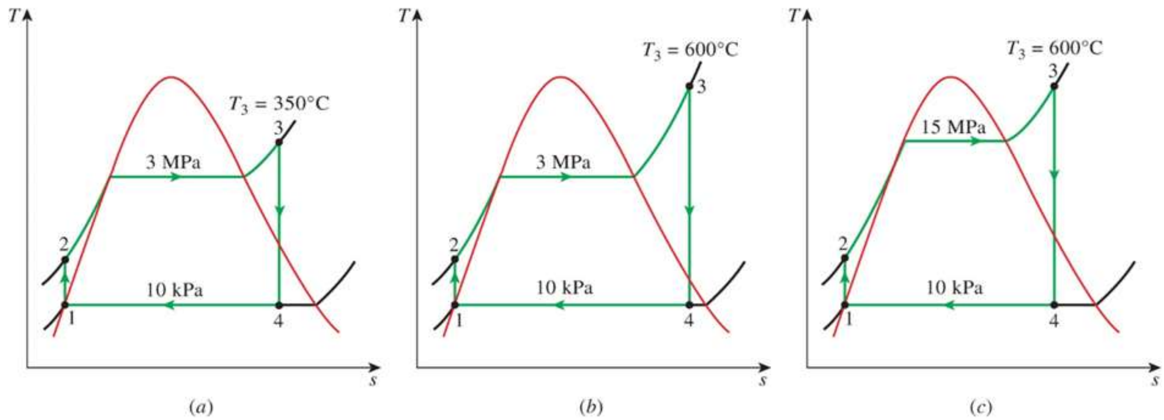
Given:
Consider a steam power plant operating on the ideal Rankine cycle. Steam enters the turbine at 3 MPa and 350°C and is condensed in the condenser at a pressure of 10 kPa.

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

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

$$P_{2(a)} := P_{3(a)} = 3.000\ \text{MPa}$$

The conditions in part (b) are defined as

$$T_{3(b)} := 600\ °\text{C} \qquad P_{3(b)} := P_{3(a)} = 3.000\ \text{MPa} \qquad P_{2(b)} := P_{3(b)} = 3.000\ \text{MPa}$$

The conditions in part (c) are defined as

$$T_{3(c)} := 600\ °\text{C} \qquad P_{3(c)} := 15\ \text{MPa} \qquad P_{2(c)} := P_{3(c)} = 15.00\ \text{MPa}$$

For all parts the following conditions are true.

$$P_4 := P_1 = 10.00\ \text{kPa} \qquad x_1 := 0$$

Going to Table A-5 @ PkPa10 & x0 shows

$$v_1 := 0.001010\ \frac{\text{m}^3}{\text{kg}} \qquad h_1 := 191.81\ \frac{\text{kJ}}{\text{kg}} \qquad s_1 := 0.6492\ \frac{\text{kJ}}{\text{kg K}}$$

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

$$s_2 := s_1 = 0.6492\ \frac{\text{kJ}}{\text{kg K}}$$

The specific work of an isentropic pump is given by

$$w_{p(a)} := v_1 \cdot \left(P_{2(a)} - P_1\right) = 3.020\ \frac{\text{kJ}}{\text{kg}}$$

Solution (contd.):
The enthalpy at state 2 is then given by

$$h_{2(a)} := h_1 + w_{p(a)} = 194.8\ \frac{\text{kJ}}{\text{kg}}$$

Going to Table A-4 @ $T_{3(a)} = 350.0\ °\text{C}$ and $P_{3(a)} = 3000\ \text{kPa}$ shows that the state is superheated.
Going to Table A-6 @ $T_{3(a)} = 350.0\ °\text{C}$ and $P_{3(a)} = 3.000\ \text{MPa}$ shows

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

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

$$s_{4(a)} := s_{3(a)} = 6.745\ \frac{\text{kJ}}{\text{kg K}}$$

Going to Table A-5 @ $P_4 = 10.00\ \text{kPa}$ and $s_{4(a)} = 6.745\ \frac{\text{kJ}}{\text{kg K}}$ shows

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

$$x_{4(a)} := \frac{s_{4(a)} - s_f}{s_g - s_f} = 0.8128 \qquad h_{4(a)} := h_f + x_{4(a)} \cdot \left(h_g - h_f\right) = 2136\ \frac{\text{kJ}}{\text{kg}}$$

The specific heat accepted by the cycle is then

$$q_{in(a)} := h_{3(a)} - h_{2(a)} = 2921\ \frac{\text{kJ}}{\text{kg}}$$

The specific heat rejected by the cycle is then

$$q_{out(a)} := h_{4(a)} - h_1 = 1944\ \frac{\text{kJ}}{\text{kg}}$$

The thermal efficiency is then given by

$$\boxed{\eta_{th(a)} := 1 - \frac{q_{out(a)}}{q_{in(a)}} = 33.44\ \%} \quad \text{(a)}$$

For part (b), the enthalpy at state 3 may be found by going to Table A-6 @ $T_{3(b)} = 600.0\ °\text{C}$ and $P_{3(b)} := 3\ \text{MPa}$. This is shown below.

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

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

$$s_{4(b)} := s_{3(b)} = 7.510\ \frac{\text{kJ}}{\text{kg K}}$$

Going to Table A-5 @ $P_4 = 10.00\ \text{kPa}$ and $s_{4(b)} = 7.510\ \frac{\text{kJ}}{\text{kg K}}$ shows

$$x_{4(b)} := \frac{s_{4(b)} - s_f}{s_g - s_f} = 0.9149 \qquad h_{4(b)} := h_f + x_{4(b)} \cdot \left(h_g - h_f\right) = 2380\ \frac{\text{kJ}}{\text{kg}}$$

The specific heat accepted by the cycle is then

$$q_{in(b)} := h_{3(b)} - h_{2(a)} = 3488\ \frac{\text{kJ}}{\text{kg}}$$

The specific heat rejected by the cycle is then

$$q_{out(b)} := h_{4(b)} - h_1 = 2188\ \frac{\text{kJ}}{\text{kg}}$$

Solution (contd.):
The thermal efficiency is then given by

$$\boxed{\eta_{th\,(b)} := 1 - \frac{q_{out\,(b)}}{q_{in\,(b)}} = 37.26\ \%}\quad \text{(b)}$$

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

$$w_{p\,(c)} := v_1 \cdot \left(P_{2\,(c)} - P_1\right) = 15.14\ \frac{\text{kJ}}{\text{kg}}$$

The enthalpy at state 2 is then given by

$$h_{2\,(c)} := h_1 + w_{p\,(c)} = 206.9\ \frac{\text{kJ}}{\text{kg}}$$

Going to Table A-6 @ $T_{3\,(c)} = 600.0\ \text{°C}$ and $P_{3\,(c)} = 15.00\ \text{MPa}$ shows

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

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

$$s_{4\,(c)} := s_{3\,(c)} = 6.680\ \frac{\text{kJ}}{\text{kg K}}$$

Going to Table A-5 @ $P_4 = 10.00\ \text{kPa}$ and $s_{4\,(c)} = 6.680\ \frac{\text{kJ}}{\text{kg K}}$ shows

$$x_{4\,(c)} := \frac{s_{4\,(c)} - s_f}{s_g - s_f} = 0.8041 \qquad h_{4\,(c)} := h_f + x_{4\,(c)} \cdot \left(h_g - h_f\right) = 2115\ \frac{\text{kJ}}{\text{kg}}$$

The specific heat accepted by the cycle is then

$$q_{in\,(c)} := h_{3\,(c)} - h_{2\,(c)} = 3376\ \frac{\text{kJ}}{\text{kg}}$$

The specific heat rejected by the cycle is then

$$q_{out\,(c)} := h_{4\,(c)} - h_1 = 1923\ \frac{\text{kJ}}{\text{kg}}$$

The thermal efficiency is then given by

$$\boxed{\eta_{th\,(c)} := 1 - \frac{q_{out\,(c)}}{q_{in\,(c)}} = 43.03\ \%}\quad \text{(c)}$$