saturation lines, and determine (*a*) the thermal efficiency of the cycle and (*b*) the net power output of the power plant.

10–13 Refrigerant-134a is used as the working fluid in a simple ideal Rankine cycle which operates the boiler at 2000 kPa and the condenser at 24°C. The mixture at the exit of the turbine has a quality of 93 percent. Determine the turbine inlet temperature, the cycle thermal efficiency, and the back-work ratio of this cycle.

10–14 A simple ideal Rankine cycle which uses water as the working fluid operates its condenser at 40°C and its boiler at 300°C. Calculate the work produced by the turbine, the heat supplied in the boiler, and the thermal efficiency of this cycle when the steam enters the turbine without any superheating.

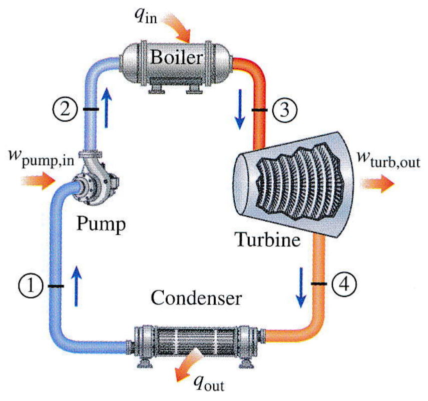


FIGURE P10–14

10–15E A simple ideal Rankine cycle with water as the working fluid operates between the pressure limits of 2500 psia in the boiler and 5 psia in the condenser. What is the minimum temperature required at the turbine inlet such that the quality of the steam leaving the turbine is not below 80 percent. When operated at this temperature, what is the thermal efficiency of this cycle?

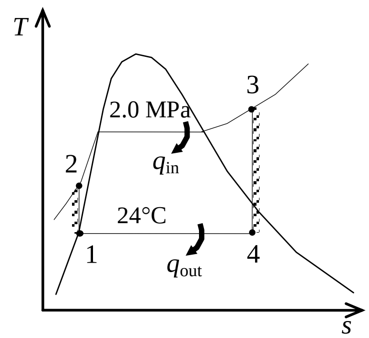
10–16 Consider a 210-MW steam power plant that operates on a simple ideal Rankine cycle. Steam enters the turbine at 10 MPa and 500°C and is cooled in the condenser at a pressure of 10 kPa. Show the cycle on a *T-s* diagram with respect to saturation lines, and determine (*a*) the quality of the steam at the turbine exit, (*b*) the thermal efficiency of the cycle, and (*c*) the mass flow rate of the steam. *Answers:* (*a*) 0.793, (*b*) 40.2 percent, (*c*) 165 kg/s

10-13 A simple ideal Rankine cycle with R-134a as the working fluid is considered. The turbine inlet temperature, the cycle thermal efficiency, and the back-work ratio of the cycle are to be determined.

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

Analysis From the refrigerant tables (Tables A-11, A-12, and A-13),

$$P_1 = P_{\text{sat @ 24°C}} = 646.2 \text{ kPa}$$
$$h_1 = h_{f @ 24°C} = 84.98 \text{ kJ/kg}$$
$$\boldsymbol{v}_1 = \boldsymbol{v}_{f @ 24°C} = 0.0008260 \text{ m}^3/\text{kg}$$



$$\begin{aligned} w_{\text{p,in}} &= \boldsymbol{v}_1(P_2 - P_1) \\ &= (0.0008260 \text{ m}^3/\text{kg})(2000 - 646.2)\text{kPa}\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right) \\ &= 1.118 \text{ kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{\text{p,in}} = 84.98 + 1.118 = 86.09 \text{ kJ/kg}$$

$$\left.\begin{array}{l} T_4 = 24°\text{C} \\ x_4 = 0.93 \end{array}\right\} \begin{array}{l} h_4 = h_f + x_4 h_{fg} = 84.98 + (0.93)(178.74) = 251.21 \text{ kJ/kg} \\ s_4 = s_f + x_4 s_{fg} = 0.31959 + (0.93)(0.60148) = 0.87897 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_3 = 2000 \text{ kPa} \\ s_3 = s_4 = 0.87897 \text{ kJ/kg}\cdot\text{K} \end{array}\right\} \begin{array}{l} h_3 = 272.29 \text{ kJ/kg} \\ T_3 = \mathbf{67.5°C} \end{array}$$

Thus,

$$q_{\text{in}} = h_3 - h_2 = 272.29 - 86.09 = 186.2 \text{ kJ/kg}$$
$$q_{\text{out}} = h_4 - h_1 = 251.21 - 84.98 = 166.2 \text{ kJ/kg}$$

The thermal efficiency of the cycle is

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{166.2}{186.2} = 0.1072 = \mathbf{10.7\%}$$

The back-work ratio is determined from

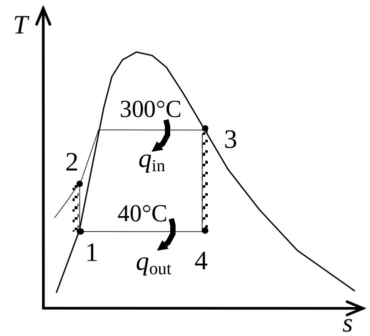
$$r_{bw} = \frac{w_{\text{P,in}}}{W_{\text{T,out}}} = \frac{w_{\text{P,in}}}{h_3 - h_4} = \frac{1.118 \text{ kJ/kg}}{(272.29 - 251.21) \text{ kJ/kg}} = \mathbf{0.0530}$$

10-14 A simple ideal Rankine cycle with water as the working fluid is considered. The work output from the turbine, the heat addition in the boiler, and the thermal efficiency of the cycle are to be determined.

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),

$$P_1 = P_{\text{sat @ 40°C}} = 7.385\ \text{kPa}$$
$$P_2 = P_{\text{sat @ 300°C}} = 8588\ \text{kPa}$$
$$h_1 = h_{f\text{@ 40°C}} = 167.53\ \text{kJ/kg}$$
$$\boldsymbol{v}_1 = \boldsymbol{v}_{f\text{@ 40°C}} = 0.001008\ \text{m}^3/\text{kg}$$



$$\begin{aligned} w_{\text{p,in}} &= \boldsymbol{v}_1(P_2 - P_1) \\ &= (0.001008\ \text{m}^3/\text{kg})(8588 - 7.385)\text{kPa}\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) \\ &= 8.65\ \text{kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{\text{p,in}} = 167.53 + 8.65 = 176.18\ \text{kJ/kg}$$

$$\left.\begin{array}{l} T_3 = 300°\text{C} \\ x_3 = 1 \end{array}\right\} \begin{array}{l} h_3 = 2749.6\ \text{kJ/kg} \\ s_3 = 5.7059\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} T_4 = 40°\text{C} \\ s_4 = s_3 \end{array}\right\} \begin{array}{l} x_4 = \dfrac{s_4 - s_f}{s_{fg}} = \dfrac{5.7059 - 0.5724}{7.6832} = 0.6681 \\ h_4 = h_f + x_4 h_{fg} = 167.53 + (0.6681)(2406.0) = 1775.1\ \text{kJ/kg} \end{array}$$

Thus,

$$w_{\text{T,out}} = h_3 - h_4 = 2749.6 - 1775.1 = \mathbf{974.5\ kJ/kg}$$
$$q_{\text{in}} = h_3 - h_2 = 2749.6 - 176.18 = \mathbf{2573.4\ kJ/kg}$$
$$q_{\text{out}} = h_4 - h_1 = 1775.1 - 167.53 = 1607.6\ \text{kJ/kg}$$

The thermal efficiency of the cycle is

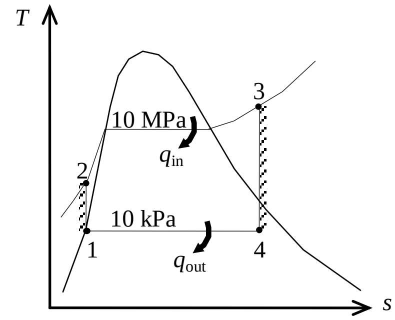
$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{1607.6}{2573.4} = \mathbf{0.375}$$

10-16 A steam power plant that operates on a simple ideal Rankine cycle is considered. The quality of the steam at the turbine exit, the thermal efficiency of the cycle, and the mass flow rate of the steam are to be determined.

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),

$$h_1 = h_{f\,@\,10\text{ kPa}} = 191.81 \text{ kJ/kg}$$
$$\boldsymbol{v}_1 = \boldsymbol{v}_{f\,@\,10\text{ kPa}} = 0.00101 \text{ m}^3\text{/kg}$$



$$\begin{aligned} w_{p,\text{in}} &= \boldsymbol{v}_1(P_2 - P_1) \\ &= (0.00101 \text{ m}^3\text{/kg})(10{,}000 - 10 \text{ kPa})\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right) \\ &= 10.09 \text{ kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 10.09 = 201.90 \text{ kJ/kg}$$

$$\left.\begin{aligned} P_3 &= 10 \text{ MPa} \\ T_3 &= 500\,°\text{C} \end{aligned}\right\} \begin{aligned} h_3 &= 3375.1 \text{ kJ/kg} \\ s_3 &= 6.5995 \text{ kJ/kg}\cdot\text{K} \end{aligned}$$

$$\left.\begin{aligned} P_4 &= 10 \text{ kPa} \\ s_4 &= s_3 \end{aligned}\right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.5995 - 0.6492}{7.4996} = \mathbf{0.7934}$$
$$h_4 = h_f + x_4 h_{fg} = 191.81 + (0.7934)(2392.1) = 2089.7 \text{ kJ/kg}$$

(*b*)
$$q_{\text{in}} = h_3 - h_2 = 3375.1 - 201.90 = 3173.2 \text{ kJ/kg}$$
$$q_{\text{out}} = h_4 - h_1 = 2089.7 - 191.81 = 1897.9 \text{ kJ/kg}$$
$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = 3173.2 - 1897.9 = 1275.4 \text{ kJ/kg}$$

and

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1275.4 \text{ kJ/kg}}{3173.2 \text{ kJ/kg}} = \mathbf{40.2\%}$$

(*c*)
$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{210{,}000 \text{ kJ/s}}{1275.4 \text{ kJ/kg}} = \mathbf{164.7 \text{ kg/s}}$$