

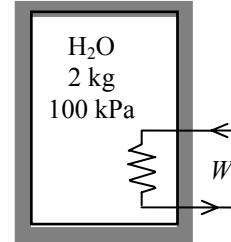
## Solutions to Tutorial 7: Chapter 7

**7-39** An insulated rigid tank contains a saturated liquid-vapor mixture of water at a specified pressure. An electric heater inside is turned on and kept on until all the liquid vaporized. The entropy change of the water during this process is to be determined.

**Analysis** From the steam tables (Tables A-4 through A-6)

$$\left. \begin{array}{l} P_1 = 100 \text{ kPa} \\ x_1 = 0.25 \end{array} \right\} \begin{array}{l} v_1 = v_f + x_1 v_{fg} = 0.001 + (0.25)(1.6941 - 0.001) = 0.4243 \text{ m}^3/\text{kg} \\ s_1 = s_f + x_1 s_{fg} = 1.3028 + (0.25)(6.0562) = 2.8168 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} v_2 = v_1 \\ \text{sat. vapor} \end{array} \right\} s_2 = 6.8649 \text{ kJ/kg} \cdot \text{K}$$



Then the entropy change of the steam becomes

$$\Delta S = m(s_2 - s_1) = (2 \text{ kg})(6.8649 - 2.8168) \text{ kJ/kg} \cdot \text{K} = \mathbf{8.10 \text{ kJ/K}}$$

**7-43** An insulated cylinder is initially filled with saturated liquid water at a specified pressure. The water is heated electrically at constant pressure. The entropy change of the water during this process is to be determined.

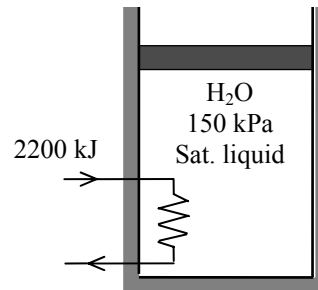
**Assumptions 1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The compression or expansion process is quasi-equilibrium.

**Analysis** From the steam tables (Tables A-4 through A-6),

$$\left. \begin{array}{l} P_1 = 150 \text{ kPa} \\ \text{sat. liquid} \end{array} \right\} \begin{array}{l} v_1 = v_{f@150 \text{ kPa}} = 0.001053 \text{ m}^3/\text{kg} \\ h_1 = h_{f@150 \text{ kPa}} = 467.13 \text{ kJ/kg} \\ s_1 = s_{f@150 \text{ kPa}} = 1.4337 \text{ kJ/kg} \cdot \text{K} \end{array}$$

Also,

$$m = \frac{V}{v_1} = \frac{0.005 \text{ m}^3}{0.001053 \text{ m}^3/\text{kg}} = 4.75 \text{ kg}$$



We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this stationary closed system can be expressed as

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

$$W_{e,\text{in}} - W_{b,\text{out}} = \Delta U$$

$$W_{e,\text{in}} = m(h_2 - h_1)$$

since  $\Delta U + W_b = \Delta H$  during a constant pressure quasi-equilibrium process. Solving for  $h_2$ ,

$$h_2 = h_1 + \frac{W_{e,\text{in}}}{m} = 467.13 + \frac{2200 \text{ kJ}}{4.75 \text{ kg}} = 930.33 \text{ kJ/kg}$$

Thus,

$$\left. \begin{array}{l} P_2 = 150 \text{ kPa} \\ h_2 = 930.33 \text{ kJ/kg} \end{array} \right\} \begin{array}{l} x_2 = \frac{h_2 - h_f}{h_{fg}} = \frac{930.33 - 467.13}{2226.0} = 0.2081 \\ s_2 = s_f + x_2 s_{fg} = 1.4337 + (0.2081)(5.7894) = 2.6384 \text{ kJ/kg} \cdot \text{K} \end{array}$$

Then the entropy change of the water becomes

$$\Delta S = m(s_2 - s_1) = (4.75 \text{ kg})(2.6384 - 1.4337) \text{ kJ/kg} \cdot \text{K} = \mathbf{5.72 \text{ kJ/K}}$$

**7-44** An insulated cylinder is initially filled with saturated R-134a vapor at a specified pressure. The refrigerant expands in a reversible manner until the pressure drops to a specified value. The final temperature in the cylinder and the work done by the refrigerant are to be determined.

**Assumptions** **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The process is stated to be reversible.

**Analysis** (a) This is a reversible adiabatic (i.e., isentropic) process, and thus  $s_2 = s_1$ . From the refrigerant tables (Tables A-11 through A-13),

$$P_1 = 0.8 \text{ MPa} \left. \begin{array}{l} \nu_1 = \nu_{g@0.8 \text{ MPa}} = 0.025621 \text{ m}^3/\text{kg} \\ u_1 = u_{g@0.8 \text{ MPa}} = 246.79 \text{ kJ/kg} \\ s_1 = s_{g@0.8 \text{ MPa}} = 0.91835 \text{ kJ/kg} \cdot \text{K} \end{array} \right\} \text{ sat. vapor}$$

Also,

$$m = \frac{\nu}{\nu_1} = \frac{0.05 \text{ m}^3}{0.025621 \text{ m}^3/\text{kg}} = 1.952 \text{ kg}$$

and

$$P_2 = 0.4 \text{ MPa} \left. \begin{array}{l} x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{0.91835 - 0.24761}{0.67929} = 0.9874 \\ u_2 = u_f + x_2 u_{fg} = 63.62 + (0.9874)(171.45) = 232.91 \text{ kJ/kg} \end{array} \right\} s_2 = s_1$$

$$T_2 = T_{\text{sat}@0.4 \text{ MPa}} = \mathbf{8.91^\circ\text{C}}$$

(b) We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this adiabatic closed system can be expressed as

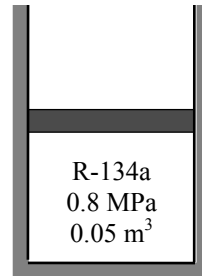
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\text{Net energy transfer by heat, work, and mass}} = \underbrace{\Delta E_{\text{system}}}_{\text{Change in internal, kinetic, potential, etc. energies}}$$

$$-W_{\text{b,out}} = \Delta U$$

$$W_{\text{b,out}} = m(u_1 - u_2)$$

Substituting, the work done during this isentropic process is determined to be

$$W_{\text{b,out}} = m(u_1 - u_2) = (1.952 \text{ kg})(246.79 - 232.91) \text{ kJ/kg} = \mathbf{27.09 \text{ kJ}}$$



**7-105** Air is accelerated in an isentropic nozzle. The maximum velocity at the exit is to be determined.

**Assumptions 1** Air is an ideal gas with constant specific heats. **2** The nozzle operates steadily.

**Properties** The properties of air at room temperature are  $c_p = 1.005 \text{ kJ/kg}\cdot\text{K}$ ,  $k = 1.4$  (Table A-2a).

**Analysis** The exit temperature is determined from ideal gas isentropic relation to be,

$$T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{(k-1)/k} = (400 + 273 \text{ K}) \left( \frac{100 \text{ kPa}}{800 \text{ kPa}} \right)^{0.4/1.4} = 371.5 \text{ K}$$

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

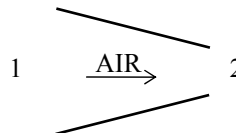
$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\psi_0}}_{\text{Rate of change in internal, kinetic, potential, etc. energies (steady)}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2)$$

$$0 = h_2 - h_1 + \frac{V_2^2 - 0}{2}$$

$$0 = c_p(T_2 - T_1) + \frac{V_2^2}{2}$$



Therefore,

$$V_2 = \sqrt{2c_p(T_2 - T_1)} = \sqrt{2(1.005 \text{ kJ/kg}\cdot\text{K})(673 - 371.5)\text{K} \left( \frac{1000 \text{ m}^2/\text{s}^2}{1 \text{ kJ/kg}} \right)} = \mathbf{778.5 \text{ m/s}}$$

**7-115** Liquid water is to be pumped by a 25-kW pump at a specified rate. The highest pressure the water can be pumped to is to be determined.

**Assumptions 1** Liquid water is an incompressible substance. **2** Kinetic and potential energy changes are negligible. **3** The process is assumed to be reversible since we will determine the limiting case.

**Properties** The specific volume of liquid water is given to be  $v_1 = 0.001 \text{ m}^3/\text{kg}$ .

**Analysis** The highest pressure the liquid can have at the pump exit can be determined from the reversible steady-flow work relation for a liquid,

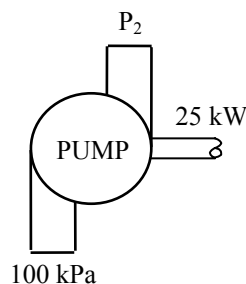
$$\dot{W}_{\text{in}} = \dot{m} \left( \int_1^2 v dP + \Delta ke^{\psi_0} + \Delta pe^{\psi_0} \right) = \dot{m} v_1 (P_2 - P_1)$$

Thus,

$$25 \text{ kJ/s} = (5 \text{ kg/s})(0.001 \text{ m}^3/\text{kg})(P_2 - 100) \text{ kPa} \left( \frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right)$$

It yields

$$P_2 = \mathbf{5100 \text{ kPa}}$$



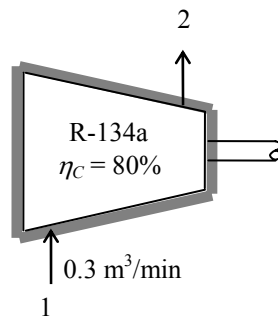
**7-135** [Also solved by EES on enclosed CD] Refrigerant-134a enters an adiabatic compressor with an isentropic efficiency of 0.80 at a specified state with a specified volume flow rate, and leaves at a specified pressure. The compressor exit temperature and power input to the compressor are to be determined.

**Assumptions 1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** The device is adiabatic and thus heat transfer is negligible.

**Analysis** (a) From the refrigerant tables (Tables A-11E through A-13E),

$$P_1 = 120 \text{ kPa} \left. \begin{array}{l} h_1 = h_{g@120 \text{ kPa}} = 236.97 \text{ kJ/kg} \\ s_1 = s_{g@120 \text{ kPa}} = 0.94779 \text{ kJ/kg} \cdot \text{K} \\ \nu_1 = \nu_{g@120 \text{ kPa}} = 0.16212 \text{ m}^3/\text{kg} \end{array} \right\} \text{sat. vapor}$$

$$P_2 = 1 \text{ MPa} \left. \begin{array}{l} h_{2s} = 281.21 \text{ kJ/kg} \\ s_{2s} = s_1 \end{array} \right\}$$



From the isentropic efficiency relation,

$$\eta_c = \frac{h_{2s} - h_1}{h_{2a} - h_1} \longrightarrow h_{2a} = h_1 + (h_{2s} - h_1)/\eta_c = 236.97 + (281.21 - 236.97)/0.80 = 292.26 \text{ kJ/kg}$$

Thus,

$$\left. \begin{array}{l} P_{2a} = 1 \text{ MPa} \\ h_{2a} = 292.26 \text{ kJ/kg} \end{array} \right\} T_{2a} = \mathbf{58.9^\circ\text{C}}$$

(b) The mass flow rate of the refrigerant is determined from

$$\dot{m} = \frac{\dot{V}_1}{\nu_1} = \frac{0.3/60 \text{ m}^3/\text{s}}{0.16212 \text{ m}^3/\text{kg}} = 0.0308 \text{ kg/s}$$

There is only one inlet and one exit, and thus  $\dot{m}_1 = \dot{m}_2 = \dot{m}$ . We take the actual compressor as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed as

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

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{W}_{\text{a,in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \dot{Q} \cong \Delta \text{ke} \cong \Delta \text{pe} \cong 0)$$

$$\dot{W}_{\text{a,in}} = \dot{m}(h_2 - h_1)$$

Substituting, the power input to the compressor becomes,

$$\dot{W}_{\text{a,in}} = (0.0308 \text{ kg/s})(292.26 - 236.97) \text{ kJ/kg} = \mathbf{1.70 \text{ kW}}$$

**7-137** Air enters an adiabatic compressor with an isentropic efficiency of 84% at a specified state, and leaves at a specified temperature. The exit pressure of air and the power input to the compressor are 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** The device is adiabatic and thus heat transfer is negligible. **4** Air is an ideal gas with variable specific heats.

**Properties** The gas constant of air is  $R = 0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}$  (Table A-1)

**Analysis** (a) From the air table (Table A-17),

$$T_1 = 290 \text{ K} \longrightarrow h_1 = 290.16 \text{ kJ/kg}, P_{r1} = 1.2311$$

$$T_2 = 530 \text{ K} \longrightarrow h_{2a} = 533.98 \text{ kJ/kg}$$

From the isentropic efficiency relation  $\eta_c = \frac{h_{2s} - h_1}{h_{2a} - h_1}$ ,

$$\begin{aligned} h_{2s} &= h_1 + \eta_c (h_{2a} - h_1) \\ &= 290.16 + (0.84)(533.98 - 290.16) = 495.0 \text{ kJ/kg} \longrightarrow P_{r2} = 7.951 \end{aligned}$$

Then from the isentropic relation ,

$$\frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}} \longrightarrow P_2 = \left( \frac{P_{r2}}{P_{r1}} \right) P_1 = \left( \frac{7.951}{1.2311} \right) (100 \text{ kPa}) = \mathbf{646 \text{ kPa}}$$

(b) There is only one inlet and one exit, and thus  $\dot{m}_1 = \dot{m}_2 = \dot{m}$ . We take the actual compressor as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed as

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

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{W}_{\text{a,in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \dot{Q} \cong \Delta \text{ke} \cong \Delta \text{pe} \cong 0)$$

$$\dot{W}_{\text{a,in}} = \dot{m}(h_2 - h_1)$$

where

$$\dot{m} = \frac{P_1 \dot{V}_1}{RT_1} = \frac{(100 \text{ kPa})(2.4 \text{ m}^3/\text{s})}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(290 \text{ K})} = 2.884 \text{ kg/s}$$

Then the power input to the compressor is determined to be

$$\dot{W}_{\text{a,in}} = (2.884 \text{ kg/s})(533.98 - 290.16) \text{ kJ/kg} = \mathbf{703 \text{ kW}}$$

