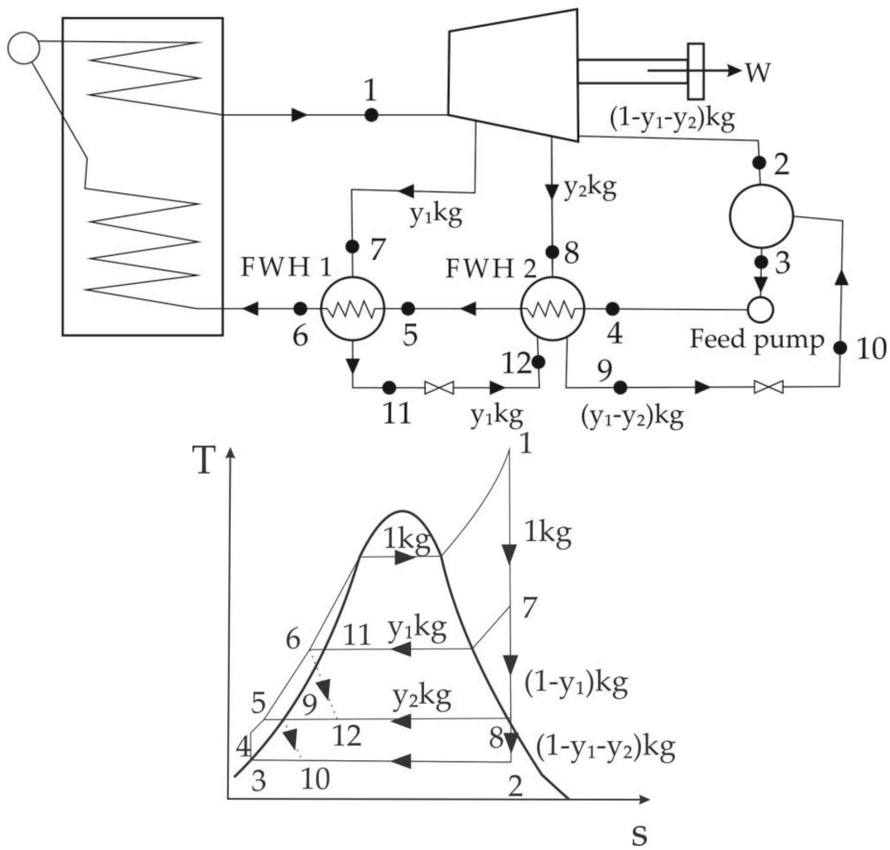
Example 5

The regenerative cycle with closed feedwater heater

In a regenerative steam cycle employing two closed-feed heaters the steam is supplied to the turbine at 40bar and 500°C and is exhausted to the condenser at 0.035bar. The intermediate bleed pressures are obtained such that the saturation temperature intervals are approximately equal, giving pressures of 10 and 1.1bar. Calculate the amount of steam bled at each stage, the work output of the plant per kilogram of boiler steam and the cycle efficiency of the plant Assume ideal process where required.



$$h_{1,42bar,500°C@superheated\ vapor} = 3442.99\,kJ/kg$$
$$s_{1,42bar,500°C@superheated\ vapor} = 7.069kJ/kg\,K$$

$$s_{2,0.035bar} = s_1 = 7.069kJ/kg\,K$$
$$s_2 = s_{2,f@0.035bar} + xs_{2,fg@0.035bar}$$
$$7.069 = 0.381 + x(8.537 - 0.381)$$
$$x = 0.82$$

$$h_2 = h_{2,f@0.035bar} + xh_{2,fg@0.035bar}$$
$$h_2 = 109.09 + 0.82(2439.89)$$
$$h_2 = 2109.80\,kJ/kg$$

$$h_{3,f@0.03bar} = 109.09\,kJ/kg$$

For the first stage expansion, 1-7, s_7=s_1= 7.0969kJ/kgK, and from tables (saturated water) at 10bar s_g<7.0969kJ/kgK, hence the steam is superheated at state 7. By interpolation between 280°C and 320°C (superheated vapor table) at 10bar we have,

$$h_{7,superheated} = 3037.05\,kJ/kg$$

For the throttling process, 11-12, we have

$$h_{6@10bar,f} = h_{11} = h_{12} = 763.22\,kJ/kg$$

For the second stage expansion, 7-8, s_7=s_8=s_1=7.069kJ/kg, and from tables at 1.1bar s_g>7.069kJ/kgK, hence the steam is wet at state 8. Therefore,

$$s_8 = s_{8,f@1.1bar} + x_8 s_{8,fg@1.1bar}$$
$$7.069 = 1.3444 + x_8(7.3158 - 1.3444)$$
$$7.069 = 1.3444 + x_8(5.9714)$$
$$x_8 = 0.9587$$

$$h_8 = h_{8,f@1.1bar} + x_8 h_{8,fg@1.1bar}$$
$$h_8 = 427.81 + 0.9587(2251.46)$$
$$h_8 = 2586.28$$

For the throttling process, 9-10

$$h_5 = h_{9f@1.1bar} = h_{10} = 427.81\,kJ/kg$$

Applying an energy balance to the first feed heater, remembering that there is no work or heat transfer;

$$y_1 h_7 + h_5 = y_1 h_{11} + h_6$$
$$y_1 = \frac{h_6 - h_5}{h_7 - h_{11}} = \frac{763.22 - 427.81}{3037.05 - 763.22} = 0.148$$

Similar for second heater, taking h_4=h_3,

$$y_2 h_8 + y_1 h_{12} + h_4 = h_5 + (y_1 + y_2) h_9$$
$$y_2 (h_8 - h_9) + y_1 h_{12} + h_4 = h_5 + y_1 h_9$$
$$y_2 = \frac{h_5 + y_1 h_9 - y_1 h_{12} - h_4}{(h_8 - h_9)} = \frac{427.81 + (0.148 \times 427.81) - (0.148 \times 763.22) - 109.09}{(2591 - 427.81)} = 0.12$$

The heat supplied to the boiler q_1 of boiler steam is given by,

$$q_{in} = h_1 - h_6 = 3442.99 - 763.22 = 2679.77 kJ/kg$$

The W_{out}, neglecting pump work is given by

$$W_{out} = (h_1 - h_7) + (1 - y_1)(h_7 - h_8) + (1 - y_1 - y_2)(h_8 - h_2)$$
$$= (3442.99 - 3037.05) + (1 - 0.148)(3037.05 - 2591) + (1 - 0.148 - 0.12)(2591 - 2109.8)$$
$$= 1138.213 kJ/kg$$

$$\eta = \frac{W_{net}}{q_{in}} = \frac{1138.213}{2679.77} = 0.4247 = 42.47\%$$