Steam Power Plants

3- 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. Then it is natural to ask the following question:

How can we take advantage of the increased efficiencies at higher boiler pressures without facing the problem of excessive moisture at the final stages of the turbine?

Two possibilities come to mind:

1. Superheat the steam to very high temperatures before it enters the turbine. This would be the desirable solution since the average temperature at which heat is added would also increase, thus increasing the cycle efficiency. This is not a viable solution, however, since it requires raising the steam temperature to unsafe levels.

2. Expand the steam in the turbine in two stages, and reheat 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 *T-s* diagram of the ideal reheat Rankine cycle and the schematic of the power plant operating on this cycle are shown in Fig. 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

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

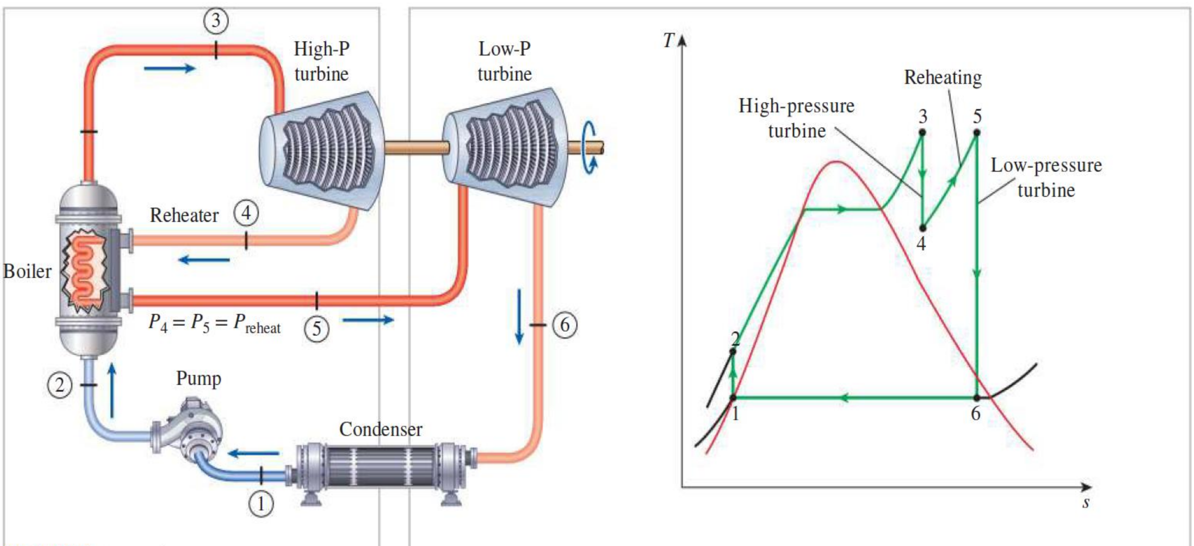

FIGURE
The ideal reheat Rankine cycle.

$$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$$

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 average temperature during the reheat process can be increased by increasing the number of expansion and reheat stages. As the number of stages is increased, the expansion and reheat processes approach an isothermal process at the maximum temperature, as shown in Fig. 10–12. The use of more than two reheat stages, however, is not practical. The theoretical improvement in efficiency from the second reheat is about half of that which results from a single reheat. If the turbine inlet pressure is not high enough, double reheat would result in superheated exhaust.

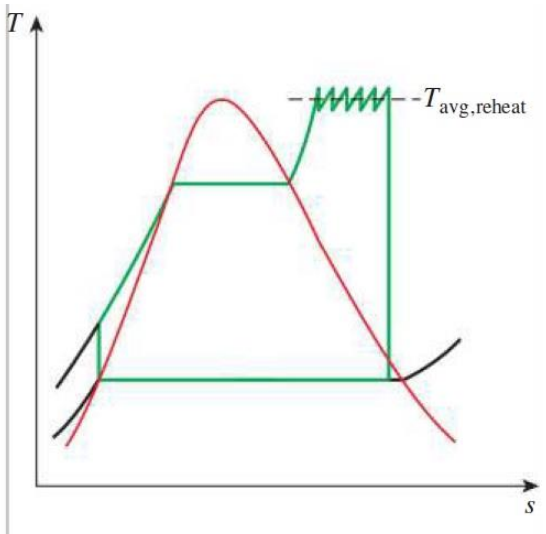

FIGURE
The average temperature at which heat is transferred during reheating increases as the number of reheat stages is increased.

EXAMPLE The Ideal Reheat Rankine Cycle

Consider a steam power plant that operates on the ideal reheat Rankine cycle. The plant maintains the inlet of the high-pressure turbine at 4000 kpa and 300°c, the inlet of the low-pressure turbine at 1300 kpa and 300°c, and the condenser at 75 kpa. The net power produced by this plant is 5000 kW. Determine the rate of heat addition and rejection and the thermal efficiency of the cycle. Is there any advantage to operating the reheat section of the boiler at 700 kpa rather than 1300 kpa while maintaining the same low-pressure turbine inlet temperature?

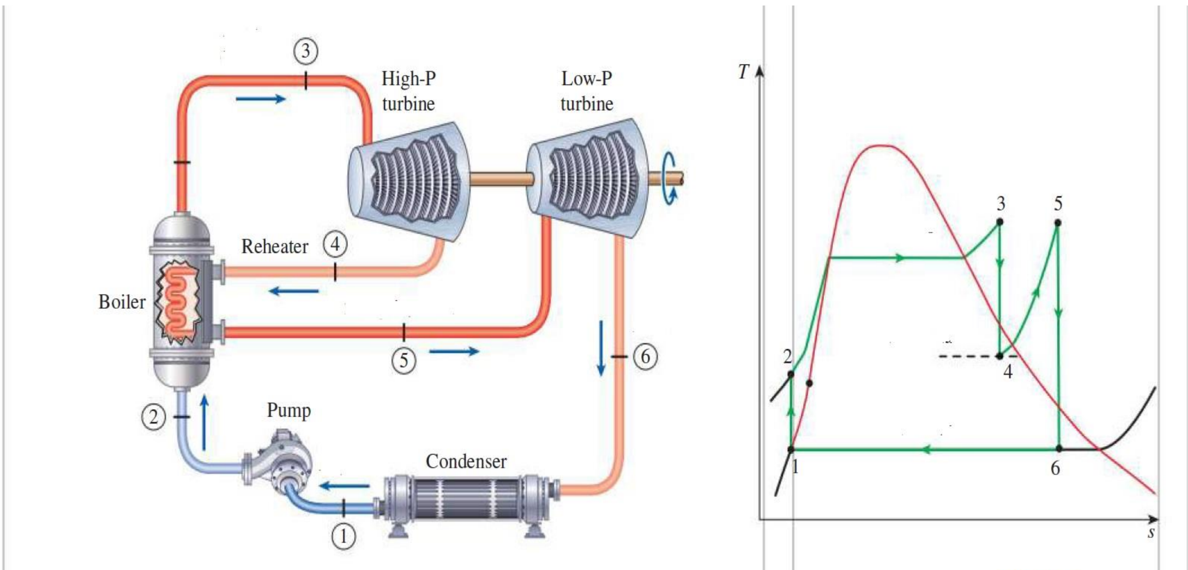

FIGURE
Schematic and *T-s* diagram for Example

$h_1 = h_f$ @ 75 kpa =384.44 kj/kg

$v_1 = v_f$ @@ 75 kpa =0.001037 m3/kg

$w_p = v_1(p1-p2)$=-1.27 kj/kg

$h_2 = h_1 - w_p$=385.71 kj/kg

P_3=4000 kpa
T_3 = 300° c
From sat. table the satate is superheated
The enthalpy h_3= 2961.7 kj/kg
The entropy s_3=s_4= 6.3639 kj/kg.k
P_4=1200 kpa with s_4=6.3639 kj/kg.k
The state is sat maxture sf<s<sg
The quality $x_4 = \frac{s_4 - sf}{sfg}$ =0.972
The enthalpy h4=hf+x4*hfg=2728.1388 kj/kg
P[5]=1200 kpa
P[5]=300 c
From sat. table the satate is superheated
The enthalpy h_5 =3046.3 kj/kg
The entropy s_5=s_6= 7.0335 kj/kg.k

P6=p1=75 kpa
The state is sat maxture sf<s<sg
The quality $x_6 = \frac{s_4 - sf}{sfg}$ =0.932
The enthalpy h6=hf+x6*hfg=2507.536 kj/kg

h1	384.44
h2	385.71
h3	2961.7
h4	2728.1388
h5	3046.3
h6	2507.536

$$q\,in = (h3 - h2) + (h5 - h4)$$

qin=2894.1512 kj/kg
$$q\,out = h6 - h1$$

qout=2123.096

wnet=qin-qout=771.055 kj/kg

$\dot{w} = \dot{m} * w_{net}$

The flow rat is $= \dot{m} = \frac{\dot{w}}{w_{net}} == \frac{5000}{771.055} = 6.485 kg/s$

the thermal efficiency of the cycle is $\eta_{the} = \frac{\dot{w}_{net}}{q_{in}} = 0.2664$