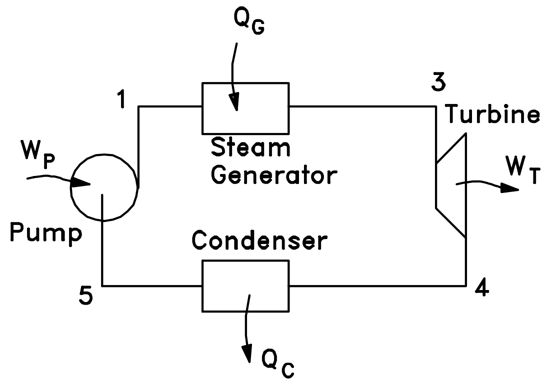
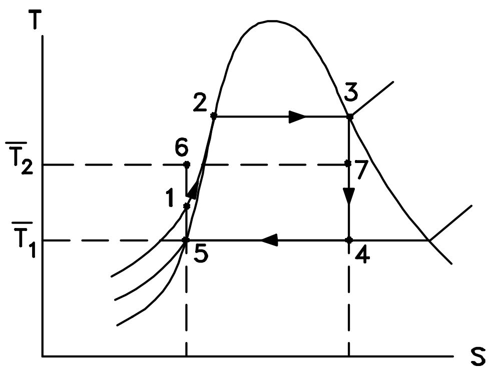
Problem: 4-1

Given: A simple Rankine cycle using water as the working fluid operates between the pressure limits of 7.5 kPa and 1800 kPa.

Find: a) the cycle thermal efficiency
b) the steam rate (specific steam consumption)





For the turbine

$$W_T = h_3 - h_4$$

From the steam tables at 1800 kPa

$$h_3 = h_g = 2794.8\ kJ/kg$$

Since process $3 \rightarrow 4$ is isentropic, h_4 is defined by $p_4 = 7.5\ kPa$ and $s_4 = s_3 = s_g = 6.3751\ kJ/kg \cdot K$ at $1800\ kPa$.
Since $s_g = 8.2523\ kJ/kg \cdot K$ at $7.5\ kPa$ and $s_f = 0.5763\ kJ/kg \cdot K$ at $7.5\ kPa$, point 4 is inside the liquid-vapor region. Thus we may use the following expression to determine h_4 at $7.5\ kPa$.

$$h_4 = [h_g - (1-x)_4 h_{fg}]$$

To find the quality at point 4, we use

$$\begin{aligned} s_3 &= s_4 = [s_g - (1-x)_4 s_{fg}] \text{ at } 7.5\ kPa \\ 6.3751 &= 8.2523 - (1-x)_4(7.6760) \end{aligned}$$

or

$$(1-x)_4 = 0.2446$$

Then

$$\begin{aligned} h_4 &= 2574.0 - (0.2446)(2406.2)\ kJ/kg \\ &= 1986.3\ kJ/kg \end{aligned}$$

and

$$\begin{aligned} W_T &= 2794.8 - 1986.3\ kJ/kg \\ &= 808.5\ kJ/kg \end{aligned}$$

From the condenser

$$Q_C = h_5 - h_4$$

where at 7.5 kPa

$$h_5 = h_f = 168.77\ kJ/kg$$

Thus

$$\begin{aligned} Q_C &= 168.77 - 1986.3\ kJ/kg \\ &= -1817.5\ kJ/kg \end{aligned}$$

The negative sign simply means that heat is leaving the condenser according to our convention.
For the pump

$$W_p = (h_5 - h_1) = -v(p_1 - p_5)$$

where at 7.5 kPa

$$v = v_f = 0.0010079\ m^3/kg$$

Thus

$$\begin{aligned} W_p &= -0.0010079(1800 - 7.5)\ kJ/kg \\ &= -1.81\ kJ/kg \end{aligned}$$

where the negative sign means that work is supplied to the pump.

$$\begin{aligned} h_1 &= h_5 - W_p \\ &= 168.77 - (-1.81)\ kJ/kg = 170.58\ kJ/kg \end{aligned}$$

From the steam generator

$$\begin{aligned} Q_G &= h_3 - h_1 \\ &= 2794.8 - 170.58\ kJ/kg \\ &= 2624.22\ kJ/kg \end{aligned}$$

Part a) The cycle thermal efficiency is

$$\begin{aligned} \eta_{th} &= \frac{W_{net}}{Q_G} \\ &= (808.5 - 1.81)/2624.22 \\ &= 30.7\% \end{aligned}$$

It is instructive to determine the cycle thermal efficiency as

$$\begin{aligned} \overline{T}_2 &= \frac{Q_G}{s_3 - s_5} = \frac{2624.22}{6.3751 - 0.5763}\ K \\ &= 452.55\ K \end{aligned}$$

and

$$\begin{aligned} \overline{T}_1 &= T_1 = \text{saturation temperature at} 7.5\ kPa \\ &= (40.316 + 273.15)\ K \\ &= 313.466\ K \end{aligned}$$

Therefore we have

$$\begin{aligned} \eta_{th} &= \frac{452.55 - 313.466}{452.55} \\ &= 30.7\% \end{aligned}$$

which is the same as before.
Part b) The steam rate is given as

$$\begin{aligned} \text{steam rate} &= \frac{3600}{W_{net}} \\ &= \frac{3600}{808.5 - 1.81}\ kg/kWh \\ &= 4.46\ kg/kWh \end{aligned}$$