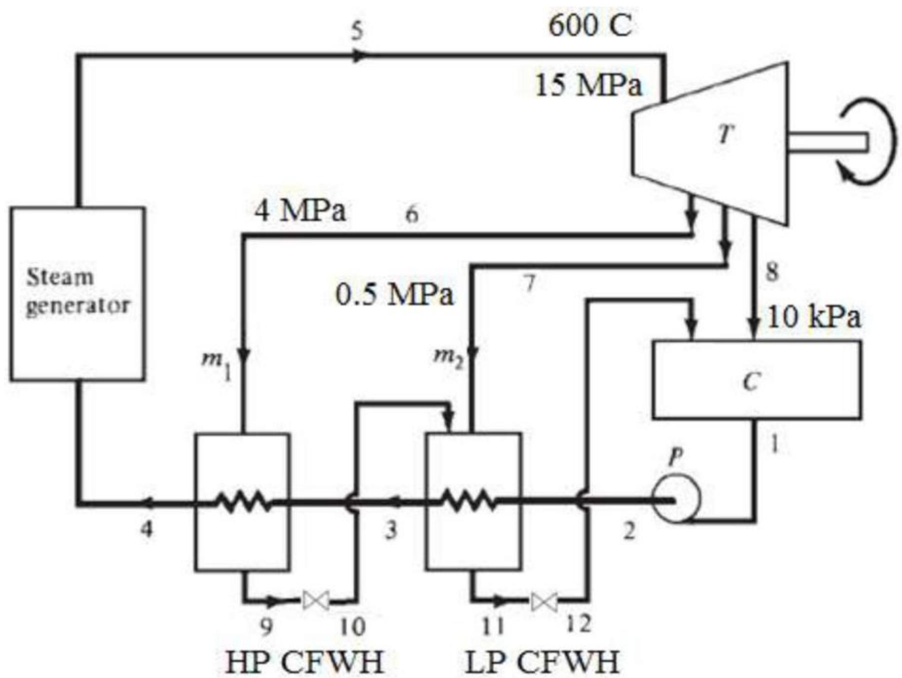
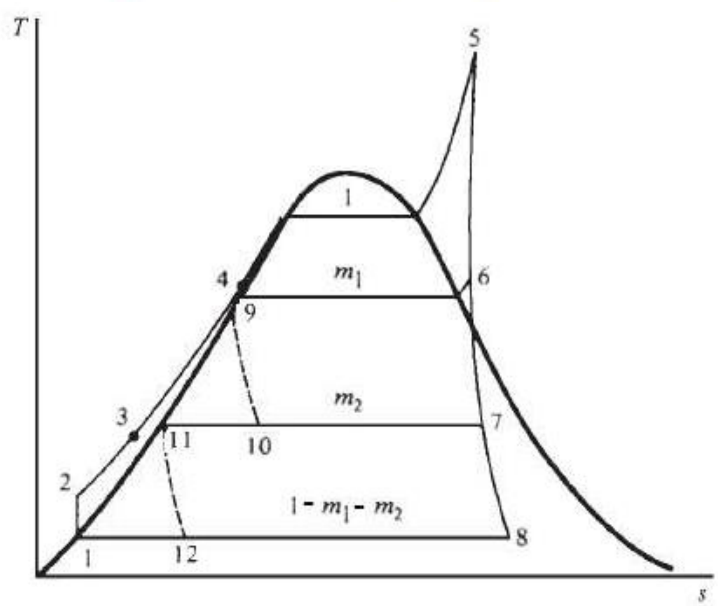
EXAMPLE 7

Consider a steam power plant operating on the ideal regenerative Rankine cycle with two closed feedwater heater. Steam enters the turbine at 15 MPa and 600°C and is condensed in the condenser at a pressure of 10 kPa. Some steam leaves the turbine at a pressure of 4 MPa and 0.5 MPa enters the closed feedwater heater respectively. Determine the thermal efficiency of the cycle and mass flow rate of steam entering the two closed FWH.

<u>SOLUTION</u>**:**





❖ State 1 pump : $P_1 = 10$ kPa, saturated liquid

$$\left.\begin{aligned} & h_1 = h_{f@P1} = 191.81 \text{ kJ/kg} \\ & v_1 = v_{f@P1} = 0.00101 \text{ m}^3/\text{kg} \\ & s_1 = 0.6492 \text{ kJ/kg K} \end{aligned}\right.$$

❖ State 2 : $p_2 = p_5 = 15$ MPa

$s_2 = s_1$

$W_{pump} = v_1(P_2 - P_1) = 0.00101\ (15000 - 10)$

$= 15.14$ kJ/kg

$h_2 = h_1 + W_{pump}$

$= 191.81 + 15.14 = 206.95$ kJ/kg

❖ State 5: $p_5 = 15$ MPa, $T_s = 600$ºC

$$\left.\begin{aligned} & h_5 = 3582.3 \text{ kJ/kg} \\ & s_5 = 6.6775 \text{ kJ/kg . K} \\ & s_5 = s_6 = s_7 = s_8 \end{aligned}\right.$$

❖ State 6: $p_6 = 4$ MPa, $s_6 = 6.6775$ kJ/kg . K

$$\left.\begin{aligned} & h_6 = 3152 \text{ kJ/kg} \\ & T_6 = 375\ ^{\circ}\text{C} \end{aligned}\right.$$

❖ State 7: $p_7 = 0.5$ MPa, $s_7 = 6.6775$ kJ/kg . K, mixture

$$\left.\begin{aligned} & h_f = h_{11} = 640.21 \text{ kJ/kg} \\ & h_{fg} = 2108.47 \text{ kJ/kg} \\ & s_f = 1.8606 \text{ kJ/kg . K} \\ & s_{fg} = 4.9606 \text{ kJ/kg . K} \end{aligned}\right.$$

$$x_7 = \frac{s_7 - s_f}{s_{fg}} = \frac{6.6775 - 1.8606}{4.9606}$$

$$x_7 = 0.971$$

$h_7 = h_f + x_7 h_{fg} = 640.21 + 0.971*2108.47$

$h_7 = 2687.5$ kJ/kg

- State 8: $p_8 = 10$ kPa
  $s_8 = s_7 = 6.6775$ kJ/kg . K
  mixture
  } $h_f = 191.81$ kJ/kg
  $h_{fg} = 2392.82$ kJ/kg
  $s_f = 0.6492$ kJ/kg . K
  $s_{fg} = 7.501$ kJ/kg . K

$$x_8 = \frac{s_8 - s_f}{s_{fg}} = \frac{6.6775 - 0.6492}{7.501}$$

$$x_8 = 0.803$$

$h_8 = h_f + x_8 h_{fg} = 191.81 + 0.803* 2392.82$

$h_8 = 2113.2$ kJ/kg

- State 9: $p_9 = 4$ MPa
  Sat.
  } $h_9 = 1087.29$ kJ/kg
  $T_9 = 250.4\,^{o}C$

- State 3: *Assume TTD = 2* ^{o}C

$$TTD = T_{11} - T_3 \qquad (T_{11} = T_{sat,\ 500kPa.})$$

$$2 = 151.86 - T_3$$

$T_3 = 149.86\ ^oC \Rightarrow T_3 \approx 150\ ^oC$

at $T_3 = 150\ ^oC \Rightarrow h_3 = h_f = 632.18$ kJ/kg

❖ <u>State 4</u>: *Assume TTD = 2* ^oC

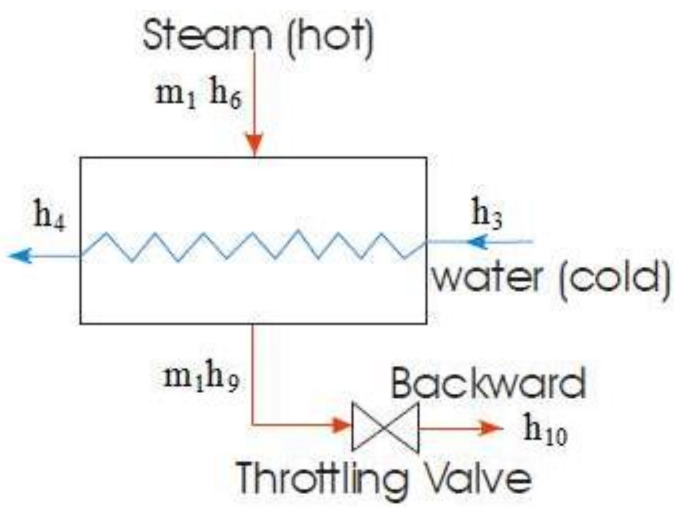
$$TTD = T_9 - T_4 \qquad (T_9 = T_{sat,4MPa.})$$

$$2 = 250.4 - T_4$$

$T_4 = 248.4\ ^oC \Rightarrow T_4 \approx 248\ ^oC$

at $T_4 = 248\ ^oC \Rightarrow h_4 = h_f = 1074$ kJ/kg

The energy balance on the high pressure FWH is given as :



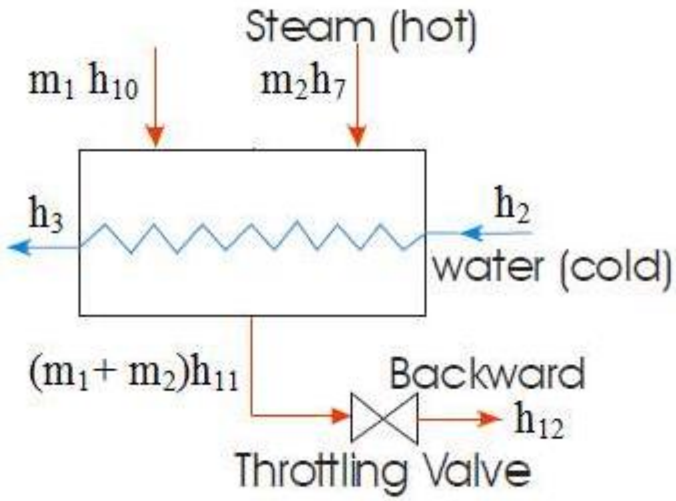
Energy entering regenerator = Energy leaving regenerator

$m_1\ h_6 + h_3 = m_1 h_9 + h_4 \Rightarrow m_1 (h_6 - h_9) = h_4 - h_3$

$m_1\ (3152 - 1087.29) = 1074 - 632.18$

$m_1 = 0.214$ kg

The energy balance on the low pressure FWH is given as :



Energy entering regenerator = Energy leaving regenerator

$m_1 h_{10} + m_2 h_7 + h_2 = (m_1 + m_2)\, h_{11} + h_3$

$\Rightarrow \quad m_1\,(h_{10} - h_{11}) + m_2\,(h_7 - h_{11}) = h_3 - h_2$

at throttling process is a constant enthalpy process , so that:

$$h_9 = h_{10}$$

$$h_{11} = h_{12}$$

$$h_{11} = h_{sat,\ 500\ kPa} = 640.21 \text{ kJ/kg}$$

$0.214(1087.29 - 640.21) + m_2(2687.5 - 640.21) = 632.18 - 206.95$

$m_2 = 0.161$ kg

$q_{in} = (h_5 - h_4) \quad \Rightarrow \quad q_{in} = (3582.3 - 1074)$

$q_{in} = 2508.3 kJ/kg$

$$q_{out} = (1 - m_1 - m_2)(h_8 - h_1) + (m_1 + m_2)(h_{12} - h_1)$$

$$q_{out} = (1 - 0.214 - 0.161)(2113.2 - 191.81) + (0.214 + 0.161)(640.21 - 191.81)$$

$$q_{out} = 1369 kJ/kg$$

$$\eta = \frac{W_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$\eta = 1 - \frac{1369}{2508.3}$$

$$\eta = 0.454 = 45.4\%$$