

Today, we will:

- Discuss major vs. minor losses in pipe flows
- Do some example problems – major and minor losses in pipe flows

C. Minor Losses

1. Terminology

* Major losses – losses in long, straight pipe sections (fully developed)
 [Use Moody chart, or Colebrook eq.]

$$h_{L, \text{major}} = f \frac{L}{D} \frac{V^2}{2g} \quad (\text{see previous lecture})$$

* Minor losses – losses due to everything else

eg. valves, elbows, tees, inlet regions, outflow regions
 changes in pipe diameter (fittings, coupler)

Note: minor losses are not always smaller or less important than major losses, but we still use the name

2 ways to account for minor losses:

- a. Loss coefficient K_L (more popular)
- b. Equivalent length (some people use)

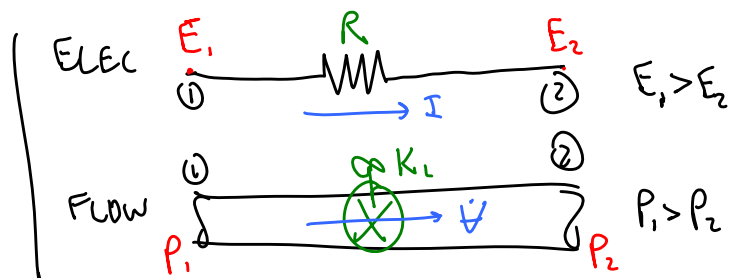
a. Loss coefficient

Define $h_{L, \text{minor}} = K_L \frac{V^2}{2g} \quad (1) \quad \{K_L\} = \{1\}$

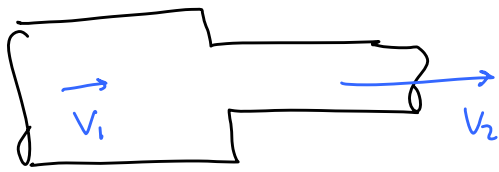
$K_L =$ (minor) loss coefficient or resistance coefficient

Analogy with electric circuit

- Voltage is analogous to pressure
- Current " " " flow rate
- Resistance " " " loss coeff.



Note: When there is a change in diameter, we use the bigger V by convention in our eq.

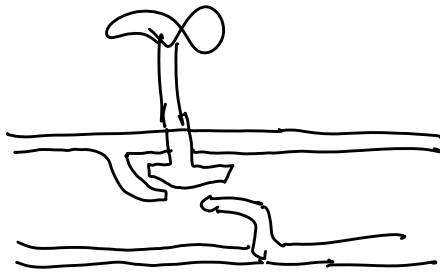


Use V_2 (not V_1) in Eq (1)

See Table 8.4 for various values of K_L

E.g. Valves

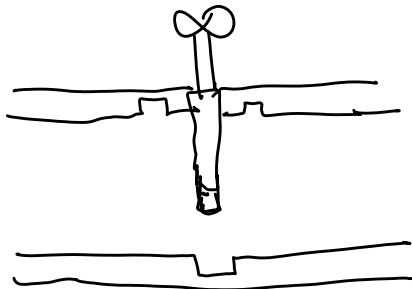
Globe



Fully open loss coefficient

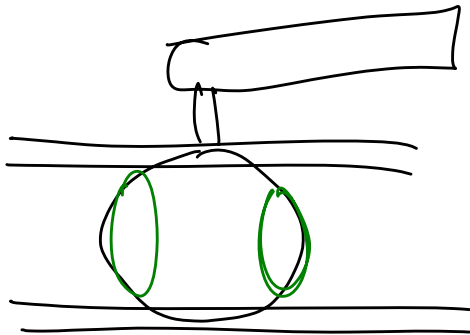
$K_L = 10$

Gate



$K_L \approx 0.2$

Ball



$K_L \approx 0.05$

In all cases K_L gets much bigger when the valve is partially closed

Minor Losses

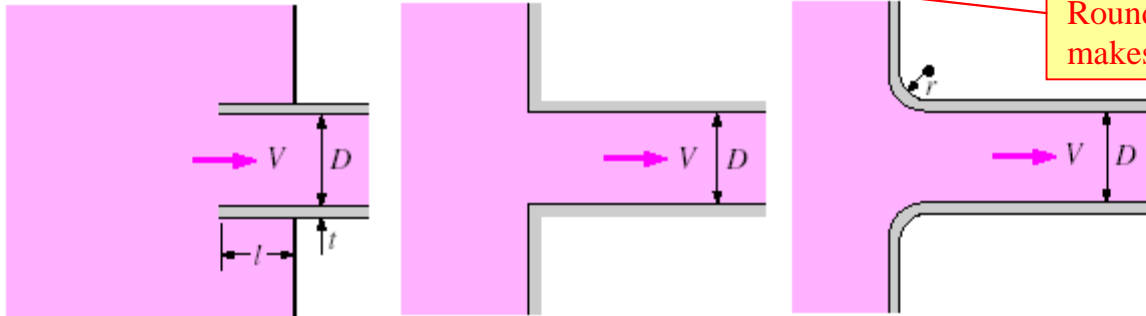
Here are some sample loss coefficients for various minor loss components. More values are listed in Table 8-4 of the Çengel-Cimbala textbook:

Pipe Inlet

Reentrant: $K_L = 0.80$
 ($t \ll D$ and $l \approx 0.1D$)

Sharp-edged: $K_L = 0.50$

Well-rounded ($r/D > 0.2$): $K_L = 0.03$
 Slightly rounded ($r/D = 0.1$): $K_L = 0.12$
 (see Fig. 8-36)



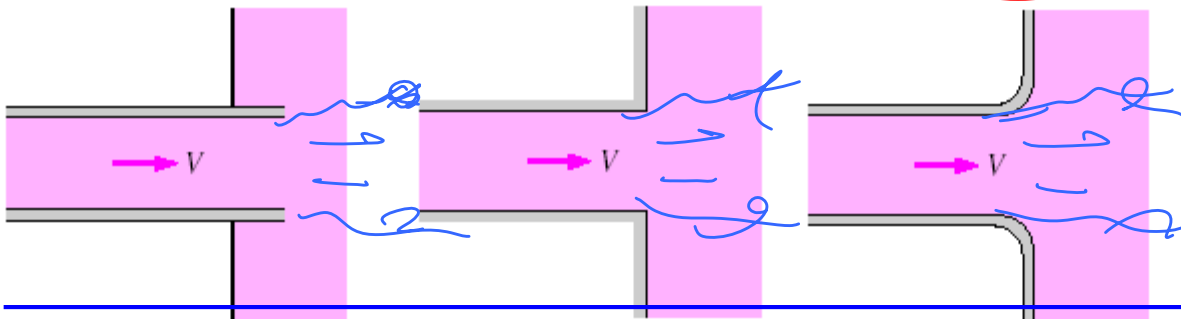
Rounding of an inlet makes a big difference.

Pipe Exit

Reentrant: $K_L = \alpha$

Sharp-edged: $K_L = \alpha$

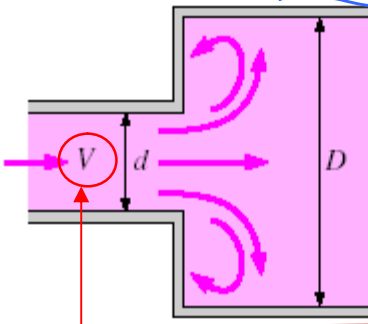
Rounded: $K_L = \alpha$



Rounding of an outlet makes no difference.

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

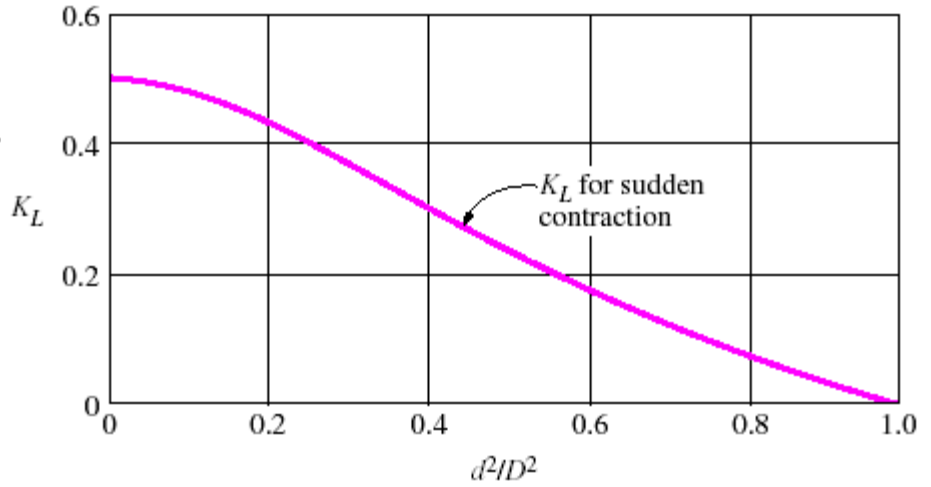
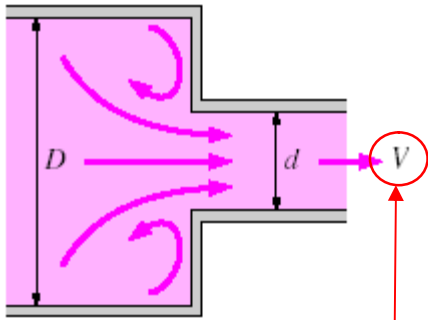
Sudden expansion: $K_L = \left(1 - \frac{d^2}{D^2}\right)^2 \alpha$



Note 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.,

$$h_{L, \text{minor}} = K_L \frac{V^2}{2g}$$

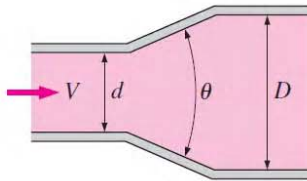
Sudden contraction: See chart.



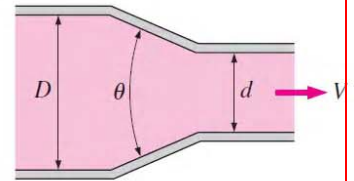
Note again that the *larger velocity* (the velocity associated with the *smaller pipe section*) is used by convention in the equation for minor head loss, i.e., $h_{L, \text{minor}} = K_L \frac{V^2}{2g}$.

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

Expansion (for $\theta = 20^\circ$):
 $K_L = 0.30$ 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 $d/D = 0.8$

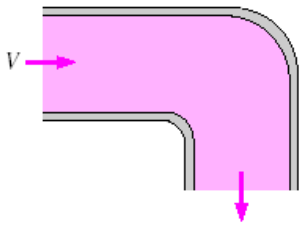


Contraction:
 $K_L = 0.02$ for $\theta = 30^\circ$
 $K_L = 0.04$ for $\theta = 45^\circ$
 $K_L = 0.07$ for $\theta = 60^\circ$

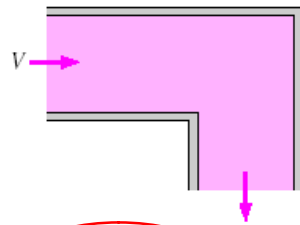


Bends and Branches

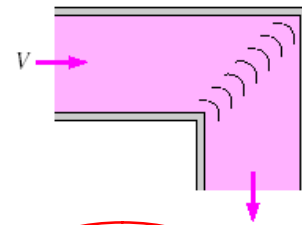
90° smooth bend:
 Flanged: $K_L = 0.3$
 Threaded: $K_L = 0.9$



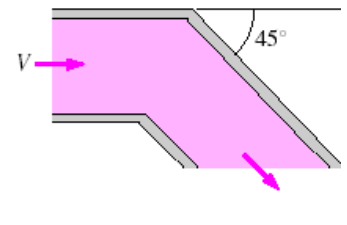
90° miter bend (without vanes): $K_L = 1.1$



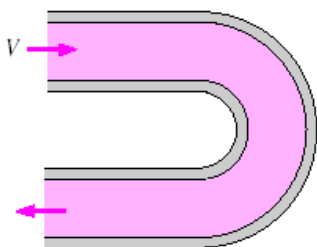
90° miter bend (with vanes): $K_L = 0.2$



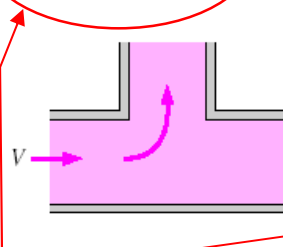
45° threaded elbow: $K_L = 0.4$



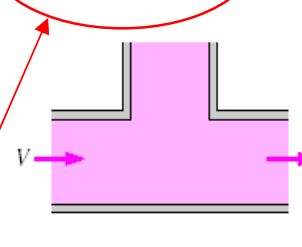
180° return bend:
 Flanged: $K_L = 0.2$
 Threaded: $K_L = 1.5$



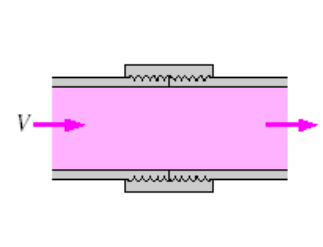
Tee (branch flow):
 Flanged: $K_L = 1.0$
 Threaded: $K_L = 2.0$



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

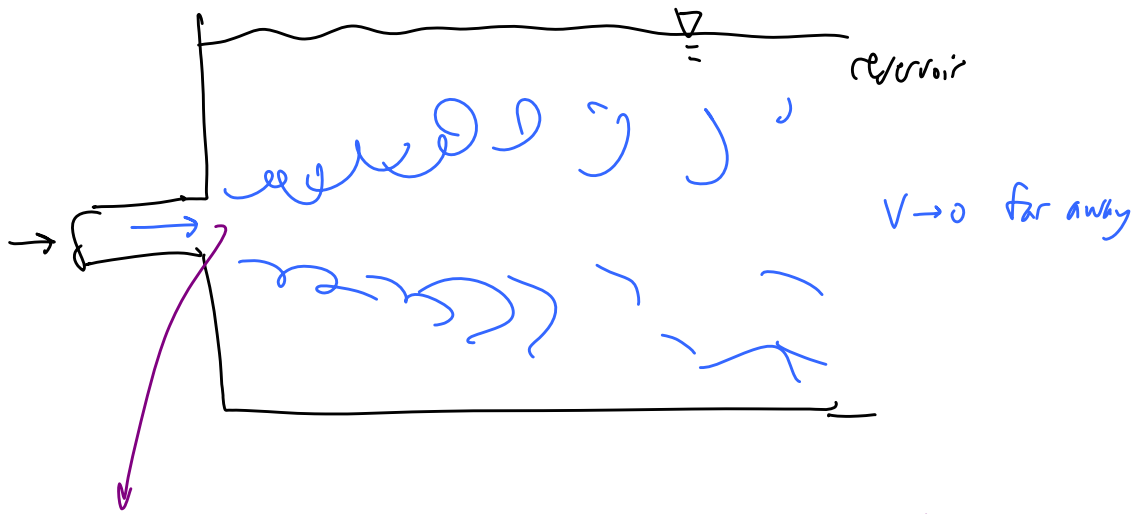


Threaded union: $K_L = 0.08$



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

Head loss at submerged outlets



All the kinetic energy exiting the pipe is "wasted"

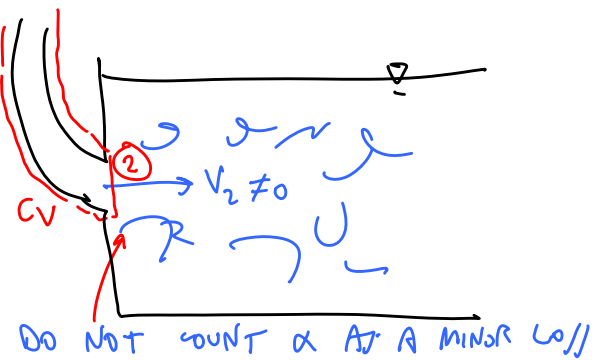
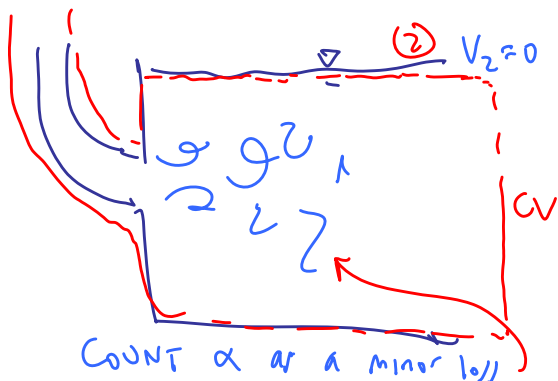
Recall the head form of the energy eq:

$$\dots + \alpha \frac{V^2}{2g} + \dots$$

All of this is wasted at this kind of an outlet

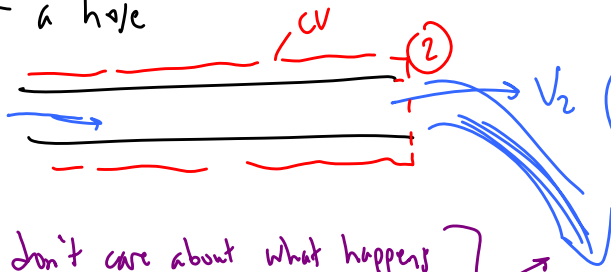
$$h_{L \text{ outlet}} = K_L \frac{V^2}{2g} \quad \therefore \boxed{K_L \text{ outlet} = \alpha}$$

Caution: Count the exit loss α ONLY when the mixing jet in the reservoir is enclosed by your CV.



eg.

end of a hose



Do NOT include the α as a minor loss

b. Equivalent length

recall for major loss;

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

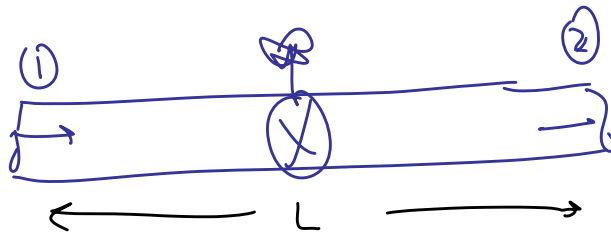
So for minor loss, define L_{equiv} so that

$$\{L_{equiv}\} = \{L\}$$

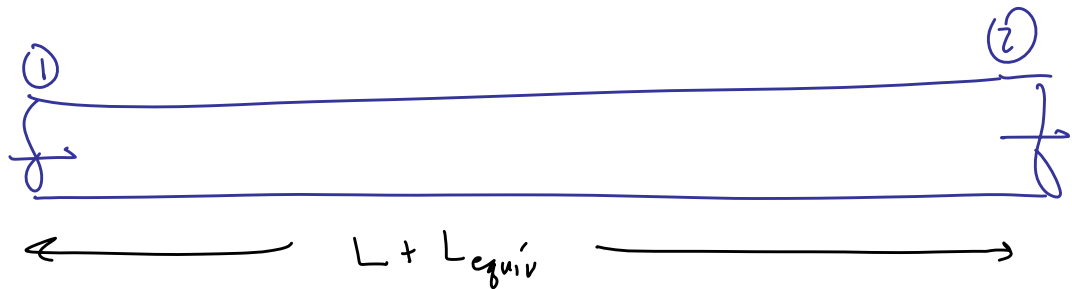
$$h_{L_{minor}} = f \frac{L_{equiv}}{D} \frac{V^2}{2g}$$

We replace the minor loss by an equivalent length of pipe

ACTUAL



EQUIVALENT



$P_1 - P_2 = \underline{\text{same}}$ in both cases

In either case,

$$h_{L_{total}} = h_L = h_{L_{major}} + h_{L_{minor}}$$

In energy eq.,

$$\frac{P_1}{\rho g} + \alpha_1 \frac{V_1^2}{2g} + z + \dots + h_L$$

General

$$h_L = \sum_i f_i \frac{L_i}{D_i} \frac{V_i^2}{2g} + \sum_j K_{L,j} \frac{V_j^2}{2g} \quad (2)$$

MAJOR LOSSES MINOR LOSSES

Sum i for all pipe diameters

Sum j over all minor losses

In many cases, if there is only one diameter throughout

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

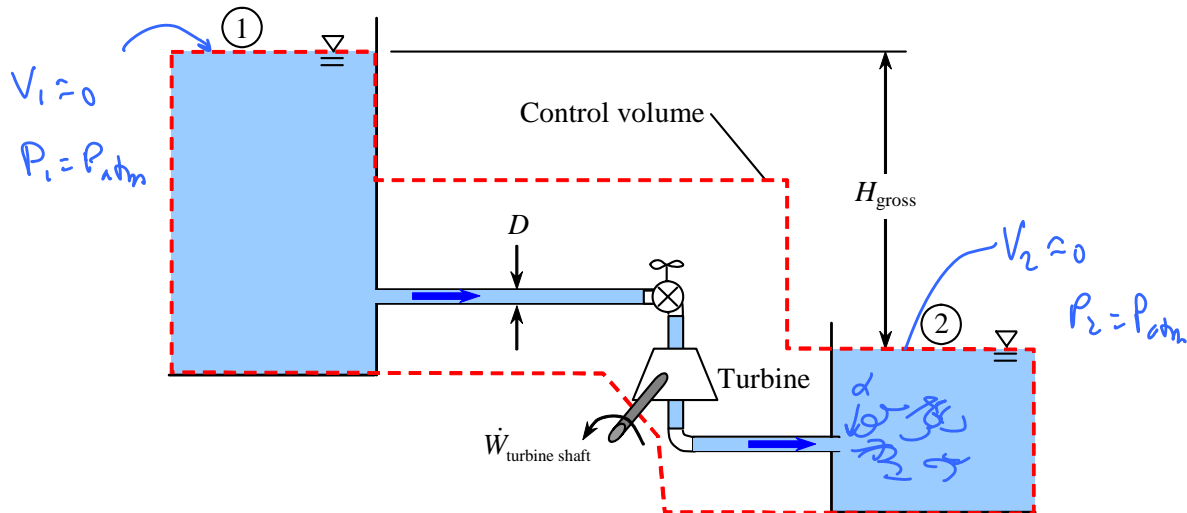
Sum of all loss coeffs

Total length of pipe

2. Example

Example Problem – Calculation of Turbine Shaft Power

Given: Water ($\rho = 998. \text{ kg/m}^3$, $\mu = 1.00 \times 10^{-3} \text{ kg/m}\cdot\text{s}$) flows from one large reservoir to another, and through a turbine as sketched. The elevation difference between the two reservoir surfaces is $H_{\text{gross}} = 120.0 \text{ m}$. The pipe is 5.0 cm I.D. cast iron pipe. The total pipe length is 30.8 m. The entrance is slightly rounded; the exit is sharp. There is one regular flanged 90-degree elbow, and one fully open flanged angle valve. The turbine is 81% efficient. The volume flow rate through the turbine is $0.0045 \text{ m}^3/\text{s}$.



To do: Calculate the shaft power produced by the turbine in units of kilowatts.

Solution:

- First we draw a control volume, as shown by the dashed line. We cut through the surface of both reservoirs (inlet 1 and outlet 2), where we know that the velocity is nearly zero and the pressure is atmospheric. We also slice through the turbine shaft. The rest of the control volume simply surrounds the piping system.
- We apply the head form of the energy equation from the inlet (1) to the outlet (2):

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

$P_1 = P_2 = P_{\text{atm}}$ (pointing to $P_1/\rho g$ and $P_2/\rho g$)
 $V_1 = V_2 \approx 0$ (pointing to $V_1^2/2g$ and $V_2^2/2g$)

- But by definition of turbine efficiency, $h_{\text{turbine,e}} = \frac{\dot{W}_{\text{turbine shaft}}}{\eta_{\text{turbine}} \dot{m} g}$ where $\dot{m} = \rho \dot{V}$. Also, since the reference velocity is the same for all the major and minor losses (the pipe diameter is constant throughout), we may use the simplified version of the equation for h_L , i.e., Eq. 8-59:

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

Therefore, we solve the energy equation for the desired unknown,

namely, turbine shaft power, $\dot{W}_{\text{turbine shaft}} = \eta_{\text{turbine}} \rho \dot{V} g \left[H_{\text{gross}} - \frac{V^2}{2g} \left(f \frac{L}{D} + \sum K_L \right) \right]$. This is our answer in variable form, but we still need to calculate the values of some of the variables.

The rest of this problem will be solved in class.

(1)

$$V = \frac{\dot{V}}{A} = \frac{4\dot{V}}{\pi D^2} \rightarrow \underline{V = 2.29183 \text{ m/s}}$$

$$Re = \frac{\rho V D}{\mu} = \underline{1.144 \times 10^5 = Re}$$

$$\epsilon = 0.26 \text{ mm} \quad \left[\text{Table 8-2, } \frac{\epsilon}{D} = \frac{0.26 \text{ mm}}{50 \text{ mm}} = 0.0052 \right]$$

get f from Moody chart or Colebrook eq. @ $Re = 1.145 \times 10^5$
; $\frac{\epsilon}{D} = 0.0052$

$$\hookrightarrow \underline{f = 0.03154}$$

$$\sum K_L = 0.12 + 5 + 0.3 + \alpha \quad \begin{array}{l} \uparrow \text{let } \alpha = 1.05 \\ \uparrow \text{for turb. flow} \\ \uparrow \text{slightly rounded inlet} \\ \uparrow \text{angle valve} \\ \uparrow \text{flanged elbow} \end{array}$$

$$\boxed{\sum K_L = 6.47}$$

↓
Plug into eq. (1)

$$\boxed{\dot{W}_{\text{turbine, shaft}} = 4.03 \text{ kW}}$$

Try it on your own for practice - plug in all the #'s & units
; you should get this answer.