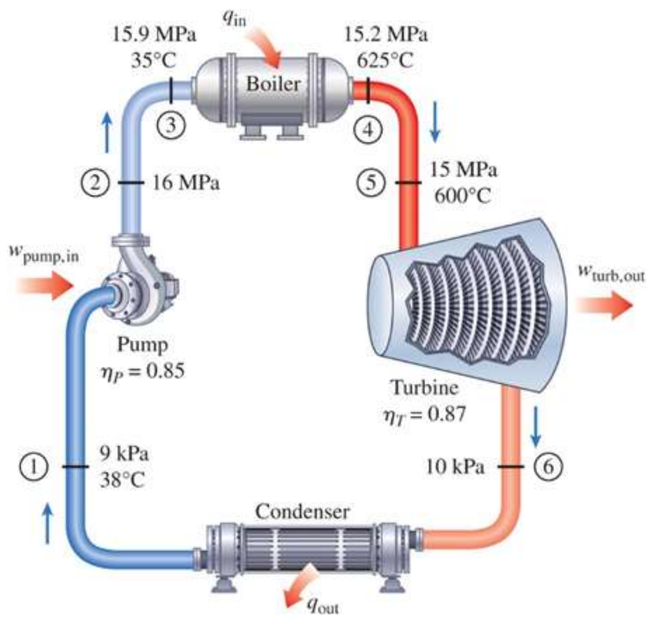
Given:

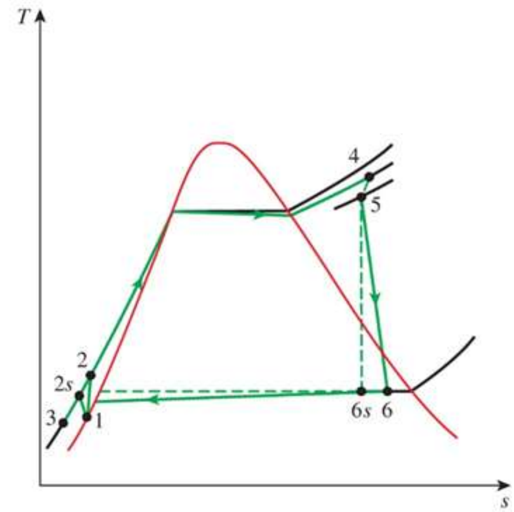
A steam power plant operates on the cycle shown below.

$P_1 := 9\ \text{kPa}$ $T_1 := 38\ °\text{C}$ $P_4 := 15.2\ \text{MPa}$ $T_4 := 625\ °\text{C}$ $\eta_p := 0.85$

$P_2 := 16\ \text{MPa}$ $P_5 := 15\ \text{MPa}$ $T_5 := 600\ °\text{C}$ $\eta_t := 0.87$

$P_3 := 15.9\ \text{MPa}$ $T_3 := 35\ °\text{C}$ $P_6 := 10\ \text{kPa}$





Required:

If the isentropic efficiency of the turbine is 87% and the isentropic efficiency of the pump is 85%, determine the thermal efficiency of the cycle and the net power output for a mass flow rate of 15 kg/s.

Solution:

The mass flow rate of the cycle is defined as

$$m' := 15\ \frac{\text{kg}}{\text{s}}$$

Going to Table A-4 @ $T_1 = 38\ °\text{C}$ and $P_1 = 9\ \text{kPa}$ shows that the state is compressed liquid and will be approximated as a saturated liquid.

$T_a := 35\ °\text{C}$ $T_b := 40\ °\text{C}$

$\nu_a := 0.001006\ \frac{\text{m}^3}{\text{kg}}$ $\nu_b := 0.001008\ \frac{\text{m}^3}{\text{kg}}$

$$\nu_1 := \frac{T_1 - T_a}{T_b - T_a} \cdot \left(\nu_b - \nu_a\right) + \nu_a = 0.001007\ \frac{\text{m}^3}{\text{kg}}$$

The specific isentropic work of the pump is given by

$$w_{ps} := \nu_1 \cdot \left(P_2 - P_1\right) = 16.11\ \frac{\text{kJ}}{\text{kg}}$$ (since the fluid is incompressible)

Solution (contd.):
The actual work of the pump is then found by the definition of the isentropic efficiency of the pump. This is shown below.

$$\eta_p = \frac{w_{ps}}{w_{pa}} \qquad \text{or} \qquad w_{pa} := \frac{w_{ps}}{\eta_p} = 18.95\ \frac{\text{kJ}}{\text{kg}}$$

Going to Table A-5 @ $T_5 = 600.0\ °\text{C}$ and $P_5 = 15000\ \text{kPa}$ shows that the state is superheated.

Going to Table A-6 @ $T_5 = 600.0\ °\text{C}$ and $P_5 = 15.00\ \text{MPa}$ shows

$$h_5 := 3583.1\ \frac{\text{kJ}}{\text{kg}} \qquad s_5 := 6.6796\ \frac{\text{kJ}}{\text{kg K}}$$

For the ideal cycle, the specific entropy at state 5 and state 6 are the same.

$$s_{6s} := s_5 = 6.680\ \frac{\text{kJ}}{\text{kg K}}$$

Going to Table A-5 @ $P_6 = 10.00\ \text{kPa}$ and $s_{6s} = 6.680\ \frac{\text{kJ}}{\text{kg K}}$ shows that the state is in the two phase region.

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

$$x_{6s} := \frac{s_{6s} - s_f}{s_g - s_f} = 0.8041 \qquad h_{6s} := h_f + x_{6s} \cdot \left(h_g - h_f\right) = 2115\ \frac{\text{kJ}}{\text{kg}}$$

The specific work of the turbine for the ideal case may then be found by

$$w_{ts} := h_5 - h_{6s} = 1468\ \frac{\text{kJ}}{\text{kg}}$$

The specific work of the turbine for the actual case may then be found by using the definition of isentropic efficiency. This is shown below.

$$\eta_t = \frac{w_{ta}}{w_{ts}} \qquad \text{or} \qquad w_{ta} := \eta_t \cdot w_{ts} = 1277\ \frac{\text{kJ}}{\text{kg}}$$

Going to Table A-5 @ $T_3 = 35.00\ °\text{C}$ and $P_3 = 15900\ \text{kPa}$ shows the state is a compressed liquid but in this case, we can actually use the compressed liquid tables.

Going to Table A-7 @ $T_3 = 35.00\ °\text{C}$ and $P_3 = 15.90\ \text{MPa}$ shows that double interpolation is needed.

$$P_a := 15\ \text{MPa} \qquad P_b := 20\ \text{MPa}$$

$$T_a := 20\ °\text{C} \qquad h_{aa} := 97.93\ \frac{\text{kJ}}{\text{kg}} \qquad h_{ab} := 102.57\ \frac{\text{kJ}}{\text{kg}}$$

$$T_b := 40\ °\text{C} \qquad h_{ba} := 180.77\ \frac{\text{kJ}}{\text{kg}} \qquad h_{bb} := 185.16\ \frac{\text{kJ}}{\text{kg}}$$

$$h_{a3} := \frac{P_3 - P_a}{P_b - P_a} \cdot \left(h_{ab} - h_{aa}\right) + h_{aa} = 98.77\ \frac{\text{kJ}}{\text{kg}}$$

$$h_{b3} := \frac{P_3 - P_a}{P_b - P_a} \cdot \left(h_{bb} - h_{ba}\right) + h_{ba} = 181.6\ \frac{\text{kJ}}{\text{kg}}$$

$$h_3 := \frac{T_3 - T_a}{T_b - T_a} \cdot \left(h_{b3} - h_{a3}\right) + h_{a3} = 160.9\ \frac{\text{kJ}}{\text{kg}}$$

Solution (contd.):

Going to Table A-5 @ $T_4 = 625.0\ °C$ and $P_4 = 15200\ kPa$ shows the state is superheated.

Going to Table A-6 @ $T_4 = 625.0\ °C$ and $P_4 = 15.20\ MPa$ shows double interpolation is needed.

$$P_a := 15\ MPa \qquad P_b := 17.5\ MPa$$

$$T_a := 600\ °C \quad h_{aa} := 3583.1\ \frac{kJ}{kg} \qquad h_{ab} := 3561.3\ \frac{kJ}{kg}$$

$$T_b := 650\ °C \quad h_{ba} := 3712.1\ \frac{kJ}{kg} \qquad h_{bb} := 3693.8\ \frac{kJ}{kg}$$

$$h_{a4} := \frac{P_4 - P_a}{P_b - P_a} \cdot \left(h_{ab} - h_{aa}\right) + h_{aa} = 3581\ \frac{kJ}{kg}$$

$$h_{b4} := \frac{P_4 - P_a}{P_b - P_a} \cdot \left(h_{bb} - h_{ba}\right) + h_{ba} = 3711\ \frac{kJ}{kg}$$

$$h_4 := \frac{T_4 - T_a}{T_b - T_a} \cdot \left(h_{b4} - h_{a4}\right) + h_{a4} = 3646\ \frac{kJ}{kg}$$

The specific heat added to the cycle is given by

$$q_{in} := h_4 - h_3 = 3485\ \frac{kJ}{kg}$$

The specific net work of the cycle is given by

$$w_{net} := w_{ta} - w_{pa} = 1258\ \frac{kJ}{kg}$$

The thermal efficiency is then found by

$$\boxed{\eta_{th} := \frac{w_{net}}{q_{in}} = 36.10\ \%}$$

The power porduced by the power plant is then found by

$$\boxed{W'_{net} := m' \cdot w_{net} = 18.87\ MW}$$