Lecture Four

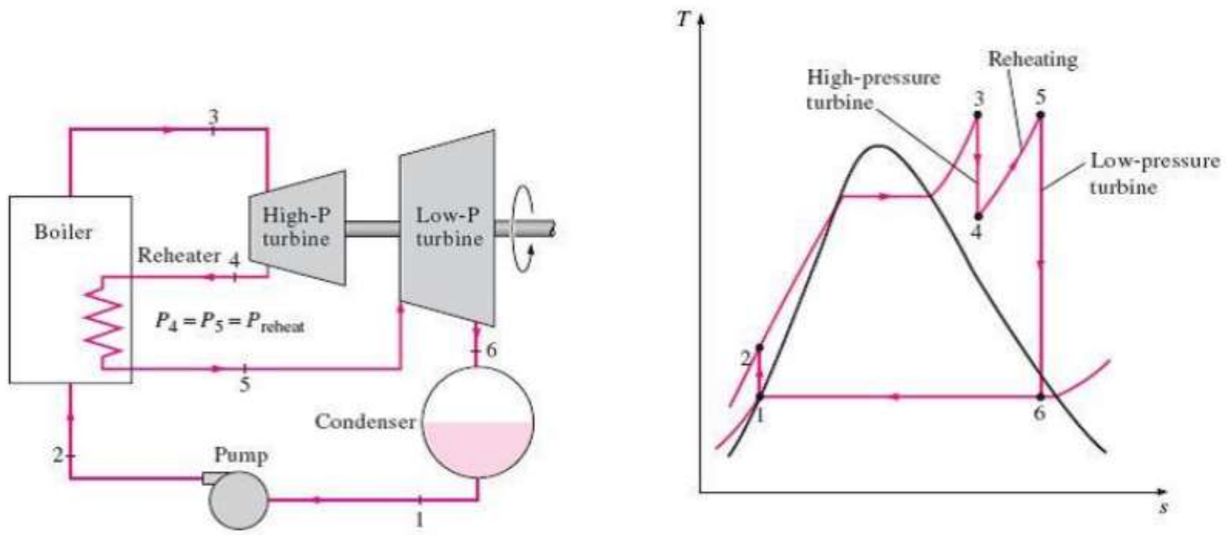
The Ideal Reheat Rankine Cycle

Increasing the boiler pressure increases the thermal efficiency of the Rankine cycle, but it also increases the moisture content of the steam to unacceptable levels. Therefore, the desirable approach is expanding the steam in the turbine in two stages, and reheats it in between. In other words, modify the simple ideal Rankine cycle with a **reheat** process. Reheating is a practical solution to the excessive moisture problem in turbines, and it is commonly used in modern steam power plants.

The figure below explains the (*T-S*) diagram of the ideal reheat Rankine cycle and the schematic of the power plant operating on this cycle. The ideal reheat Rankine cycle differs from the simple ideal Rankine cycle in that the expansion process takes place in two stages. In the 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. Thus the total heat input and the total turbine work output for a reheat cycle become:

$$q_{add} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$$

$$w_{out} = w_{turbine\,1} + w_{turbine\,2} = (h_3 - h_4) + (h_5 - h_6)$$



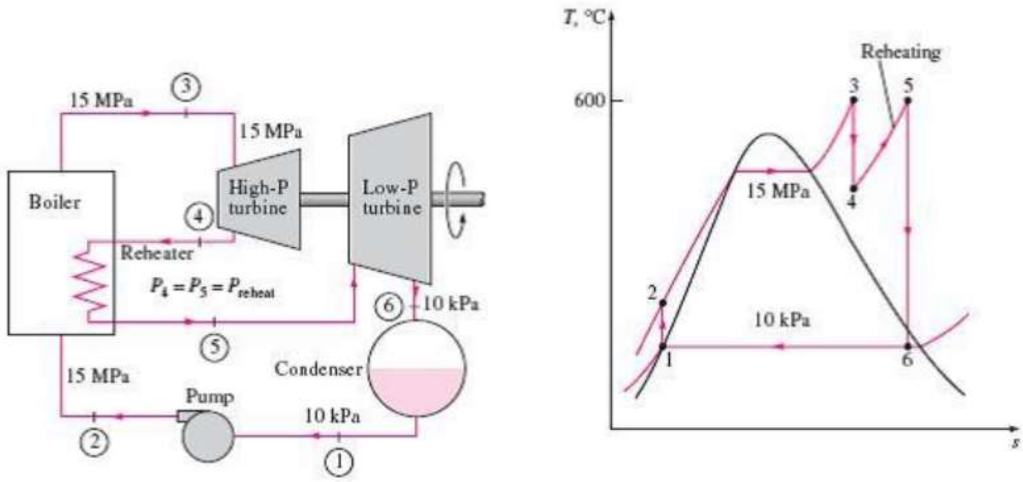
The Ideal Reheat Rankine Cycle

The incorporation of the single reheat in a modern power plant improves the cycle efficiency by 4 to 5 percent by increasing the average temperature at which heat is transferred to the steam.

The reheat temperatures are very close or equal to the turbine inlet temperature. The optimum reheat pressure is about one-fourth of the maximum cycle pressure. For example, the optimum reheat pressure for a cycle with a boiler pressure of 12 MPa is about 3 MPa.

Example (5.4) Consider a steam power plant operating on the ideal reheat Rankine cycle. Steam enters the high-pressure turbine at 15 MPa and 600°C and is condensed in the condenser at a pressure of 10 kPa. If the moisture content of the steam at the exit of the low-pressure turbine is not to exceed 10.4%, determine: (a) the pressure at which the steam should be reheated (b) the thermal efficiency of the cycle. Assume the steam is reheated to the inlet temperature of the high-pressure turbine.

Solution:



a) State 6: at $P_6 = 10$ kPa and $x_6 = 0.896$

$$s_6 = s_f + x_6 s_{fg} = 0.6492 + 0.896 \times (7.34996) = 7.3688 \text{ kJ/kg. K}$$

$$h_6 = h_f + x_6 h_{fg} = 191.8 + 0.896 \times (2392.1) = 2335.1 \text{ kJ/kg}$$

Thus, $T_5 = 600°\text{C}$ and $s_5 = s_6$

And, $P_5 = 4$ MPa and $h_5 = 3674.9$ kJ/kg

So the steam should be reheated at a pressure of 4 MPa to prevent a moisture content greater than 10.4%.

State 2: at $P_2 = 15$ MPa and $s_2 = s_1$

$w_{pump} = v_1(P_2 - P_1) = 0.00101 \times (15 \times 10^3 - 10) = 15.14$ kJ/kg

$w_{pump} = h_2 - h_1 \rightarrow h_2 = 191.81 + 15.14 = 206.96$ kJ/kg

State 3: at $P_3 = 15$ MPa and $T_3 = 600°C$

From superheated steam tables: $h_3 = 3583.1$ kJ/kg and $s_3 = 6.6796$ kJ/kg. K

State 4: at $P_4 = 4$ MPa and $s_3 = s_4$

From superheated steam tables: $h_4 = 3155$ kJ/kg and $T_4 = 375.5°C$

$q_{in} = (h_3 - h_2) + (h_5 - h_4)$

$q_{in} = (3583.1 - 206.95) + (3674.9 - 3155.0) = 3896.1$ kJ/kg

$q_{out} = h_6 - h_1 = 2335.1 - 191.8 = 2143.3$ kJ/kg

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2143.3}{3896.1}$$

$\boldsymbol{\eta_{th} = 45\%}$ **Ans.**