Volumetric Flow Rate

- Def: volume flowing past section/ unit time

$$\dot{V} = A \quad v$$

- Note v is the average fluid velocity across a section of pipe
  - Examples: gpm, ft3 / s, m3/ s

Mass Flow Rate

- Def: mass flowing past section / unit time

$$\dot{m} = \rho \dot{V}$$

- Examples: kg / s, lb_m / s

Weight Flow Rate

- Def: weight of fluid flowing past section per unit time

$$\dot{w} = \gamma \dot{V}$$

- Examples: lb_f / s, N / s

Steady Flow (or State) Processes

- Def: fluid flows through system with no change in the fluids' properties with time
- Note fluid properties can change from point to point, but any any point the properties are constant with time

Continuity Equation for any Fluid in Closed Pipe

- At steady state, from cross section 1 to cross section 2:

$$\rho_1 A_1 v_1 = \dot{m}_1 = \rho_2 A_2 v_2 = \dot{m}_2$$

Continuity Equation for Typical Fluid in Closed Pipe

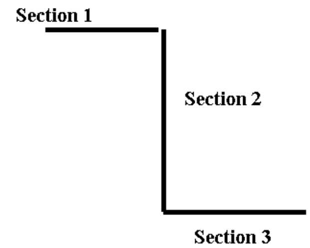
- May be treated as incompressible, so at steady state, from cross section 1 to cross section 2

$$\dot{V}_1 = A_1 v_1 = \dot{V}_2 == A_2 v_2$$

Closed Pipe vs. Unconstrained Liquid

- Water out shower head or over falls increases velocity as it falls
- But velocity of fluid going downward in vertical pipe can't increase velocity
- Why? (a) Constrained by pipe sides and (b) fluid in front of any section is in the way of that section going faster

Proof of Constant Velocity in Vertical Pipe



Commercially Available Pipe And Tubing

- Inner diameter(for flow) not the same as its nominal size.
- Exact inner diameter and flow areas are listed in Appendix of text for (a) common materials like steel, copper, and ductile iron and their (b) common pressure ratings.

More on Commercially Available Pipe And Tubing

- Note "tubing" of same material and nominal size has different diameter and flow areas than that of the "pipe."
- Def: Schedule number refers to wall thickness. The higher the schedule, the greater the pressure rating and smaller the inner diameter and flow area for same nominal size.

More on Commercially Available Pipe and Tubing

- Note type K Cupper tubing does no correspond to the type L used in homes
- More sizes and types listed in Cameron Hydraulic Data published by Ingersoll Dressler pumps or Crane Technical Paper #410 published by Crane Co.

Typical Velocities in Pipe and Tubing

- See Table 6.3 on p. 152 of text
- Rules of thumb: about 5 ft/ s for ½ inch pipe to 30 ft / s in 10 in pipe
- Later you will learn why (has to do with fluid friction vs. velocity)

Calculating Average Velocity from Volumetric Flow

$$v = \frac{\dot{V}}{A}$$

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Kinetic Energy of Flowing Fluid

- Def: Energy due to motion. Units of ft – lbf or J (i. e., N – m)

$$KE = \frac{mv_{ave}^2}{2g_c}$$

- Per unit mass. Units of (ft – lbf) / lbm fluid equals approx ft fluid or (N – m) / kg fluid

$$KE = \frac{v_{ave}^2}{2g_c}$$

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Kinetic Energy per Unit Weight

- Substitute m =(weight w) (g / g_c) to get KE per unit weight:
- Units of (ft – lbf) / lbf fluid equals ft fluid or (N – m) / N fluid equals m fluid

$$KE = \frac{v_{ave}^2}{2g}$$

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Potential Energy of Flowing Fluid

- Def: Gravitational pull on object. Same units as KE

  PE = (weight w)(height z)

- Substitute weight w = m (g / g_c) to get per unit mass.

$$PE = \frac{zg}{g_c}$$

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Potential Energy per Unit Weight

- PE = z
- Same units as KE per unit weight

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Flow Work to Get Fluid in or out of Chosen section of pipe

- Work = (Force) (Distance)
- But Force =(Pressure) (Flow Area)
- and (Flow Area) (Distance traveled) = Volume of fluid
- Therefore Work = PV

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Flow Work per Unit Mass

- (P)(specific mass volume) = $\dfrac{P}{\rho}$
- Same units as KE per unit mass

Flow Energy per Unit Weight

- (Pressure) (Specific weight volume) = $\dfrac{P}{\gamma}$
- Same units as KE per unit weight

Example Flow Energy Calculation

- Pump discharges fluid at P_1 = 150 psig in pipe. Pipe drops fluid into tank at P_2 = 0 gage

$$\frac{\text{Flow Energy}}{\text{unit weight}} = \frac{P_2 - P_1}{\gamma} = \frac{(150-0)144\frac{\text{in}^2}{\text{ft}^2}}{62.4\frac{\text{lb}_f}{\text{ft}^2}}$$

- = 346 ft fluid.

1st Law for Steady – State, Open System

$$Q_{in} - Q_{out} + W_{in} - W_{out} = \Delta U + \Delta KE + \Delta PE + \Delta PV$$

- Assume negligible Q, W, and single, homogeneous fluid
- Assume no fluid friction
- Therefore, $\Delta U = 0$

End Up With Bernoulli Equation

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g}$$

- This is form per unit weight
- Each term has units of ft or m fluid

Terms in Bernoulli Equation

- Def: Pressure head = 1st term
- Def: Elevation head= 2nd term
- Def: Velocity head = 3rd term
- **Rule of Thumb: ΔPressure Head greater than Δ Elevation Head greater than Δ Velocity Head**

Alternative form of Bernoulli Equation

$$\frac{P_1}{\rho} + Z_1\frac{g}{g_c} + \frac{V_1^2}{2g_c} = \frac{P_2}{\rho} + Z_2\frac{g}{g_c} + \frac{V_2^2}{2g_c}$$

- This is form per unit mass
- Each term given same name as that of unit weight form
- Each term is ft fluid head or (N-m) /kg fluid

Homework for Chapter 6

- Problems 6.31, 32, 34, 38, & 42
- Problems using spreadsheet:
  - 65, 88, & 101