

Chapter 8

Objective: Laying groundwork to estimate fluid friction losses

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Frictional Energy Losses

- In Chapter 6 we assumed these losses were negligible
- In Chapter 7 you were told the losses or calculated them by difference

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Losses Depend on

1. The type of flow – laminar, unstable transition, & turbulent
2. Secondly, the roughness of the pipe surface
3. For transition, vibration

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Laminar Flow

- Like a marching band, columns of molecules stay in line
- Unlike marching band, center rows of molecules move at faster velocity than the side rows
- Bundles of fluid do not change position, either radially or axially

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Laminar Flow Examples

- Examples:
 - Cigarette smoke a few inches from cigarette
 - Kitchen faucet open just a little

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Turbulent Flow

- The opposite of order:
 - Bundles of fluid move randomly, chaotically
 - Bundles of fluid do change position, both radially and axially
- Examples:
 - Cigarette smoke a few feet from cigarette
 - Kitchen faucet open a lot

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Transition flow

- Switching back and forth between laminar and turbulent
- Vibration will cause switch from laminar to turbulent

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Losses vs. Flow Types

- Have much more mixing and frictional losses with turbulent flow
- Therefore, turbulent is preferred for heat transfer & blending
- But the higher losses means higher power requirements for pumping

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Reynolds Number (N_R) to Predict flow Type

- Number is a ratio of inertial forces (i.e., kinetic energy) to viscous forces
- Kinetic energy \propto to mv_{ave}^2 or ρv_{ave}^2
- Viscous forces \propto to viscosity and rate of shear or $\eta v_{ave}/D$
 - Where D is a dimension in the radial direction of the pipe, duct, etc.

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Formula for N_R

- General formula:

$$N_R = \frac{\text{Inertial Forces}}{\text{Viscous Forces}} = \frac{\rho v_{ave}^2}{\frac{\eta v_{ave}}{D}} = \frac{\rho v_{ave} D}{\eta} = \frac{v_{ave} D}{\nu}$$

- Where D is the diameter of the pipe
- And ν is kinematic viscosity $= \eta/\rho$

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N_R For Round Pipe Only

- Same formula, D is diameter
- Or in terms of Volumetric flow rate:

$$N_R = \frac{4\dot{V}\rho}{\pi D \eta} = \frac{4\dot{V}}{\pi D \nu}$$

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N_R Versus Type Flow

- If $N_R < 2000$ or 2300, Laminar
- If $N_R > 4000$, Turbulent
- In between is Transition

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Interpreting N_R vs. Type Flow

- At large N_R , inertial forces so large that the viscous forces can't prevent chaotic motion of turbulent flow
- At low N_R , viscous forces maintain a well-ordered parade

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Calculating N_R

- Is dimensionless, if we use consistent units
- Trick is to be consistent, given that there are many different units for viscosity, etc.
- Text opts to use mass in slugs/ft³. Be careful with your units.

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N_R in US units

- Mass density of lb_m/ft³ is in numerator. Therefore, viscosity must be in mass units of lb_m/(ft – s), not (lb_f/ft²) – s in text.
- Multiply g_c times (lb_f/ft²) – s to get lb_m/(ft – s)

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N_R in SI units

- Mass density of kg/m³ is in numerator. Therefore, viscosity must be in mass units of kg/(m – s).
- Multiply g_c times N/m² – s to get viscosity in = kg/(m – s)

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Help in Calculating N_R

1. See Bernoulli Handout for even more details on calculating the Reynolds number
2. See Units Handout for viscosity conversion factors

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N_R in Non-Round Ducts

- Key assumption: Cross section is full of fluid.
- Use $D = 4R$ where R is Hydraulic Radius:

$$R = \frac{\text{CrossSectionalAreaOfFlow}}{\text{WettedPerimeter}}$$

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Example: Round Pipe

- For Pipe of Diameter D

$$4R = \frac{4 \frac{\pi}{4} D^2}{\pi D} = D$$

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Example: Annulus

- For annulus between D_0 and D_1

$$4R = \frac{4 \frac{\pi}{4} (D_0^2 - D_1^2)}{\pi(D_0 + D_1)} = D_0 - D_1$$

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Example: Rectangular Duct

- For duct of inner dimensions a by b

$$4R = \frac{4ab}{2a + 2b} = \frac{2ab}{a + b}$$

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Velocity Profiles

- Up to now, always used average velocity in our equations
- In fact, we have a velocity profile, with zero velocity at surface of pipe and maximum value at center
- Profile is parabolic for laminar, and flatter for turbulent

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Velocity Profile Eq. for Laminar

- Local velocity v at radius r given by:

$$v = 2v_{ave} \left[1 - \left(\frac{r}{r_{max}} \right)^2 \right]$$

Where r varies from zero to r_{max}

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Results from Profile Eq.

- If $r = r_{max}$, local $v = 0$
- If $r = 0$, local $v = 2 v_{ave}$
- When local $v = v_{ave}$

$$r = r_{max} \sqrt{0.5} = 0.707 r_{max}$$

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Homework – Chapter 8

- From Chapter 8: Prob. 2, 3 & 10
- From Chapter 9: Prob. 30 & 51

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