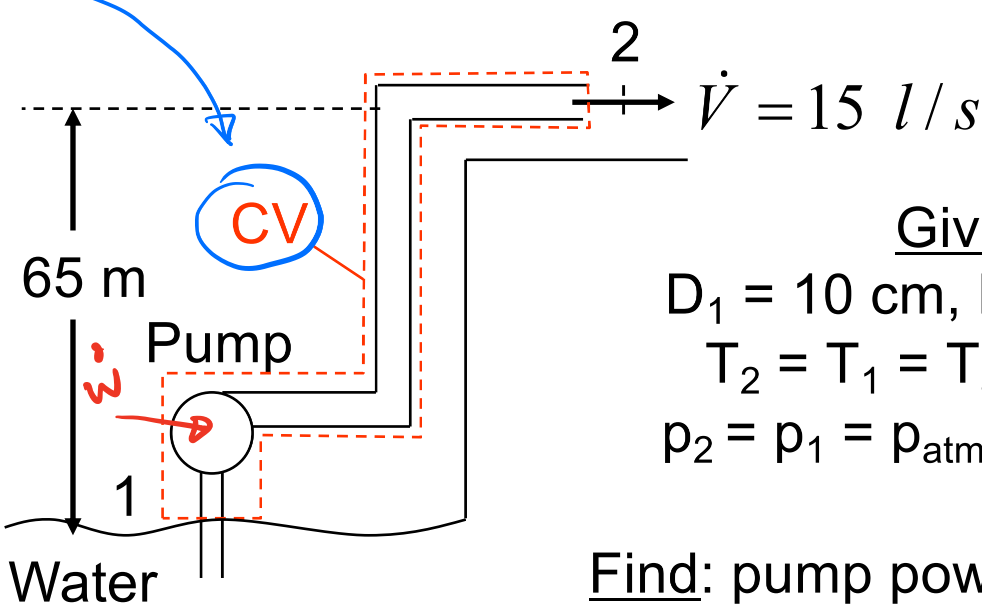
Lecture 17
System Integration

Integrated Systems

- Combination of multiple devices that serve a given purpose
- Includes complete cycles or other systems / subsystems
- Often select a control volume that spans the entire system or subsystem

Water Pumping Example



Given
D_1 = 10 cm, D_2 = 15 cm;
$T_2 = T_1 = T_{atm}$ = 20°C
$p_2 = p_1 = p_{atm}$ = 101.3 Pa

Find: pump power required

Assumptions: 1) SSSF, 2) adiabatic, 3) water is incompressible, 4) isothermal (frictionless), 5) $P_2 = P_1$

Basic Equations

$$\frac{dE_{cv}}{dt} = \dot{m}_1\left(h_1 + \frac{V_1^2}{2} + gz_1\right) - \dot{m}_2\left(h_2 + \frac{V_2^2}{2} + gz_2\right) + \dot{Q} - \dot{W}$$

($\frac{dE_{cv}}{dt}$ → 0 (SSSF); $\dot{Q}$ → 0 (adiabatic))

$$\frac{dm_{cv}}{dt} = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_2 = \dot{m}_1 = \dot{m}$$

($\frac{dm_{cv}}{dt}$ → 0 (SF))

$$\dot{m} = \frac{AV}{v} = \frac{\dot{V}}{v}, \quad dh = c\,dT + v\,dP \text{ (incomp.)}$$

Solution

$$\dot{W} = -\dot{m}\left[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right]$$

but

$$h_2 - h_1 = \int_{T_1}^{T_2} c\,dT + v(P_2 - P_1) = 0$$

(0 (since $T_2 = T_1$); 0 (since $P_2 = P_1$))

Also

$$\dot{m} = \frac{\dot{V}_2}{v_2}, \quad v_2 \approx v_{f, T_2} = 0.0010018 \text{ m}^3/\text{kg} \text{ (Table A-2)}$$

$$\dot{m} = \frac{0.015 \text{ m}^3/\text{s}}{0.0010018 \text{ m}^3/\text{kg}} = 14.97 \text{ kg/s}$$

$$V_1 = \frac{\dot{m}_1 v_1}{A_1} = \frac{14.97 \text{ kg/s} \cdot 0.0010018 \text{ m}^3/\text{kg}}{\pi \frac{(0.1 \text{ m})^2}{4}} = 1.9 \text{ m/s}$$

$$V_2 = \frac{\dot{m}_2 v_2}{A_2} = \frac{14.97 \, \text{kg/s} \cdot 0.0010018 \, \text{m}^3/\text{kg}}{\frac{\pi (0.15 \, \text{m})^2}{4}} = 0.85 \, \text{m/s}$$

Then

$$\dot{W} = -14.97 \, \frac{\text{kg}}{\text{s}} \Big(\underbrace{-1.44}_{\Delta ke} + \underbrace{637.5}_{\Delta pe} \Big) \frac{\text{m}^2}{\text{s}^2} \cdot \frac{1 \, \text{kJ/kg}}{1000 \, \frac{\text{m}^2}{\text{s}^2}}$$

$$\dot{W} = -9.54 \, \text{kW}$$ power input to pump

Notes

- $\Delta ke \ll \Delta pe \Rightarrow$ could have neglected Δke
- neglects friction $\Rightarrow$ minimum power requirement
  - (neglects friction) ↓ would appear as temp. rise
  - (minimum power requirement) ↳ inverse of hydroelectric dam example