EXAMPLE 7–15 Effect of Efficiency on Compressor Power Input

Air is compressed by an adiabatic compressor from 100 kPa and 12°C to a pressure of 800 kPa at a steady rate of 0.2 kg/s. If the isentropic efficiency of the compressor is 80 percent, determine (*a*) the exit temperature of air and (*b*) the required power input to the compressor.

EXAMPLE 4–10 **Heating of a Gas at Constant Pressure**

A piston–cylinder device initially contains air at 150 kPa and 27°C. At this state, the piston is resting on a pair of stops, as shown in Fig. 4–32, and the enclosed volume is 400 L. The mass of the piston is such that a 350-kPa pressure is required to move it. The air is now heated until its volume has doubled. Determine (*a*) the final temperature, (*b*) the work done by the air, and (*c*) the total heat transferred to the air.

7–132 Hot combustion gases enter the nozzle of a turbojet engine at 260 kPa, 747°C, and 80 m/s, and they exit at a pressure of 85 kPa. Assuming an isentropic efficiency of 92 percent and treating the combustion gases as air, determine (*a*) the exit velocity and (*b*) the exit temperature.
Answers: (*a*) 728 m/s, (*b*) 786 K

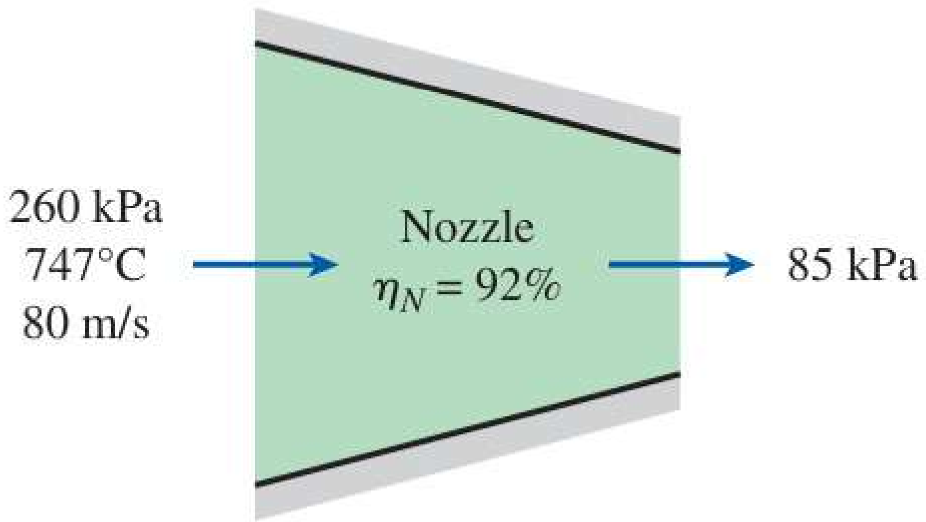


FIGURE P7–132

5-185 Air is allowed to leave a piston-cylinder device with a pair of stops. Heat is lost from the cylinder. The amount of mass that has escaped and the work done are 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 leaving the device is assumed to be constant. **2** Kinetic and potential energies are negligible. 3 Air is an ideal gas with constant specific heats at the average temperature.

Properties The properties of air are $R = 0.287$ kPa.m^3/kg.K (Table A-1), $c_v = 0.733$ kJ/kg.K, $c_p = 1.020$ kJ/kg.K at the anticipated average temperature of 450 K (Table A-2b).

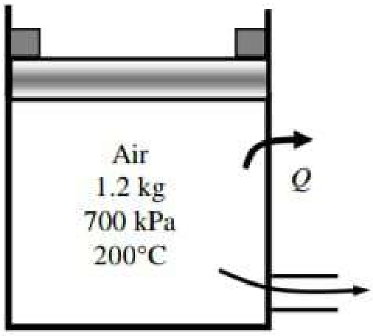
Analysis We take the tank as the system, which is a control volume since mass crosses the boundary. Noting that the microscopic energies of flowing and nonflowing fluids are represented by enthalpy h and internal energy u, respectively, the mass and energy balances for this uniform-flow system can be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

Mass balance: $$m_{in} - m_{out} = \Delta m_{\text{system}} \rightarrow m_e = m_1 - m_2$$

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

$$W_{\text{b,in}} - Q_{\text{out}} - m_e h_e = m_2 u_2 - m_1 u_1 \quad (\text{since ke} \cong \text{pe} \cong 0)$$

or $$W_{\text{b,in}} - Q_{\text{out}} - m_e C_p T_e = m_2 c_v T_2 - m_1 c_v T_1$$



The temperature of the air withdrawn from the cylinder is assumed to be the average of initial and final temperatures of the air in the cylinder. That is,

$$T_e = (1/2)(T_1 + T_2) = (1/2)(473 + T_2)$$

The volumes and the masses at the initial and final states and the mass that has escaped from the cylinder are given by

$$V_1 = \frac{m_1 R T_1}{P_1} = \frac{(1.2\,\text{kg})(0.287\,\text{kPa.m}^3/\text{kg.K})(200+273\,\text{K})}{(700\,\text{kPa})} = 0.2327\,\text{m}^3$$

$$V_2 = 0.80 V_1 = (0.80)(0.2327) = 0.1862\,\text{m}^3$$

$$m_2 = \frac{P_2 V_2}{R T_2} = \frac{(600\,\text{kPa})(0.1862\,\text{m}^3)}{(0.287\,\text{kPa.m}^3/\text{kg.K})T_2} = \frac{389.18}{T_2}\,\text{kg}$$

$$m_e = m_1 - m_2 = \left(1.2 - \frac{389.18}{T_2}\right)\text{kg}$$

Noting that the pressure remains constant after the piston starts moving, the boundary work is determined from

$$W_{\text{b,in}} = P_2(V_1 - V_2) = (600\,\text{kPa})(0.2327 - 0.1862)\text{m}^3 = \mathbf{27.9\,kJ}$$

Substituting,

$$27.9\,\text{kJ} - 40\,\text{kJ} - \left(1.2 - \frac{389.18}{T_2}\right)(1.020\,\text{kJ/kg.K})(1/2)(473 + T_2)$$
$$= \left(\frac{389.18}{T_2}\right)(0.733\,\text{kJ/kg.K})T_2 - (1.2\,\text{kg})(0.733\,\text{kJ/kg.K})(473\,\text{K})$$

The final temperature may be obtained from this equation by a trial-error approach or using EES to be

$$T_2 = \mathbf{415.0\,K}$$

Then, the amount of mass that has escaped becomes

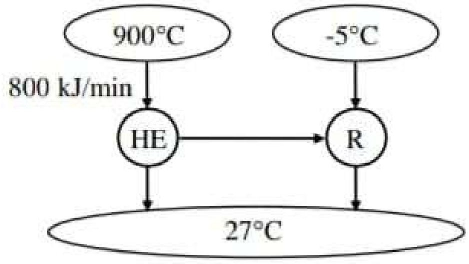
$$m_e = 1.2 - \frac{389.18}{415.0\,\text{K}} = \mathbf{0.262\,kg}$$

6-105 A Carnot heat engine is used to drive a Carnot refrigerator. The maximum rate of heat removal from the refrigerated space and the total rate of heat rejection to the ambient air are to be determined.

Assumptions The heat engine and the refrigerator operate steadily.

Analysis (a) The highest thermal efficiency a heat engine operating between two specified temperature limits can have is the Carnot efficiency, which is determined from

$$\eta_{\text{th,max}} = \eta_{\text{th,C}} = 1 - \frac{T_L}{T_H} = 1 - \frac{300\text{ K}}{1173\text{ K}} = 0.744$$



Then the maximum power output of this heat engine is determined from the definition of thermal efficiency to be

$$\dot{W}_{\text{net,out}} = \eta_{\text{th}}\dot{Q}_H = (0.744)(800\text{ kJ/min}) = 595.2\text{ kJ/min}$$

which is also the power input to the refrigerator, $\dot{W}_{\text{net,in}}$.

The rate of heat removal from the refrigerated space will be a maximum if a Carnot refrigerator is used. The COP of the Carnot refrigerator is

$$\text{COP}_{\text{R,rev}} = \frac{1}{(T_H/T_L)-1} = \frac{1}{(27+273\text{ K})/(-5+273\text{ K})-1} = 8.37$$

Then the rate of heat removal from the refrigerated space becomes

$$\dot{Q}_{L,\text{R}} = (\text{COP}_{\text{R,rev}})(\dot{W}_{\text{net,in}}) = (8.37)(595.2\text{ kJ/min}) = \mathbf{4982\text{ kJ/min}}$$

(b) The total rate of heat rejection to the ambient air is the sum of the heat rejected by the heat engine ($\dot{Q}_{L,\text{HE}}$) and the heat discarded by the refrigerator ($\dot{Q}_{H,\text{R}}$),

$$\dot{Q}_{L,\text{HE}} = \dot{Q}_{H,\text{HE}} - \dot{W}_{\text{net,out}} = 800 - 595.2 = 204.8\text{ kJ/min}$$

$$\dot{Q}_{H,\text{R}} = \dot{Q}_{L,\text{R}} + \dot{W}_{\text{net,in}} = 4982 + 595.2 = 5577.2\text{ kJ/min}$$

and

$$\dot{Q}_{\text{ambient}} = \dot{Q}_{L,\text{HE}} + \dot{Q}_{H,\text{R}} = 204.8 + 5577.2 = \mathbf{5782\text{ kJ/min}}$$

6-101 A commercial refrigerator with R-134a as the working fluid is considered. The condenser inlet and exit states are specified. The mass flow rate of the refrigerant, the refrigeration load, the COP, and the minimum power input to the compressor are to be determined.

Assumptions **1** The refrigerator operates steadily. **2** The kinetic and potential energy changes are zero.

Properties The properties of R-134a and water are (Steam and R-134a tables)

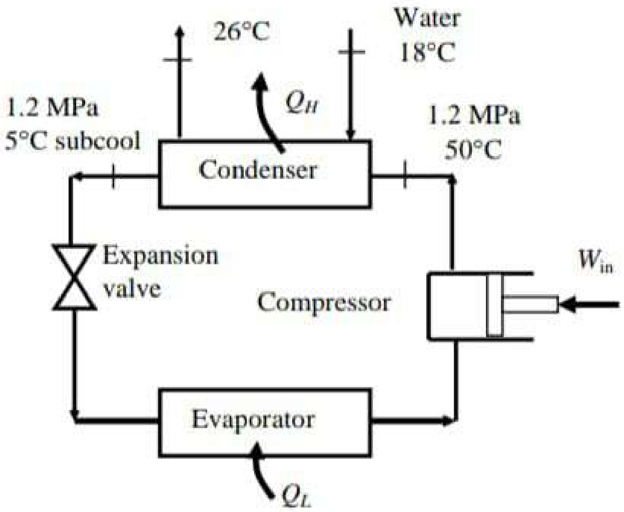
$$\left.\begin{array}{l} P_1 = 1.2\text{ MPa} \\ T_1 = 50°\text{C} \end{array}\right\} h_1 = 278.28\text{ kJ/kg}$$

$$T_2 = T_{\text{sat@1.2MPa}} + \Delta T_{\text{subcool}} = 46.3 - 5 = 41.3°\text{C}$$

$$\left.\begin{array}{l} P_2 = 1.2\text{ MPa} \\ T_2 = 41.3°\text{C} \end{array}\right\} h_2 = 110.19\text{ kJ/kg}$$

$$\left.\begin{array}{l} T_{w,1} = 18°\text{C} \\ x_{w,1} = 0 \end{array}\right\} h_{w,1} = 75.54\text{ kJ/kg}$$

$$\left.\begin{array}{l} T_{w,2} = 26°\text{C} \\ x_{w,2} = 0 \end{array}\right\} h_{w,2} = 109.01\text{ kJ/kg}$$



Analysis (*a*) The rate of heat transferred to the water is the energy change of the water from inlet to exit

$$\dot{Q}_H = \dot{m}_w (h_{w,2} - h_{w,1}) = (0.25\text{ kg/s})(109.01 - 75.54)\text{ kJ/kg} = 8.367\text{ kW}$$

The energy decrease of the refrigerant is equal to the energy increase of the water in the condenser. That is,

$$\dot{Q}_H = \dot{m}_R (h_1 - h_2) \longrightarrow \dot{m}_R = \frac{\dot{Q}_H}{h_1 - h_2} = \frac{8.367\text{ kW}}{(278.28 - 110.19)\text{ kJ/kg}} = \mathbf{0.0498 kg/s}$$

(*b*) The refrigeration load is

$$\dot{Q}_L = \dot{Q}_H - \dot{W}_{\text{in}} = 8.37 - 3.30 = \mathbf{5.07 kW}$$

(*c*) The COP of the refrigerator is determined from its definition,

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{5.07\text{ kW}}{3.3\text{ kW}} = \mathbf{1.54}$$

(*d*) The COP of a reversible refrigerator operating between the same temperature limits is

$$\text{COP}_{\max} = \frac{1}{T_H / T_L - 1} = \frac{1}{(18 + 273)/(-35 + 273) - 1} = 4.49$$

Then, the minimum power input to the compressor for the same refrigeration load would be

$$\dot{W}_{\text{in,min}} = \frac{\dot{Q}_L}{\text{COP}_{\max}} = \frac{5.07\text{ kW}}{4.49} = \mathbf{1.13 kW}$$