Homework-11 Solutions

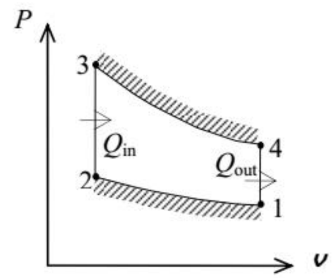
Q 9-39

Solution:

Assumptions **1** The air-standard assumptions are applicable. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with constant specific heats.

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K, c_v = 0.718 kJ/kg·K, R = 0.287 kJ/kg·K, and k = 1.4 (Table A-2).

Analysis (*a*) Process 1-2: isentropic compression.



$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = (308\text{ K})(9.5)^{0.4} = 757.9\text{ K}$$

$$\frac{P_2 v_2}{T_2} = \frac{P_1 v_1}{T_1} \longrightarrow P_2 = \frac{v_1}{v_2}\frac{T_2}{T_1}P_1 = (9.5)\left(\frac{757.9\text{ K}}{308\text{ K}}\right)(100\text{ kPa}) = 2338\text{ kPa}$$

Process 3-4: isentropic expansion.

$$T_3 = T_4\left(\frac{v_4}{v_3}\right)^{k-1} = (800\text{ K})(9.5)^{0.4} = \mathbf{1969\ K}$$

Process 2-3: v= constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow P_3 = \frac{T_3}{T_2}P_2 = \left(\frac{1969\text{ K}}{757.9\text{ K}}\right)(2338\text{ kPa}) = \mathbf{6072\ kPa}$$

(*b*)

$$m = \frac{P_1 V_1}{RT_1} = \frac{(100\text{ kPa})(0.0006\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(308\text{ K})} = 6.788\times10^{-4}\text{ kg}$$

$$Q_{in} = m(u_3 - u_2) = mc_v(T_3 - T_2) = (6.788\times10^{-4}\text{ kg})(0.718\text{ kJ/kg}\cdot\text{K})(1969 - 757.9)\text{K} = \mathbf{0.590\ kJ}$$

(c) Process 4-1: v= constant heat rejection.

$$Q_{out} = m(u_4 - u_1) = mc_v(T_4 - T_1) = -(6.788\times10^{-4}\text{ kg})(0.718\text{ kJ/kg}\cdot\text{K})(800 - 308)\text{K} = 0.240\text{ kJ}$$

$$W_{net} = Q_{in} - Q_{out} = 0.590 - 0.240 = 0.350\text{ kJ}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}} = \frac{0.350\text{ kJ}}{0.590\text{ kJ}} = \mathbf{59.4\%}$$

(*d*)

$$V_{min} = V_2 = \frac{V_{max}}{r}$$

$$\text{MEP} = \frac{W_{net,out}}{V_1 - V_2} = \frac{W_{net,out}}{V_1(1-1/r)} = \frac{0.350\text{ kJ}}{(0.0006\text{ m}^3)(1-1/9.5)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{652\ kPa}$$

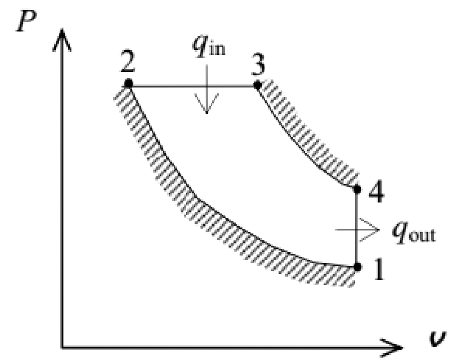
Q 9-57

Solution:

Assumptions **1** The air-standard assumptions are applicable. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with constant specific heats.

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K, $c_{\boldsymbol{v}}$ = 0.718 kJ/kg·K, R = 0.287 kJ/kg·K, and k = 1.4 (Table A-2).

Analysis (*a*) Process 1-2: isentropic compression.



$$T_2 = T_1\left(\frac{\boldsymbol{V}_1}{\boldsymbol{V}_2}\right)^{k-1} = (293\ \text{K})(20)^{0.4} = 971.1\ \text{K}$$

Process 2-3: P = constant heat addition.

$$\frac{P_3\boldsymbol{V}_3}{T_3} = \frac{P_2\boldsymbol{V}_2}{T_2} \longrightarrow \frac{\boldsymbol{V}_3}{\boldsymbol{V}_2} = \frac{T_3}{T_2} = \frac{2200\text{K}}{971.1\text{K}} = 2.265$$

Process 3-4: isentropic expansion.

$$T_4 = T_3\left(\frac{\boldsymbol{V}_3}{\boldsymbol{V}_4}\right)^{k-1} = T_3\left(\frac{2.265\boldsymbol{V}_2}{\boldsymbol{V}_4}\right)^{k-1} = T_3\left(\frac{2.265}{r}\right)^{k-1} = (2200\ \text{K})\left(\frac{2.265}{20}\right)^{0.4} = 920.6\ \text{K}$$

$$q_{\text{in}} = h_3 - h_2 = c_p\left(T_3 - T_2\right) = (1.005\ \text{kJ/kg}\cdot\text{K})(2200 - 971.1)\text{K} = 1235\ \text{kJ/kg}$$

$$q_{\text{out}} = u_4 - u_1 = c_{\boldsymbol{v}}\left(T_4 - T_1\right) = (0.718\ \text{kJ/kg}\cdot\text{K})(920.6 - 293)\text{K} = 450.6\ \text{kJ/kg}$$

$$w_{\text{net,out}} = q_{\text{in}} - q_{\text{out}} = 1235 - 450.6 = 784.4\ \text{kJ/kg}$$

$$\eta_{\text{th}} = \frac{w_{\text{net,out}}}{q_{\text{in}}} = \frac{784.4\ \text{kJ/kg}}{1235\ \text{kJ/kg}} = \mathbf{63.5\%}$$

(*b*)

$$\boldsymbol{v}_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\ \text{K})}{95\ \text{kPa}} = 0.885\ \text{m}^3/\text{kg} = \boldsymbol{v}_{\text{max}}$$

$$\boldsymbol{v}_{\text{min}} = \boldsymbol{v}_2 = \frac{\boldsymbol{v}_{\text{max}}}{r}$$

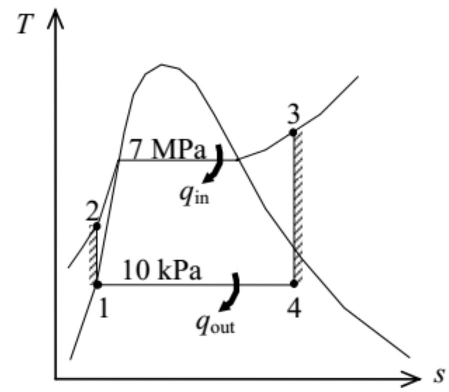
$$\text{MEP} = \frac{w_{\text{net,out}}}{\boldsymbol{v}_1 - \boldsymbol{v}_2} = \frac{w_{\text{net,out}}}{\boldsymbol{v}_1(1 - 1/r)} = \frac{784.4\ \text{kJ/kg}}{(0.885\ \text{m}^3/\text{kg})(1 - 1/20)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{933\ kPa}$$

Q 10-21

Solution:

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis (*a*) From the steam tables (Tables A-4, A-5, and A-6),



$$h_1 = h_{f@\,10\text{ kPa}} = 191.81 \text{ kJ/kg}$$

$$\boldsymbol{v}_1 = \boldsymbol{v}_{f@\,10\text{ kPa}} = 0.00101 \text{ m}^3\text{/kg}$$

$$w_{p,\text{in}} = \boldsymbol{v}_1(P_2 - P_1)$$

$$= (0.00101 \text{ m}^3\text{/kg})(7{,}000 - 10 \text{ kPa})\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)$$

$$= 7.06 \text{ kJ/kg}$$

$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 7.06 = 198.87 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 7 \text{ MPa} \\ T_3 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3411.4 \text{ kJ/kg} \\ s_3 = 6.8000 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 10 \text{ kPa} \\ s_4 = s_3 \end{array}\right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.8000 - 0.6492}{7.4996} = 0.8201$$

$$h_4 = h_f + x_4 h_{fg} = 191.81 + (0.8201)(2392.1) = 2153.6 \text{ kJ/kg}$$

Thus,

$$q_{\text{in}} = h_3 - h_2 = 3411.4 - 198.87 = 3212.5 \text{ kJ/kg}$$

$$q_{\text{out}} = h_4 - h_1 = 2153.6 - 191.81 = 1961.8 \text{ kJ/kg}$$

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = 3212.5 - 1961.8 = 1250.7 \text{ kJ/kg}$$

and

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1250.7 \text{ kJ/kg}}{3212.5 \text{ kJ/kg}} = \mathbf{38.9\%}$$

(*b*)
$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{45{,}000 \text{ kJ/s}}{1250.7 \text{ kJ/kg}} = \mathbf{36.0 \text{ kg/s}}$$

(*c*) The rate of heat rejection to the cooling water and its temperature rise are

$$\dot{Q}_{\text{out}} = \dot{m}q_{\text{out}} = (35.98 \text{ kg/s})(1961.8 \text{ kJ/kg}) = 70{,}586 \text{ kJ/s}$$

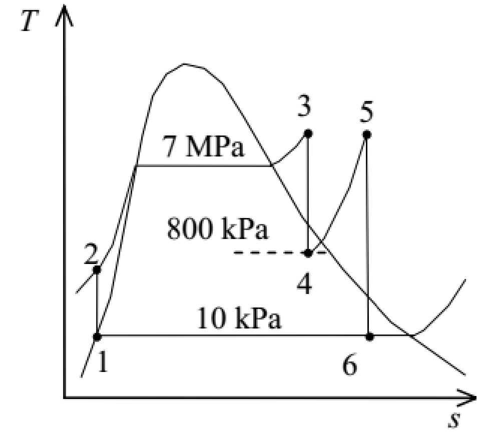
$$\Delta T_{\text{coolingwater}} = \frac{\dot{Q}_{\text{out}}}{(\dot{m}c)_{\text{coolingwater}}} = \frac{70{,}586 \text{ kJ/s}}{(2000 \text{ kg/s})(4.18 \text{ kJ/kg}\cdot°\text{C})} = \mathbf{8.4°C}$$

Q 10-39

Solution:

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis From the steam tables (Tables A-4, A-5, and A-6),



$$h_1 = h_{f@\,10\,\text{kPa}} = 191.81\ \text{kJ/kg}$$
$$\boldsymbol{v}_1 = \boldsymbol{v}_{f@\,10\,\text{kPa}} = 0.001010\ \text{m}^3/\text{kg}$$

$$\begin{aligned} w_{\text{p,in}} &= \boldsymbol{v}_1(P_2 - P_1) \\ &= (0.001010\ \text{m}^3/\text{kg})(7000-10)\text{kPa}\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) \\ &= 7.06\ \text{kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{\text{p,in}} = 191.81 + 7.06 = 198.87\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_4 = 800\ \text{kPa} \\ x_4 = 0.93 \end{array}\right\} \begin{array}{l} h_4 = h_f + x_4 h_{fg} = 720.87 + (0.93)(2047.5) = 2625.0\ \text{kJ/kg} \\ s_4 = s_f + x_4 s_{fg} = 2.0457 + (0.93)(4.6160) = 6.3385\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_3 = 7000\ \text{kPa} \\ s_3 = s_4 \end{array}\right\} \begin{array}{l} h_3 = 3085.5\ \text{kJ/kg} \\ T_3 = \mathbf{373.3°C} \end{array}$$

$$\left.\begin{array}{l} P_6 = 10\ \text{kPa} \\ x_6 = 0.90 \end{array}\right\} \begin{array}{l} h_6 = h_f + x_6 h_{fg} = 191.81 + (0.93)(2392.1) = 2416.4\ \text{kJ/kg} \\ s_6 = s_f + x_6 s_{fg} = 0.6492 + (0.93)(7.4996) = 7.6239\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_5 = 800\ \text{kPa} \\ s_5 = s_6 \end{array}\right\} \begin{array}{l} h_5 = 3302.0\ \text{kJ/kg} \\ T_5 = \mathbf{416.2°C} \end{array}$$

Thus,

$$q_{\text{in}} = (h_3 - h_2) + (h_5 - h_4) = 3085.5 - 198.87 + 3302.0 - 2625.0 = 3563.6\ \text{kJ/kg}$$
$$q_{\text{out}} = h_6 - h_1 = 2416.4 - 191.81 = 2224.6\ \text{kJ/kg}$$

and

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{2224.6}{3563.6} = 0.3757 = \mathbf{37.6\%}$$