Efficiency of the Rankine cycle

Considering 1 kg of fluid :

Applying steady flow energy equation (S.F.E.E.) to boiler, turbine, condenser and pump :

(i) For boiler (as control volume)

$$Q_1 = h_1 - h_4$$

(*ii*) **For turbine** (as control volume)

$$W_T = h_1 - h_2$$

(*iii*) **For condenser**

$$Q_2 = h_2 - h_3$$

(*iv*) **For the feed pump**

$$W_P = h_4 - h_3$$

Efficiency of Rankine cycle

$$\eta_{Rankine} = \frac{W_{net}}{Q_1}$$

$$= \frac{h_1 - h_2}{h_1 - h_4}$$

Increase the Efficiency of the Rankine cycle

- Superheating the steam to high temperatures (Increases T_{high}*(mean)*.

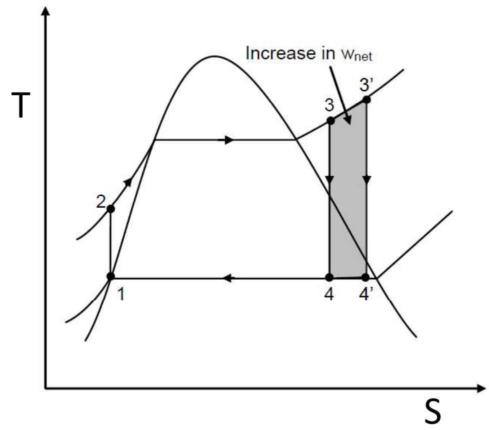
- Increasing the boiler pressure (Increases T_{high}*(mean)*.
- Reheating

Increasing the Boiler Pressure: The mean temperature during the heat addition process is to increase the operating pressure of the boiler, which automatically raises the temperature at which boiling take place. Increase the thermal efficiency of the cycle .

- ❖ Increase in turbine work
- ❖ Increase in mean temperature of heat addition
- ❖ Decrease in heat rejection
- ❖ Increase in efficiency
- ❖ Decrease in dryness fraction at exit of turbine

Superheating the steam: The average temperature at which heat is added to the steam can be increased without increasing the boiler pressure by superheating the steam to high temperatures. Superheating the steam to higher temperatures has very desirable effect : It decreases the moisture content of the steam at the turbine exit . The temperature to which steam can be superheated is limited by metallurgical consideration .

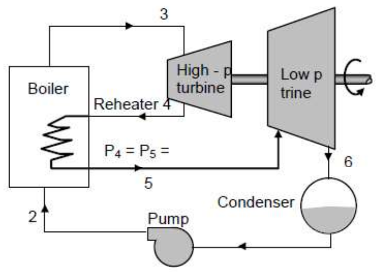
- ❖Increase in turbine work
- ❖Increase in mean temperature of heat addition
- ❖Increase in heat rejection
- ❖Increase in efficiency
- ❖Increase in dryness fraction at exit of turbine
- ❖Increase in heat supply

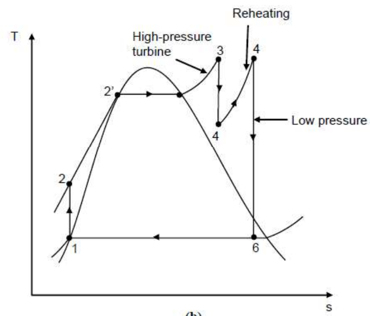


✓ Steam is heated by flue gases

Reheating : The efficiency of the Rankine cycle can increase by expanding the steam in the turbine in two stages, and reheating it in between. Reheating is a practical solution to the excessive moisture problem in turbines, and it is commonly used in modern steam power plants.

In first stage (the high-pressure turbine), steam is expanded isentropically to an intermediate pressure and sent back to the boiler where it is reheated at constant pressure, usually to the inlet temperature of the first turbine stage. Steam then expands isentropically in the second stage (low-pressure turbine) to the condenser pressure.



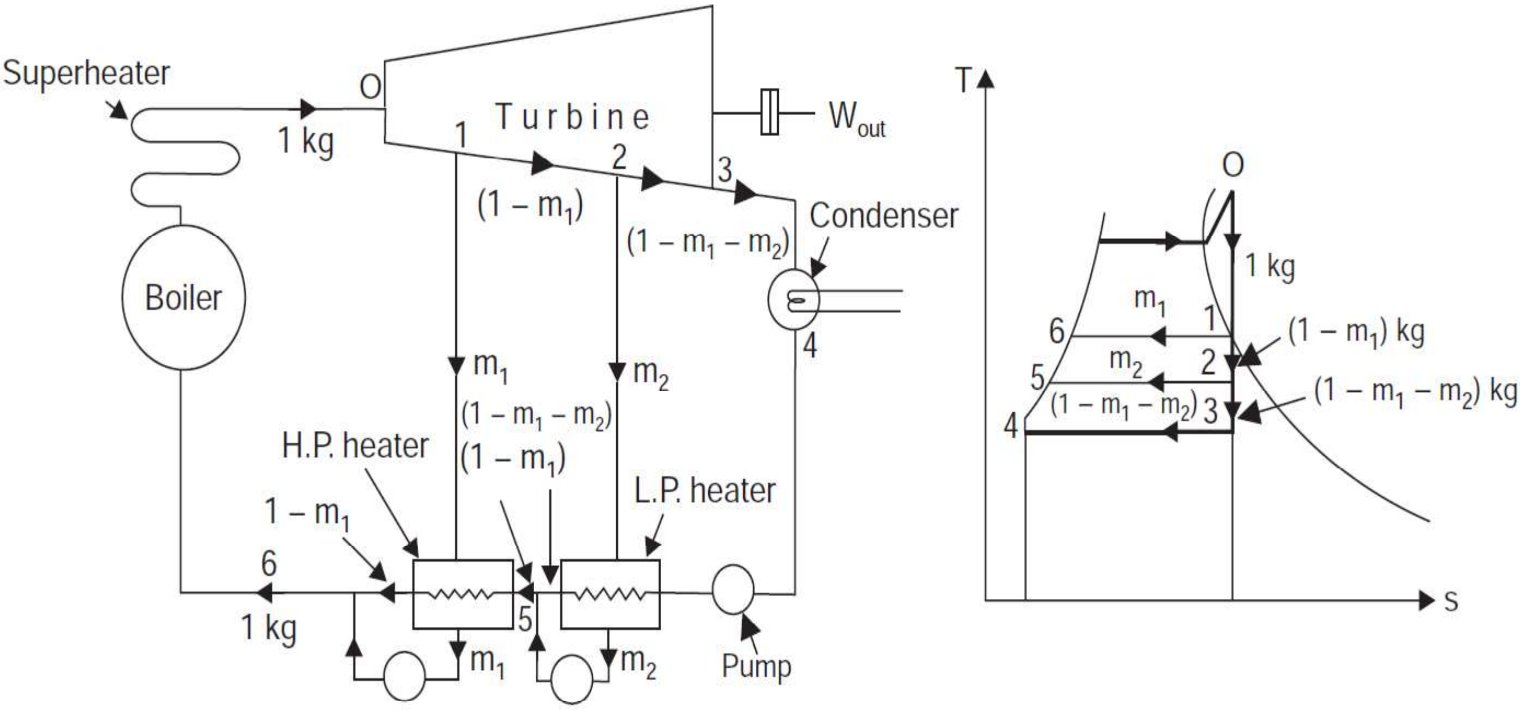


(b)

Regenerative Rankine Cycle

In the Rankine cycle it is observed that the condensate which is fairly at low temperature has an irreversible mixing with hot boiler water and this results in decrease of cycle efficiency. Methods are, therefore, adopted to heat the feed water from the hot well of condenser irreversibly by interchange of heat within the system and thus improving the cycle efficiency. This heating method is called regenerative feed heat and the cycle is called regenerative cycle.

The principle of regeneration can be practically utilised by extracting steam from the turbine at several locations and supplying it to the regenerative heaters. The resulting cycle is known as regenerative or bleeding cycle



Regenerative cycle.

Let, m_1 = kg of high pressure (H.P.) steam per kg of steam flow,

m_2 = kg of low pressure (L.P.) steam extracted per kg of steam flow, and

$(1 - m_2 - m_2)$ = kg of steam entering condenser per kg of steam flow.

Neglecting pump work :

The heat supplied externally in the cycle

$$= (h_0 - h_{f_6})$$

Isentropic work done $= m_1 (h_0 - h_1) + m_2 (h_0 - h_2) + (1 - m_1 - m_2) (h_0 - h_3)$

The thermal efficiency of regenerative cycle is

$$\eta_{\text{thermal}} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{m_1 (h_0 - h_1) + m_2 (h_0 - h_2) + (1 - m_1 - m_2)(h_0 - h_3)}{(h_0 - h_{f_6})}$$

Advantages of Regenerative cycle over Simple Rankine cycle

1. The heating process in the boiler tends to become reversible.
2. The thermal stresses set up in the boiler are minimized. This is due to the fact that temperature ranges in the boiler are reduced.
3. The thermal efficiency is improved because the average temperature of heat addition to the cycle is increased.
4. Heat rate is reduced.
5. The blade height is less due to the reduced amount of steam passed through the low pressure stages.
6. Due to many extractions there is an improvement in the turbine drainage and it reduces erosion due to moisture.
7. A small size condenser is required.

Disadvantages :

1. The plant becomes more complicated.
2. Because of addition of heaters greater maintenance is required.
3. For given power a large capacity boiler is required.
4. The heaters are costly and the gain in thermal efficiency is not much in comparison to the heavier costs.