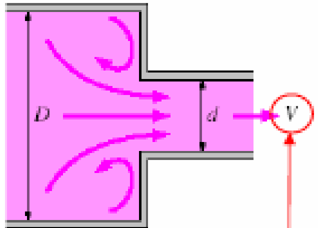
TABLE 8.2

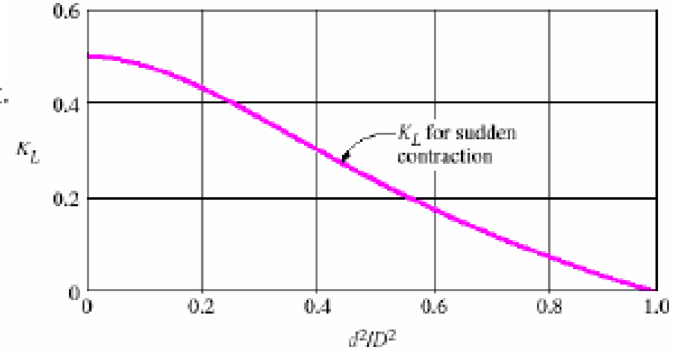
Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$ **(Data from Refs. 5, 10, 27)**

Component	K_L
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210



Sudden contraction: See chart.





Note: These are backwards. The K_L values listed for Expansion should be those for Contraction, and vice-versa.

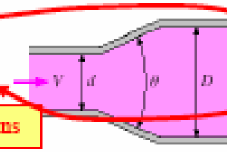
Note again that the *larger velocity* (the velocity associated with the *smaller pipe section*) is used by convention in the equation for minor head loss, i.e., $h_{L,\text{minor}} = K_L \dfrac{V^2}{2g}$.

Gradual Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Expansion:

$K_L = 0.02$ for $\theta = 20°$
$K_L = 0.04$ for $\theta = 45°$
$K_L = 0.07$ for $\theta = 60°$

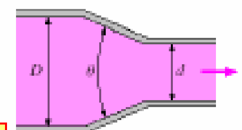
These are for contractions



Contraction (for $\theta = 20°$):

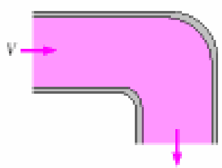
$K_L = 0.30$ for $d/D = 0.2$
$K_L = 0.25$ for $d/D = 0.4$
$K_L = 0.15$ for $d/D = 0.6$
$K_L = 0.10$ for $d/D = 0.8$

These are for expansions

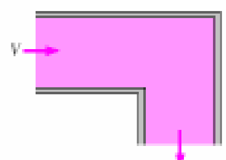


Bends and Branches

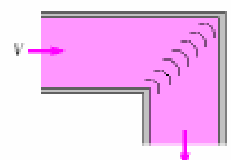
90° smooth bend:
Flanged: $K_L = 0.3$
Threaded: $K_L = 0.9$



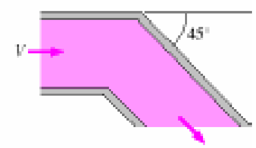
90° miter bend
(without vanes): $K_L = 1.1$



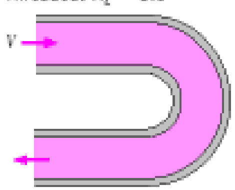
90° miter bend
(with vanes): $K_L = 0.2$



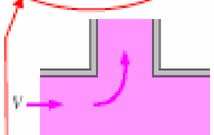
45° threaded elbow:
$K_L = 0.4$



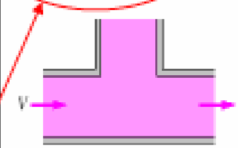
180° return bend:
Flanged: $K_L = 0.2$
Threaded: $K_L = 1.5$



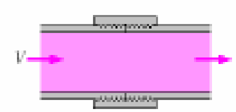
Tee (branch flow):
Flanged: $K_L = 1.0$
Threaded: $K_L = 2.0$



Tee (line flow):
Flanged: $K_L = 0.2$
Threaded: $K_L = 0.9$

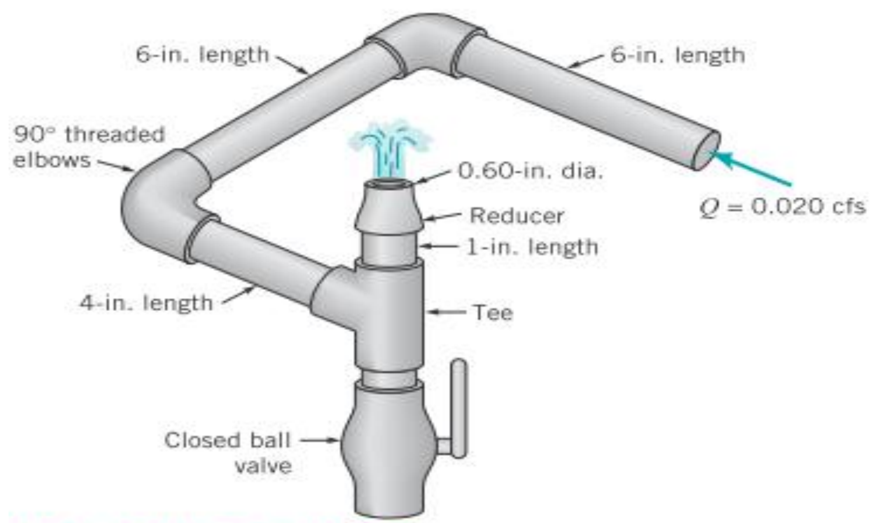


Threaded union:
$K_L = 0.08$



For tees, there are two values of K_L, one for *branch flow* and one for *line flow*.

8.70 Water flows steadily through the 0.75-in-diameter galvanized iron pipe system shown in **Video V8.14** and Fig. P8.70 at a rate of 0.020 cfs. Your boss suggests that friction losses in the straight pipe sections are negligible compared to losses in the threaded elbows and fittings of the system. Do you agree or disagree with your boss? Support your answer with appropriate calculations.



■ FIGURE P8.70

FIGURE P8.70

Major loss $= f\,\frac{\ell}{D}\frac{V^2}{2g}$ where

$\ell = (6+6+4+1)\,\text{in.} = 17\,\text{in.}$, $D = 0.75\,\text{in.}$

and

$$V = \frac{Q}{A} = \frac{0.02\,\frac{\text{ft}^3}{\text{s}}}{\frac{\pi}{4}(0.75/12)^2\,\text{ft}^2} = 6.52\,\frac{\text{ft}}{\text{s}}$$

Thus, with

$$Re = \frac{VD}{\nu} = \frac{6.52\,\frac{\text{ft}}{\text{s}}\left(\frac{0.75}{12}\,\text{ft}\right)}{1.21\times 10^{-5}\,\frac{\text{ft}^2}{\text{s}}} = 3.37\times 10^{4} \text{ and}$$

$$\frac{\varepsilon}{D} = \frac{0.0005\,\text{ft}}{\left(\frac{0.75}{12}\,\text{ft}\right)} = 8\times 10^{-3}$$ (see Table 8.1) we obtain (see Fig. 8.20)

$$f = 0.038 \text{ so that } f\,\frac{\ell}{D}\frac{V^2}{2g} = 0.038\,\frac{17\,\text{in.}}{0.75\,\text{in.}}\frac{V^2}{2g} = 0.861\,\frac{V^2}{2g} \qquad (1)$$

Also,

$$\text{Minor loss} = \sum K_L \frac{V^2}{2g} = \left[2(1.5) + 2 + 0.15\right]\frac{V^2}{2g} = 5.15\,\frac{V^2}{2g} \qquad (2)$$

90° elbow tee reducer with $\frac{A_2}{A_1} = \left(\frac{0.6\,\text{in.}}{0.75\,\text{in.}}\right)^2 = 0.64$

(see Fig. 8.26)

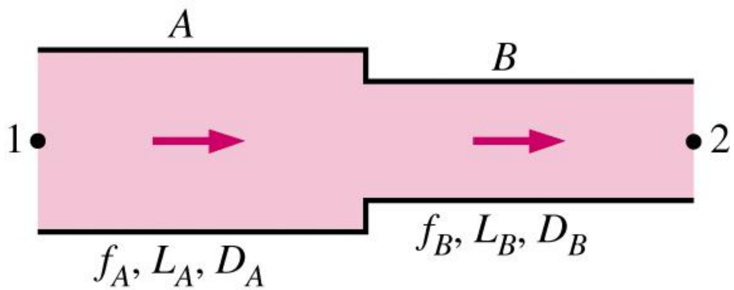
Thus, from Eqs. (1) and (2):

$$\frac{\text{major loss}}{\text{minor loss}} = \frac{0.861\,\frac{V^2}{2g}}{5.15\,\frac{V^2}{2g}} = 0.167 = 16.7\%$$

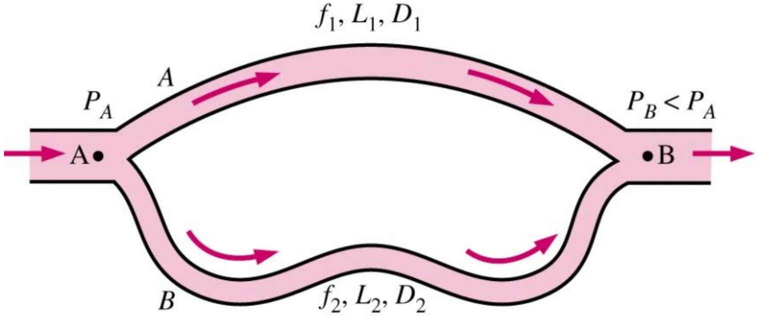
Probably <u>disagree</u> with boss because pipe friction is about 17% of other losses.

Piping Networks and Pump Selection

- Two general types of networks
  - Pipes in series
    - Volume flow rate is constant
    - Head loss is the summation of parts
  - Pipes in parallel
    - Volume flow rate is the sum of the components
    - Pressure loss across all branches is the same



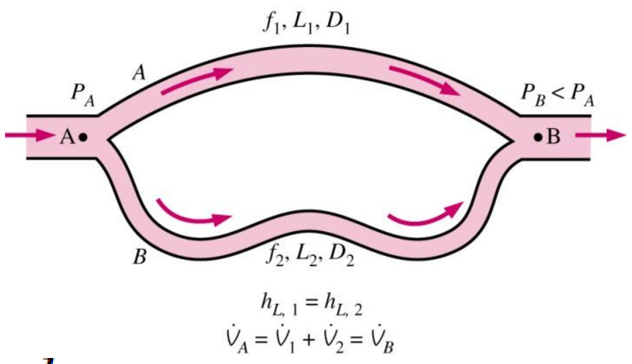
$$\dot{V}_A = \dot{V}_B$$
$$h_{L,\,1\text{-}2} = h_{L,\,A} + h_{L,\,B}$$



$$h_{L,\,1} = h_{L,\,2}$$
$$\dot{V}_A = \dot{V}_1 + \dot{V}_2 = \dot{V}_B$$

Piping Networks and Pump Selection

- For parallel pipes, perform CV analysis between points A and B



$$V_A = V_B$$

$$\frac{P_A}{\rho g} + \cancel{\alpha_1 \frac{V_A^2}{2g}} + \cancel{z_A} = \frac{P_B}{\rho g} + \cancel{\alpha_2 \frac{V_B^2}{2g}} + \cancel{z_B} + h_L$$

$$h_L = \frac{\Delta P}{\rho g}$$

- Since Δp is the same for all branches, head loss in all branches is the same

$$h_{L,1} = h_{L,2} \Longrightarrow f_1 \frac{L_1}{D_1} \frac{V_1^2}{2g} = f_2 \frac{L_2}{D_2} \frac{V_2^2}{2g}$$

Piping Networks and Pump Selection

- Head loss relationship between branches allows the following ratios to be developed

$$\frac{V_1}{V_2} = \left(\frac{f_2}{f_1}\frac{L_2}{L_1}\frac{D_1}{D_2}\right)^{\frac{1}{2}} \qquad \frac{\dot{\mathcal{V}}_1}{\dot{\mathcal{V}}_2} = \frac{D_1^2}{D_2^2}\left(\frac{f_2}{f_1}\frac{L_2}{L_1}\frac{D_1}{D_2}\right)^{\frac{1}{2}}$$

- Real pipe systems result in a system of non-linear equations. Very easy to solve with EES!
- Note: the analogy with electrical circuits should be obvious
  - Flow flow rate (VA) : current (I)
  - Pressure gradient (Δp) : electrical potential (V)
  - Head loss (h_L): resistance (R), however h_L is very nonlinear

Piping Networks and Pump Selection

- When a piping system involves pumps and/or turbines, pump and turbine head must be included in the energy equation

$$\frac{P_1}{\rho g} + \alpha_1 \frac{V_1^2}{2g} + z_1 + \boxed{h_{pump,u}} = \frac{P_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2 + \boxed{h_{turbine,e}} + h_L$$

- The useful head of the pump ($h_{pump,u}$) or the head extracted by the turbine ($h_{turbine,e}$), are functions of volume flow rate, i.e., they are not constants.
- Operating point of system is where the system is in balance, e.g., where pump head is equal to the head losses.

8.58 Given 90° threaded elbows used in conjunction with copper pipe (drawn tubing) of 0.75-in. diameter, convert the loss for a single elbow to equivalent length of copper pipe for wholly turbulent flow.

$$\ell_{eq} = \frac{K_L D}{f}$$

For 90° threaded elbow, $K_L = 1.5$

For copper pipe (drawn tubing), $\varepsilon = 0.000005\ ft$

So

$$\frac{\varepsilon}{D} = \frac{0.000005}{(0.75/12)} = 8 \times 10^{-5}$$

From Moody chart (wholly turbulent flow)

$$f \cong 0.0115$$

$$\ell_{eq} = \frac{(1.5)(0.75/12)}{0.0115} = \underline{\underline{8.15\ ft}}$$