Homework 11 Solutions

#1 2-75 Water is pumped from a lake to a storage tank at a specified rate. The overall efficiency of the pump-motor unit and the pressure difference between the inlet and the exit of the pump are to be determined.

Assumptions **1** The elevations of the tank and the lake remain constant. **2** Frictional losses in the pipes are negligible. **3** The changes in kinetic energy are negligible. **4** The elevation difference across the pump is negligible.

Properties We take the density of water to be $\rho = 1000 \text{ kg/m}^3$.

Analysis (*a*) We take the free surface of the lake to be point 1 and the free surfaces of the storage tank to be point 2. We also take the lake surface as the reference level ($z_1 = 0$), and thus the potential energy at points 1 and 2 are $pe_1 = 0$ and $pe_2 = gz_2$. The flow energy at both points is zero since both 1 and 2 are open to the atmosphere ($P_1 = P_2 = P_{atm}$). Further, the kinetic energy at both points is zero ($ke_1 = ke_2 = 0$) since the water at both locations is essentially stationary. The mass flow rate of water and its potential energy at point 2 are

$$\dot{m} = \rho\dot{V} = (1000 \text{ kg/m}^3)(0.070 \text{ m}^3/\text{s}) = 70 \text{ kg/s}$$

$$pe_2 = gz_2 = (9.81 \text{ m/s}^2)(20 \text{ m})\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 0.196 \text{ kJ/kg}$$
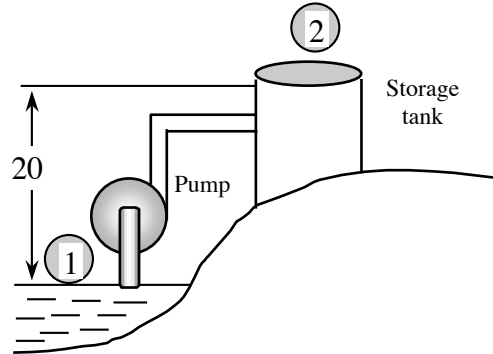
Then the rate of increase of the mechanical energy of water becomes

$$\Delta\dot{E}_{\text{mech,fluid}} = \dot{m}(e_{\text{mech,out}} - e_{\text{mech,in}}) = \dot{m}(pe_2 - 0) = \dot{m}pe_2 = (70 \text{ kg/s})(0.196 \text{ kJ/kg}) = 13.7 \text{ kW}$$

The overall efficiency of the combined pump-motor unit is determined from its definition,

$$\eta_{\text{pump-motor}} = \frac{\Delta\dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{elect,in}}} = \frac{13.7 \text{ kW}}{20.4 \text{ kW}} = 0.672 \quad \text{or} \quad \textbf{67.2\%}$$

(*b*) Now we consider the pump. The change in the mechanical energy of water as it flows through the pump consists of the change in the flow energy only since the elevation difference across the pump and the change in the kinetic energy are negligible. Also, this change must be equal to the useful mechanical energy supplied by the pump, which is 13.7 kW:

$$\Delta\dot{E}_{\text{mech,fluid}} = \dot{m}(e_{\text{mech,out}} - e_{\text{mech,in}}) = \dot{m}\frac{P_2 - P_1}{\rho} = \dot{V}\Delta P$$

Solving for ΔP and substituting,

$$\Delta P = \frac{\Delta\dot{E}_{\text{mech,fluid}}}{\dot{V}} = \frac{13.7 \text{ kJ/s}}{0.070 \text{ m}^3/\text{s}}\left(\frac{1 \text{ kPa}\cdot\text{m}^3}{1 \text{ kJ}}\right) = \textbf{196 kPa}$$

Therefore, the pump must boost the pressure of water by 196 kPa in order to raise its elevation by 20 m.

Discussion Note that only two-thirds of the electric energy consumed by the pump-motor is converted to the mechanical energy of water; the remaining one-third is wasted because of the inefficiencies of the pump and the motor.
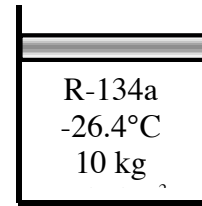
#2 **3-36** A piston-cylinder device that is filled with R-134a is heated. The final volume is to be determined.

Analysis This is a constant pressure process. The initial specific volume is

$$v_1 = \frac{V}{m} = \frac{1.595\,\text{m}^3}{10\,\text{kg}} = 0.1595\,\text{m}^3/\text{kg}$$

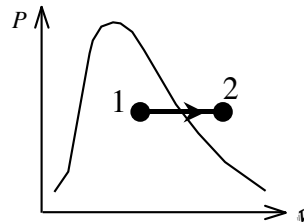The initial state is determined to be a mixture, and thus the pressure is the saturation pressure at the given temperature

$$P_1 = P_{sat\,@\,-26.4\,C} = 100\,\text{kPa} \quad (\text{Table A-12})$$

The final state is superheated vapor and the specific volume is

$$\left.\begin{array}{l} P_2 = 100\,\text{kPa} \\ T_2 = 100\ \text{C} \end{array}\right\} \ v_2 = 0.30138\,\text{m}^3/\text{kg} \quad (\text{Table A-13})$$

The final volume is then

$$V_2 = mv_2 = (10\,\text{kg})(0.30138\,\text{m}^3/\text{kg}) = \textbf{3.0138 m}^3$$

R-134a
-26.4°C
10 kg

#3 **4-74** Argon is compressed in a polytropic process. The work done and the heat transfer are to be determined.

Assumptions **1** Argon is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of 151 K and 4.86 MPa. **2** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$.

Properties The properties of argon are $R = 0.2081\,\text{kJ/kg·K}$ and $c_v = 0.3122\,\text{kJ/kg·K}$ (Table A-2a).

Analysis We take argon as the system. This is a *closed system* since no mass crosses the boundaries of the system. The energy balance for this system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$Q_{in} - W_{b,out} = \Delta U = mc_v(T_2 - T_1)$$

Argon
120 kPa
30°C
$P v^n =$
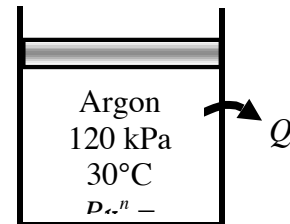
Using the boundary work relation for the polytropic process of an ideal gas gives

$$w_{b,out} = \frac{RT_1}{1-n}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right] = \frac{(0.2081\,\text{kJ/kg·K})(303\,\text{K})}{1-1.2}\left[\left(\frac{1200}{120}\right)^{0.2/1.2} - 1\right] = -147.5\,\text{kJ/kg}$$

Thus,

$$w_{b,in} = \textbf{147.5 kJ/kg}$$

The temperature at the final state is

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(n-1)/n} = (303\,\text{K})\left(\frac{1200\,\text{kPa}}{120\,\text{kPa}}\right)^{0.2/1.2} = 444.7\,\text{K}$$

From the energy balance equation,
$$q_{in} = w_{b,out} + c_v(T_2 - T_1) = -147.5 \text{ kJ/kg} + (0.3122 \text{ kJ/kg}\cdot\text{K})(444.7 - 303)\text{K} = -103.3 \text{ kJ/kg}$$
Thus,
$$q_{out} = \textbf{103.3 kJ/kg}$$

#4 4-60 The enthalpy changes for neon and argon are to be determined for a given temperature change.

Assumptions At specified conditions, neon and argon behave as an ideal gas.

Properties The constant-pressure specific heats of argon and neon are 0.5203 kJ/kg·K and 1.0299 kJ/kg·K, respectively (Table A-2a).

Analysis The enthalpy changes are
$$\Delta h_{argon} = c_p \Delta T = (0.5203 \text{ kJ/kg}\cdot\text{K})(400 - 100)\text{K} = \textbf{156.1 kJ/kg}$$
$$\Delta h_{neon} = c_p \Delta T = (1.0299 \text{ kJ/kg}\cdot\text{K})(400 - 100)\text{K} = \textbf{309.0 kJ/kg}$$

#5 5-119 R-134a is condensed in a condenser. The heat transfer per unit mass is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** There are no work interactions.

Analysis We take the pipe in which R-134a is condensed as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}}^{\text{0 (steady)}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$
$$\dot{m}h_1 = \dot{m}h_2 + \dot{Q}_{out}$$
$$\dot{Q}_{out} = \dot{m}(h_1 - h_2)$$
$$q_{out} = h_1 - h_2$$

1200 kPa   R134   1200
80 C   kPa

q_{out}

The enthalpies of R-134a at the inlet and exit of the condenser are (Table A-12, A-13).
$$\left.\begin{array}{l} P_1 = 1200 \text{ kPa} \\ T_1 = 80 \text{ C} \end{array}\right\} h_1 = 311.39 \text{ kJ/kg}$$
$$\left.\begin{array}{l} P_2 = 1200 \text{ kPa} \\ x = 0 \end{array}\right\} h_2 \cong h_{f@1200 \text{ kPa}} = 117.77 \text{ kJ/kg}$$

Substituting,
$$q_{out} = 311.39 - 117.77 = \textbf{193.6 kJ/kg}$$

#6 5-123 An insulated rigid tank is evacuated. A valve is opened, and air is allowed to fill the tank until mechanical equilibrium is established. The final temperature in the tank is to be determined.

Assumptions 1 This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process since the state of fluid at the inlet remains constant. **2** Air is an ideal gas with constant specific heats. **3** Kinetic and potential energies are negligible. **4** There are no work interactions involved. **5** The device is adiabatic and thus heat transfer is negligible.

Properties The specific heat ratio for air at room temperature is $k = 1.4$ (Table A-2).

Analysis We take the tank as the system, which is a control volume since mass crosses the boundary. Noting that the microscopic energies of flowing and nonflowing fluids are represented by enthalpy h and internal energy u, respectively, the mass and energy balances for this uniform-flow system can be expressed as
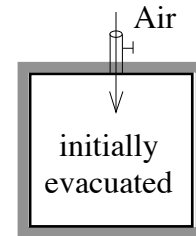
Mass balance:

$$m_{in} - m_{out} = \Delta m_{system} \quad \rightarrow \quad m_i = m_2 \quad (\text{since } m_{out} = m_{initial} = 0)$$

Energy balance:

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$m_i h_i = m_2 u_2 \quad (\text{since } Q \cong W \cong E_{out} = E_{initial} = ke \cong pe \cong 0)$$

Combining the two balances:

$$u_2 = h_i \rightarrow c_v T_2 = c_p T_i \rightarrow T_2 = (c_p / c_v) T_i = k T_i$$

Substituting,

$$T_2 = 1.4 \times 290 \text{ K} = 406 \text{ K} = \textbf{133°C}$$

Air

initially evacuated