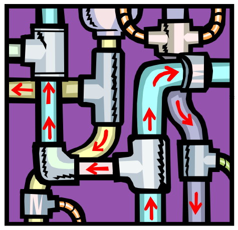
Chapter 8b

Energy Losses
Due to Friction
In Pipes



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Fluid Friction

- Loss of energy in a system due to friction along pipe walls
- Friction of fluid shearing against itself (mostly in laminar flow)
- This energy is usually lost as thermal energy (heat).

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General Energy Equation

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - h_R - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

- This chapter will concentrate on calculating frictional losses (h_L) based on Reynolds Number

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Review of Reynolds Number

$$N_R = \frac{vD\rho}{\eta} = \frac{vD}{\upsilon}$$

- If $N_R < 2000$, flow is laminar
- If $N_R > 4000$, flow is turbulent

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Darcy's Equation

- Energy loss is proportional to velocity head and the L/D ratio of the pipe.

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

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Darcy – Turbulent or Laminar

- Darcy's Equation can be used to calculate flow in either case.
- For laminar flow, $f = 64/N_R$
- For turbulent flow, we need to determine friction factor from Moody diagram.

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Laminar Flow Example

- Determine energy loss of heavy fuel oil @ 77°F flowing thru 500 ft of 4 inch dia pipe at 150 gpm.
- Determine Reynolds number first

$$N_R = \frac{vD\rho}{\eta} = \frac{vD}{\upsilon}$$

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Laminar Flow Example

- Appendix B has density & viscosity, so use: $N_R = \frac{vD\rho}{\eta}$

$$v = \frac{150\,gpm}{1} \times \frac{ft^3/s}{449\,gpm} \times \frac{4}{\pi(.333\,ft)^2} = 3.83\,ft/s$$

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Calculate Reynolds Number

$$N_R = \frac{(3.83\,ft/s)(0.333\,ft)(1.76\,slugs/\,ft^3)}{2.24\times10^{-3}\,lb\cdot s/\,ft^2}$$

- N_R = 1002 (laminar flow)
- Use $f = 64/\,N_R = 64/1002 = 0.064$

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Use Darcy's Equation

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

$$h_L = 0.064 \times \frac{500\,ft}{0.333\,ft} \times \frac{(3.82\,ft/s)^2}{2(32.2\,ft/s^2)}$$

- $h_L = 21.8\,ft$

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Friction Loss in Turbulent Flow

- Still use Darcy's Equation, but we must determine *f* using the Moody Diagram.
- Moody Diagram uses relative roughness of pipe and Reynolds number to determine friction factor.

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Relative Roughness

- Relative Roughness is a ratio of pipe diameter to inside surface roughness.
- See Table 8.2 for roughness of various pipes.
- Table lists metric and English units

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Friction Factor using Moody

- Determine Relative roughness based on pipe dia. and Table 8.2
- Follow roughness curve to calculated Reynolds number
- Determine friction factor on left vertical axis. **Be careful of logarithmic scaling.**

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Moody Chart Exercise

- Determine friction factor:

NR	D/ε	f
6.7×10^3	150	0.043
1.6×10^4	2000	0.0284
1.6×10^6	2000	0.0171
2.5×10^5	733	0.0223

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Turbulent Flow Example

- Pumping water @ 70°F, 50 gpm, thru 500 ft of 1.5 inch ID steel pipe

$v = Q / A$

$$v = \frac{50\,gpm}{1} \times \frac{ft^3/s}{449\,gpm} \times \frac{4}{\pi(.125\,ft)^2} = 9.07\,ft/s$$

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Determine Reynolds Number

$$N_R = \frac{(9.07\,ft/s)(0.125\,ft)(1.94\,slugs/ft^3)}{1.77\times10^{-5}\,lb\cdot s/ft^2}$$

- $N_R = 1.2 \times 10^5$ (turbulent flow)
- Roughness of pipe = 1.5×10^{-4}
- D/ε = 0.125/(1.5×10^{-4}) = 833
- Friction Factor = 0.023

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Calculate (h_L)

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

$$h_L = 0.023 \times \frac{500\,ft}{0.125\,ft} \times \frac{(9.07\,ft/s)^2}{2(32.2\,ft/s^2)}$$

- h_L = 118 ft

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Equations for friction factor

- Instead of using Moody Diagram
- Laminar: $f = 64/N_R$
- Turbulent: See Equation 8-7
  - –Good for D/ε from 100 to 10^6
  - –Good for N_R from 5×10^3 to 10^8

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Friction in Noncircular pipes

- Calculate Reynolds Number and Darcy's Equation by replacing D with 4R
- R = hydraulic radius, where
- R = Wetted Area/Wetted Perimeter

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Hazen-Williams Formula

- For water systems (English version)
  - 2 inch to 6 ft diameter pipes
  - Flow not to exceed 10 ft/s
  - Developed for water at 60°F
- $\boldsymbol{v = 1.32\ C_h\ R^{0.63}\ s^{0.54}}$
- Note that R = hydraulic radius
  - So R = D/4 for round pipes

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Hazen-Williams Formula

- C_h is found on Table 8.3
- $s = h_L/L$ (energy loss/ft of length)
- SI version is the same except for initial constant = 0.85
- SI version: $\boldsymbol{v = 0.85\ C_h\ R^{0.63}\ s^{0.54}}$

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Versions of Hazen-Williams

- Table 8.4 has alternate forms to solve for h_L, Q or Diameter
- Note units when using these equations. Must be consistent.

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Nomograph of Hazen-Williams

- Figure 8.9 allows you to determine unknown graphically.
- Note that nomograph is based on C_h = 100. See Equations (8-10) to (8-13) for conversions to other coefficients.

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Nomograph Example

- Given:
  - 4 inch Schedule 40 pipe
  - C_h = 130 (New, clean pipe)
  - Allowable loss = 25 ft/1000 ft
- Find: Flow rate & velocity.

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Homework – Chapter 8b

- Chap 8b Problems, page 249:
- Chap 8-33, 45, 49, 53
- Plus Chap 9 Problem 9-47

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