Heat supplied $= Q_{451} + Q_{76}$

Neglecting feed pump work, $Q_{451} = h_1 - h_3$

For reheat process $Q_{76} = h_6 - h_2$

For Turbine, Work Output $= W_{12} + W_{67}$

Since for turbine, exp is adiabatic i.e. $\Delta Q = 0$ and isentropic $\Delta S = 0$

$$W_{12} = h_1 - h_2$$

$$W_{67} = h_6 - h_7$$

Hence Rankine with Reheat Eff

$$= \frac{W_{12} + W_{67}}{Q_{451} + Q_{76}}$$

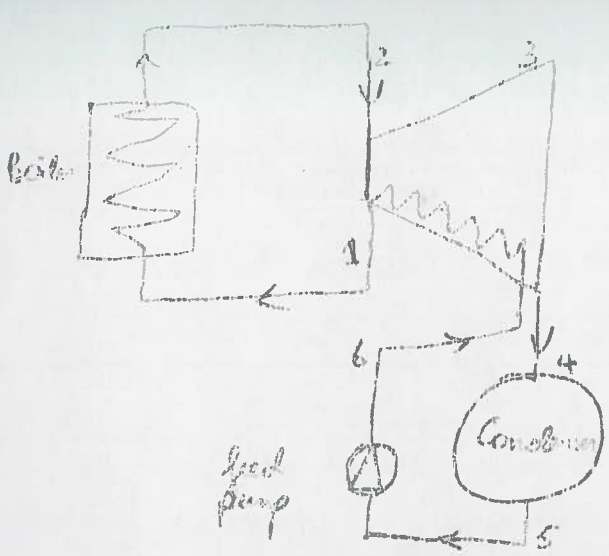
$$= \frac{(h_1 - h_2) + (h_6 - h_7)}{(h_1 - h_3) + (h_6 - h_2)}$$

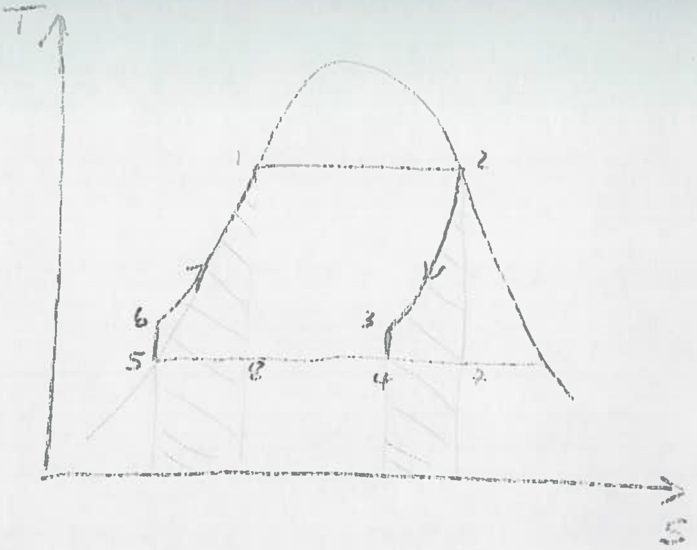
Rankine Cycle with Regeneration

It has been said earlier, that heating of the condensate in the boiler from the exit conditions of the feed pump to the boiling temp, decreases the cycle efficiency as boiling should ideally be at a single high temperature. Therefore if a system heats the feed water before entering the boiler, it increases the overall efficiency. One hypothetical method is to heat the feed water in counter flow to the expanding steam in the steam turbine itself. That is have the feedwater pass through ducts in the steam turbine ~~so~~ so that the feedwater ends up leaving the turbine HP side at the boiling temp.

For a simple rankine cycle, i.e. rankine without superheat, the cycle is as follows.

⟶ End of 5th lesson





For the hypothetical reversible (no temp difference between expanding steam and feed water being heated) the shaded areas are equal.

For this hypothetical rankine with regeneration, eff is equal to Carnot since external heating & cooling are done at two fixed temperatures.

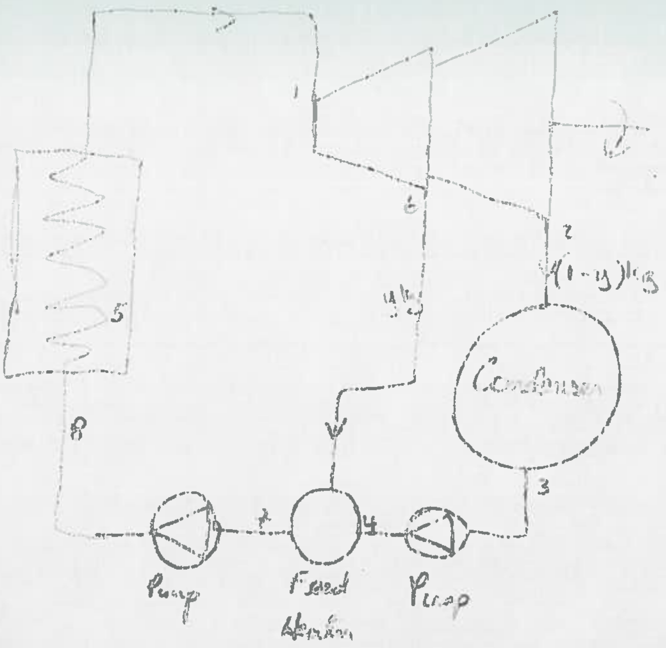
A practical method for the Rankine regenerative cycle is by the use of feed heater where the feed water is heated by means of small amounts of steam bleeded from the steam turbine.

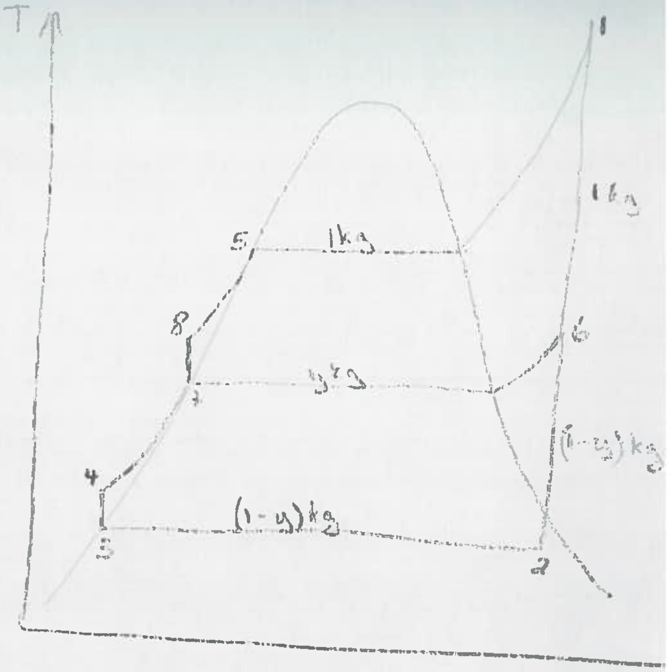
There are two types of feed water heaters.

a) open feed water heaters where the bleed steam and the condensate are mixed together

b) closed feed water heaters where the bleed steam heats the condensate by the use of a heat exchanger, but the two fluids remain separate.

Let us consider the open feed heaters. Note that in the T s diagram for a regenerative rankine cycle below, the mass flow rate is not always the same on all the lines.





Here for a superheated steam condition at turbine inlet, steam is expanded in the turbine to a pressure which is the saturation pressure for the temperature of point 7. y kg of the total 1kg are bleed off at this point and mixed with the remaining (1-y) kg which are left to expand completely in the turbine to the condenser pressure. The amount y kg is determined so that after mixing the total amount, 1kg is at condition 7. In this way, the heating of the fluid from 4 to 7 is not done in the boiler, from a much higher temp source, but is achieved by lower quality heat from the bleed steam. Thus the cycle efficiency is increased.

It can be found that the optimum bleed steam saturation temperature is

$$t_{bleed\ sat} = t_7 = \frac{t_5 + t_3}{2}$$

i.e. the $t_{bleed\ sat}$ is the mean of the saturation temp at the boiler pressure and the saturation temp at the condenser pressure.

For better efficiencies more feed heaters should be incorporated into the cycle so that in the limit all the heating of the condensate to the boiler saturation temp is done by feed heaters. Open heaters require that a pump is installed for every heater. This is undesirable and hence closed feed heaters are used which do not mix the feed steam with