Given: $kJ := 1000J$

Consider a steam power plant operating on the ideal Rankine cycle. Steam enters the turbine at 3 MPa and 350°C and is condensed in the condenser at a pressure of 10 kPa.

$P_{3(a)} := 3MPa \qquad T_{3(a)} := 350\,°C \qquad P_1 := 10kPa$

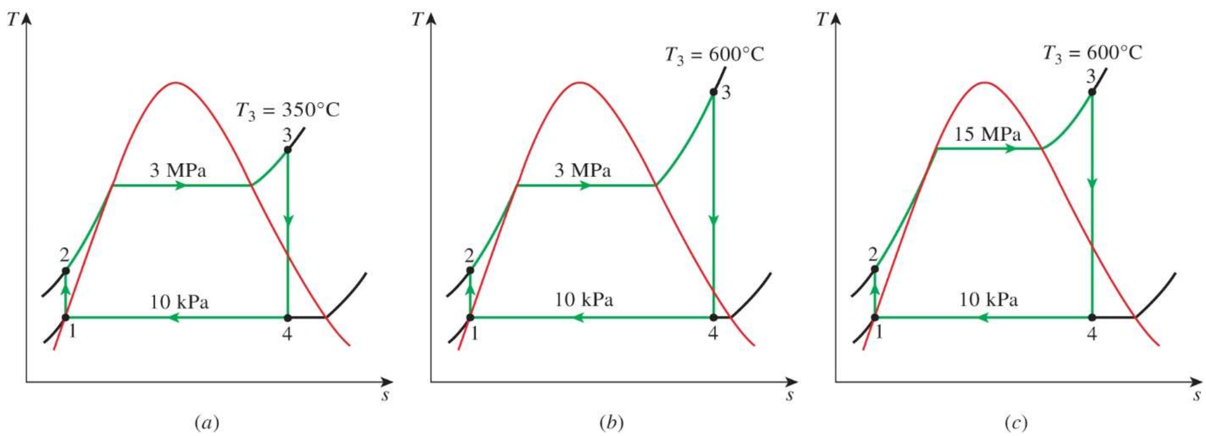
Required:

Determine the thermal efficiency of the power plant

(a) under these operation parameters,

(b) if the steam is superheated to 600°C instead of 350°C, and

(c) if the boiler pressure is raised to 15 MPa while the steam is superheated to 600°C.



Solution:

The conditions in part (a) are defined as

$P_{2(a)} := P_{3(a)} = 3 \cdot MPa$

The conditions in part (b) are defined as

$T_{3(b)} := 600\,°C \qquad P_{3(b)} := P_{3(a)} = 3 \cdot MPa \quad P_{2(b)} := P_{3(b)} = 3 \cdot MPa$

The conditions in part (c) are defined as

$T_{3(c)} := 600\,°C \qquad P_{3(c)} := 15MPa \qquad P_{2(c)} := P_{3(c)} = 15 \cdot MPa$

For all parts the following conditions are true.

$P_4 := P_1 = 10 \cdot kPa \qquad x_1 := 0$

Going to Table A-5 @ $P_1 = 10 \cdot kPa$ & $x_1 = 0$ shows

$\nu_1 := 0.001010 \dfrac{m^3}{kg} \qquad h_1 := 191.81 \dfrac{kJ}{kg} \qquad s_1 := 0.6492 \dfrac{kJ}{kg \cdot K}$

For an ideal Rankine cycle, the specific entropy at state 2 is

$s_2 := s_1 = 0.6492 \cdot \dfrac{kJ}{kg \cdot K}$

Solution (contd.):

The specific work of an isentropic pump is given by

$$w_{p(a)} := \nu_1 \cdot \left(P_{2(a)} - P_1\right) = 3.0199 \cdot \frac{kJ}{kg}$$

The enthalpy at state 2 is then given by

$$h_{2(a)} := h_1 + w_{p(a)} = 194.83 \cdot \frac{kJ}{kg}$$

Going to Table A-4 @ $T_{3(a)} = 350 \cdot °C$ & $P_{3(a)} = 3 \cdot MPa$ shows that the state is superheated.

Going to Table A-6 @ $T_{3(a)} = 350 \cdot °C$ & $P_{3(a)} = 3 \cdot MPa$ shows

$$h_{3(a)} := 3116.1 \frac{kJ}{kg} \qquad s_{3(a)} := 6.7450 \frac{kJ}{kg \cdot K}$$

For an ideal Rankine cycle, the specific entropy at state 4 is

$$s_{4(a)} := s_{3(a)} = 6.7450 \cdot \frac{kJ}{kg \cdot K}$$

Going to Table A-5 @ $P_4 = 10 \cdot kPa$ & $s_{4(a)} = 6.745 \cdot \frac{kJ}{kg \cdot K}$ shows

$$s_f := 0.6492 \frac{kJ}{kg \cdot K} \qquad s_g := 8.1488 \frac{kJ}{kg \cdot K} \qquad h_f := 191.81 \frac{kJ}{kg} \qquad h_g := 2583.9 \frac{kJ}{kg}$$

$$x_{4(a)} := \frac{s_{4(a)} - s_f}{s_g - s_f} = 0.813$$

$$h_{4(a)} := h_f + x_{4(a)} \cdot \left(h_g - h_f\right) = 2136.1 \cdot \frac{kJ}{kg}$$

The specific heat accepted by the cycle is then

$$q_{in(a)} := h_{3(a)} - h_{2(a)} = 2921.3 \cdot \frac{kJ}{kg}$$

The specific heat rejected by the cycle is then

$$q_{out(a)} := h_{4(a)} - h_1 = 1944.3 \cdot \frac{kJ}{kg}$$

The thermal efficiency is then given by

$$\boxed{\eta_{th(a)} := 1 - \frac{q_{out(a)}}{q_{in(a)}} = 33.4 \cdot \%} \qquad \text{(a)}$$

For part (b), the enthalpy at state 3 may be found by going to Table A-6 @ $T_{3(b)} = 600 \cdot °C$ & $P_{3(b)} = 3 \cdot MPa$. This is shown below.

$$h_{3(b)} := 3682.8 \frac{kJ}{kg} \qquad s_{3(b)} := 7.5103 \frac{kJ}{kg \cdot K}$$

Solution (contd.):

For an ideal Rankine cycle, the entropy at state 4 is

$$s_{4(b)} := s_{3(b)} = 7.51 \cdot \frac{kJ}{kg \cdot K}$$

Going to Table A-5 @ $P_4 = 10 \cdot kPa$ & $s_{4(b)} = 7.5103 \cdot \frac{kJ}{kg \cdot K}$ shows

$$x_{4(b)} := \frac{s_{4(b)} - s_f}{s_g - s_f} = 0.915$$

$$h_{4(b)} := h_f + x_{4(b)} \cdot \left(h_g - h_f\right) = 2380.2 \cdot \frac{kJ}{kg}$$

The specific heat accepted by the cycle is then

$$q_{in(b)} := h_{3(b)} - h_{2(a)} = 3488.0 \cdot \frac{kJ}{kg}$$

The specific heat rejected by the cycle is then

$$q_{out(b)} := h_{4(b)} - h_1 = 2188.4 \cdot \frac{kJ}{kg}$$

The thermal efficiency is then given by

$$\boxed{\eta_{th(b)} := 1 - \frac{q_{out(b)}}{q_{in(b)}} = 37.3 \cdot \%} \quad \text{(b)}$$

For part (c), the specific work of the isentropic pump is found by

$$w_{p(c)} := \nu_1 \cdot \left(P_{2(c)} - P_1\right) = 15.1399 \cdot \frac{kJ}{kg}$$

The enthalpy at state 2 is then given by

$$h_{2(c)} := h_1 + w_{p(c)} = 206.95 \cdot \frac{kJ}{kg}$$

Going to Table A-6 @ $T_{3(c)} = 600 \cdot °C$ & $P_{3(c)} = 15 \cdot MPa$ shows

$$h_{3(c)} := 3583.1 \frac{kJ}{kg} \qquad s_{3(c)} := 6.6796 \frac{kJ}{kg \cdot K}$$

For an ideal Rankine cycle, the entropy at state 4 is

$$s_{4(c)} := s_{3(c)} = 6.68 \cdot \frac{kJ}{kg \cdot K}$$

Solution (contd.):

Going to Table A-5 @ $P_4 = 10 \cdot \text{kPa}$ & $s_{4(c)} = 6.6796 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$ shows

$$x_{4(c)} := \frac{s_{4(c)} - s_f}{s_g - s_f} = 0.804$$

$$h_{4(c)} := h_f + x_{4(c)} \cdot \left(h_g - h_f\right) = 2115.3 \cdot \frac{\text{kJ}}{\text{kg}}$$

The specific heat accepted by the cycle is then

$$q_{in(c)} := h_{3(c)} - h_{2(c)} = 3376.2 \cdot \frac{\text{kJ}}{\text{kg}}$$

The specific heat rejected by the cycle is then

$$q_{out(c)} := h_{4(c)} - h_1 = 1923.5 \cdot \frac{\text{kJ}}{\text{kg}}$$

The thermal efficiency is then given by

$$\boxed{\eta_{th(c)} := 1 - \frac{q_{out(c)}}{q_{in(c)}} = 43.0 \cdot \%} \qquad \text{(c)}$$