5.9 Multi–Stage Regenerative Cycles:

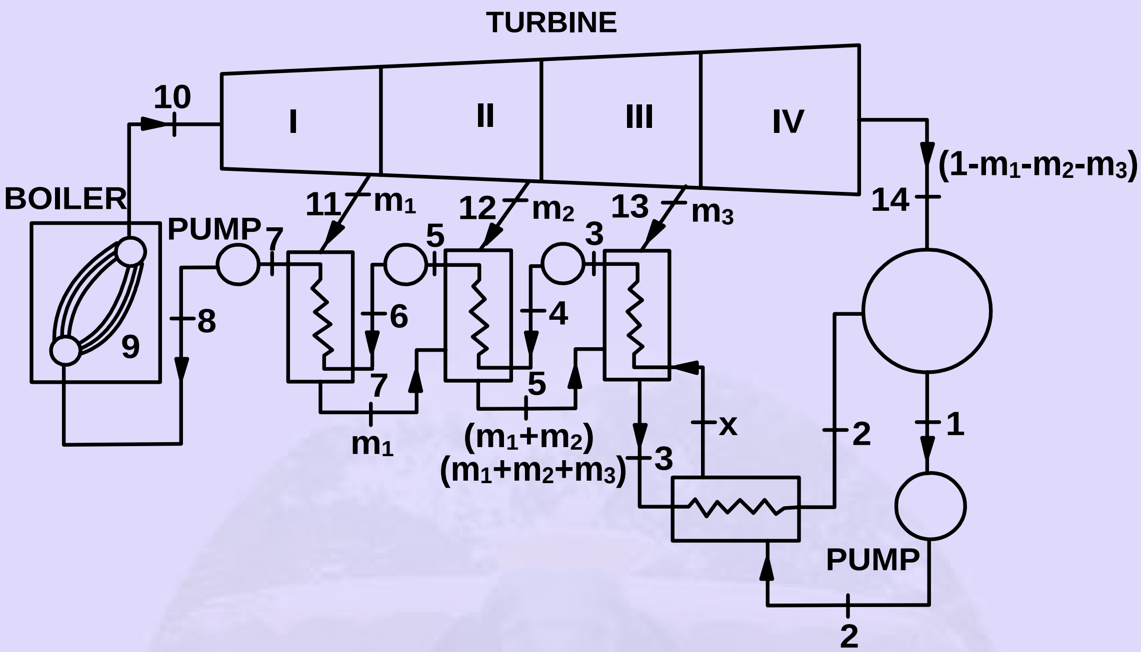

Fig.5.9(a). Three stage regenerative cycle

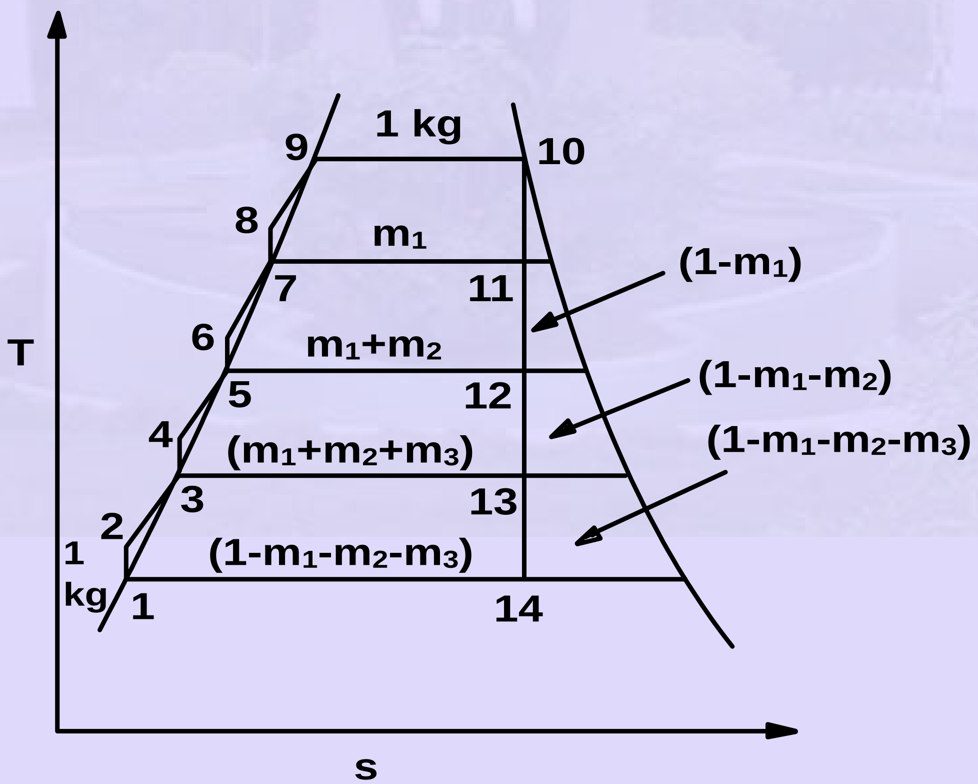

Fig.5.9(b). T-s diagram

Above figure shows an arrangement in which there are 3 stages of feed water heating employing closed heaters. Steam to the 1st, 2nd and 3rd heaters is supplied at states 11, 12 and 13 respectively. The feed water leaving each heater is at the saturation temperature corresponding to the pressure of bled steam supplied to that heater. The corresponding T-s diagram for the cycle is shown above.

Considering one kg of steam leaving the boiler and entering the turbine at state 10.

Let, m_1 = mass of steam supplied to 1st heater.

m_2 = mass of steam supplied to 2nd heater.

m_3 = mass of steam supplied to 3rd heater.

Heat balance for 1st heater gives,

$$m_1(h_{11} - h_7) = (h_7 - h_6) \approx (h_7 - h_5)$$

$$m_1 = \frac{(h_7 - h_5)}{(h_{11} - h_7)}$$

Heat balance for 2nd heater gives,

$$h_4 + m_2h_{12} + m_1h_7 = h_5 + h_5(m_1 + m_2)$$

$$m_2(h_{12} - h_5) = (h_5 - h_4) + m_1(h_5 - h_7)$$

$$m_2 = \frac{(h_5 - h_3) - m_1(h_7 - h_5)}{(h_{12} - h_5)} \quad ; \quad \because (h_4 \approx h_3)$$

Also, heat balance for 3rd heater + drain cooler, gives,

$$m_3h_{13} + (m_1 + m_2)h_5 + h_2 = (m_1 + m_2 + m_3)h_2 + h_3$$

$$m_3h_{13} + (m_1 + m_2)h_5 + (1 - m_1 - m_2 - m_3)h_2 = h_3$$

$$m_3(h_{13} - h_2) = (h_3 - h_2) - (m_1 + m_2)(h_5 - h_2)$$

$$m_3(h_{13} - h_1) \approx (h_3 - h_1) - (m_1 + m_2)(h_5 - h_1)$$

$$m_3 = \frac{(h_3 - h_1) - (m_1 + m_2)(h_5 - h_1)}{(h_{13} - h_1)}$$

$$\text{Turbine work} = \left\{ \begin{array}{l} (h_{10} - h_{11}) + (1 - m_1)(h_{11} - h_{12}) + (1 - m_1 - m_2)(h_{12} - h_{13}) \\ + (1 - m_1 - m_2 - m_3)(h_{13} - h_{14}) \end{array} \right\}$$

$$= (h_{10} - h_{14}) - m_1(h_{11} - h_{14}) - m_2(h_{12} - h_{14}) - m_3(h_{13} - h_{14})$$

$$\text{Heat supplied} = (h_{10} - h_7)$$

$$\eta = \frac{\text{work done}}{\text{Heat supplied}}$$

$$\eta = \frac{\left\{ \begin{array}{l} (h_{10} - h_{11}) + (1 - m_1)(h_{11} - h_{12}) + (1 - m_1 - m_2)(h_{12} - h_{13}) \\ + (1 - m_1 - m_2 - m_3)(h_{13} - h_{14}) \end{array} \right\}}{(h_{10} - h_7)}$$