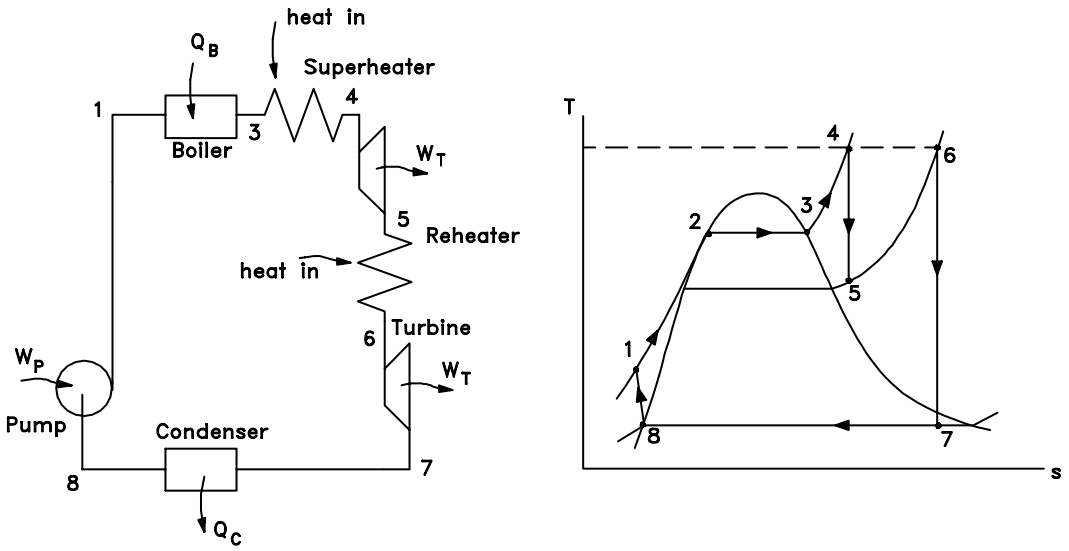
Problem: 4-2

Given: A reheat Rankine cycle using water as the working fluid operates between the pressure limits of 7.5 kPa and 17.0 MPa. Steam is superheated to 550 $^{\circ}C$ before it is expanded to the reheat pressure of 4.0 MPa. Steam is reheated to a final temperature of 550 $^{\circ}C$.

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



For the turbine

$$W_T = (h_4 - h_5) + (h_6 - h_7)$$

From the steam tables at 17 MPa and 550 $^{\circ}C$

$$\begin{aligned} h_4 &= 3428.0\ kJ/kg \\ s_4 &= 6.4430\ kJ/kg \cdot K \end{aligned}$$

At $p_5 = 4.0\ MPa$ and $s_5 = s_4 = 6.4430\ kJ/kg \cdot K$

$$h_5 = 3009.1\ kJ/kg$$

At 4 MPa and 550 $^{\circ}C$

$$
\begin{aligned}
h_6 &= 3558.6\ kJ/kg \\
s_6 &= 7.2333\ kJ/kg \cdot K \\
s_6 &= s_7 = [s_g - (1-x)_7 s_{fg}] \text{ at } 7.5\ kPa
\end{aligned}
$$

which leads to

$$
\begin{aligned}
7.2333 &= 8.2523 - (1-x)_7(7.6760) \\
(1-x)_7 &= 0.1328
\end{aligned}
$$

Therefore h_7 at 7.5 kPa can be calculated as

$$
\begin{aligned}
h_7 &= [h_g - (1-x)_7 h_{fg}] \\
&= 2574.9 - (0.1328)(2406.2)\ kJ/kg \\
&= 2255.4\ kJ/kg
\end{aligned}
$$

and

$$
\begin{aligned}
W_T &= (3428.0 - 3009.1) + (3558.6 - 2255.4)\ kJ/kg \\
&= 1722.1\ kJ/kg
\end{aligned}
$$

For the condenser

$$
\begin{aligned}
Q_C &= h_8 - h_7 \\
&= 168.77 - 2255.4 \\
&= -2086.63\ kJ/kg
\end{aligned}
$$

For the pump

$$
\begin{aligned}
W_p &= h_8 - h_1 = -v_8(p_1 - p_8) \\
&= -.0010079(17,000 - 7.5)\ kJ/kg \\
&= -17.13\ kJ/kg
\end{aligned}
$$

and

$$\begin{aligned} h_1 &= h_8 - W_p \\ &= 168.77 - (-17.13) \\ &= 185.9\ kJ/kg \end{aligned}$$

For the boiler plus superheater plus reheater

$$\begin{aligned} Q_B &= (h_4 - h_1) + (h_6 - h_5) \\ &= (3428.0 - 185.9) + (3558.6 - 3009.1)\ kJ/kg \\ &= 3791.6\ kJ/kg \end{aligned}$$

Part a) The cycle thermal efficiency is

$$\begin{aligned} \eta_{th} &= \frac{W_{net}}{Q_B} \\ &= (1722.1 - 185.9)/3791.6 \\ &= 40.52\% \end{aligned}$$

Part b) The steam rate is given as

$$\begin{aligned} \text{steam rate} &= \frac{3600}{W_{net}}\ kg/kWh \\ &= \frac{3600}{1722.1 - 185.9}\ kg/kWh \\ &= 2.34\ kg/kWh \end{aligned}$$

The calculations show that the moisture content is 13.28%.
However, a actual turbine with efficiency less than 100% will probably bring the moisture content down to an acceptable level of under 10%. The reheat pressure of about 4.0 MPa is therefore quite suitable for the actual case.