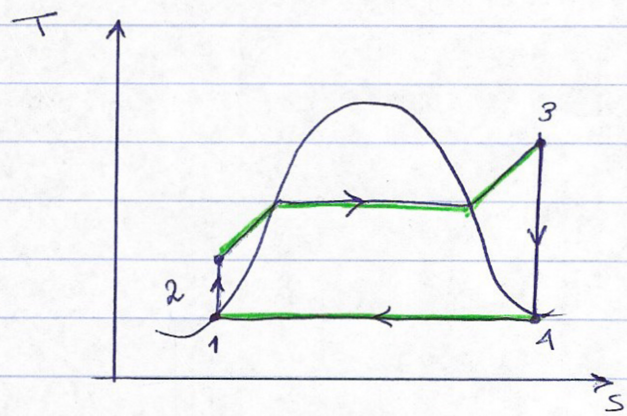
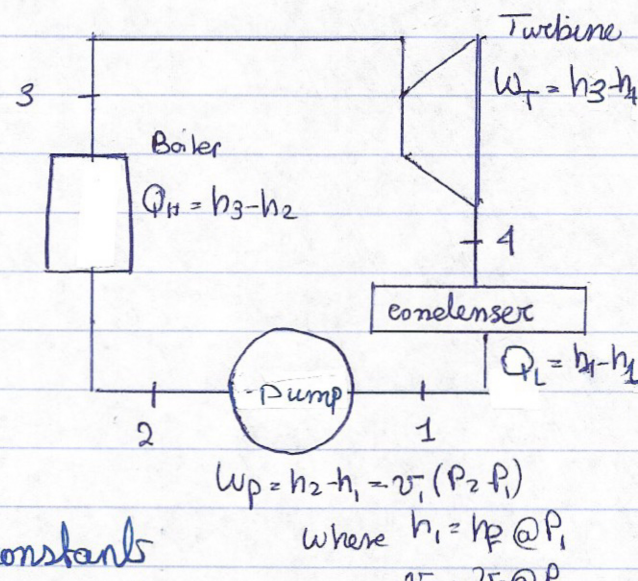
Chapter 9: Power & Refrigeration systems with phase change

Ideal Rankine cycle





- From $2 \rightarrow 3$: pressure is constant
- From $4 \rightarrow 1$, Pressure is constant

- From $1 \rightarrow 2$: entropy is constant
- From $3 \rightarrow 4$, entropy is constant

- In the pump we can use relation $w = v_i \, dP = v_i (P_e - P_i)$

نعوض بالحالات

To find efficiency : $\eta_{Rankine} = \dfrac{W_t - W_p}{q_H} = \dfrac{q_H - q_L}{q_H}$

$$= \frac{(h_3 - h_2) - (h_4 - h_1)}{(h_3 - h_2)}$$

effect of pressure & temprature on the Rankine Cycle

$$\eta \propto 1 - \frac{T_L}{T_H} \quad \begin{cases} T_L \downarrow \ \eta \uparrow \\ T_H \uparrow \ \eta \uparrow \end{cases}$$

1- Decreasing The pressure of the condenser ($\downarrow T_L$)

$P_{cond} = P_{sat}$ at T_L and T_L here is usually not controlled

it is obtained by lake, river or ocean water

2- Superheating the steam to high tempretures ($\uparrow T_H$)

The temprature T_H is also limited to assure that the metals can handle it

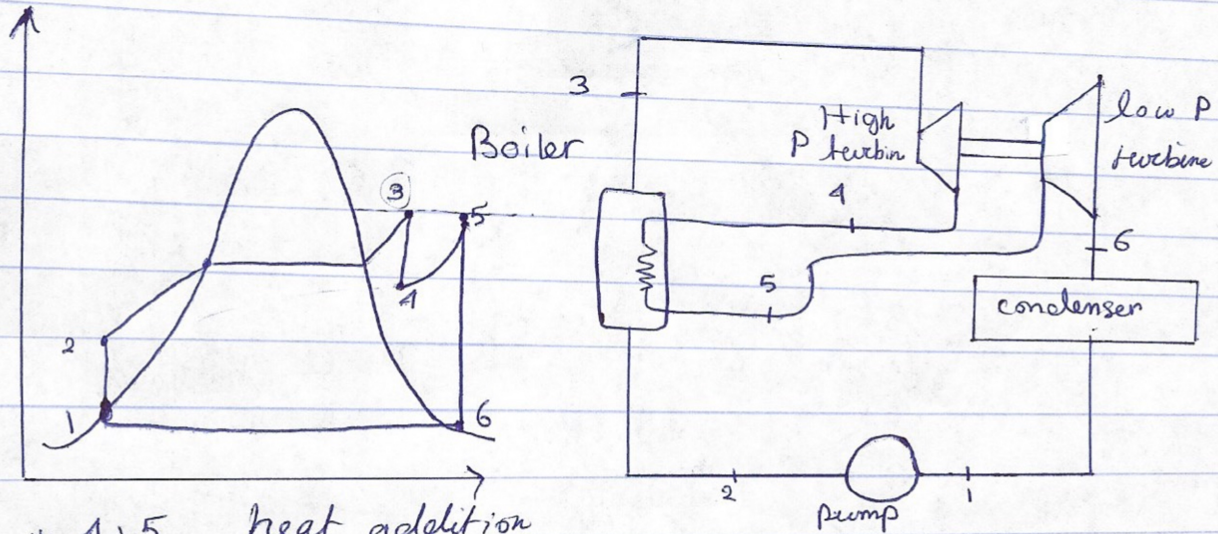
3- Increasing the Boiler temprature ($\uparrow T_H$)

the moisture content of the steam at the turbine exit increases this results in the cavitation of the turbine blades

The ideal re-heat Rankine cycle

The expansion process takes place in two stages

1- high pressure stage
2- low pressure stage



* 4→5 heat addition
at a lower pressure

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

$$W_T = W_{Low\,T} + W_{H\,T} = (h_3 - h_4) + (h_5 - h_6)$$

$\eta \uparrow$ by 1 to 5 percent

Notice that $P_4 = P_5 = P_{reheat}$

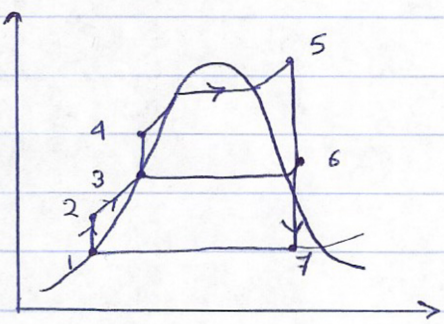
- This cycle will increase the efficiency and yet avoid moisture in the steam in the turbine

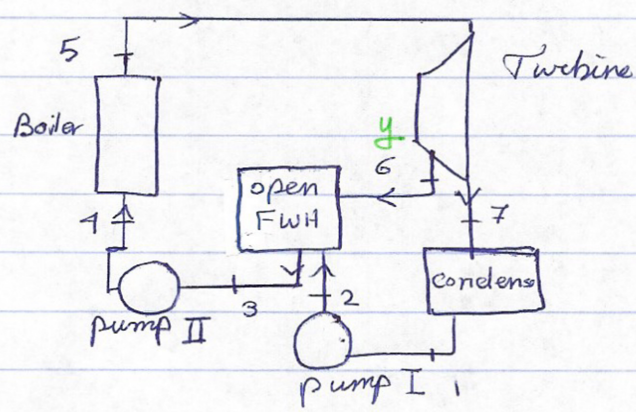
The ideal regenerative rankine cycle

FWH: regenerator or feed water heater

Types of FWH:
1- closed FWH
2- Open FWH = Mixing chamber

1- open FWH (Direct contact)
In an open FWH we mix the steam with water coming out of the pump





$q_H = h_5 - h_4$

$q_L = (1-y)(h_7 - h_1)$

$W_T = (h_5 - h_6) + (1-y)(h_6 - h_7)$

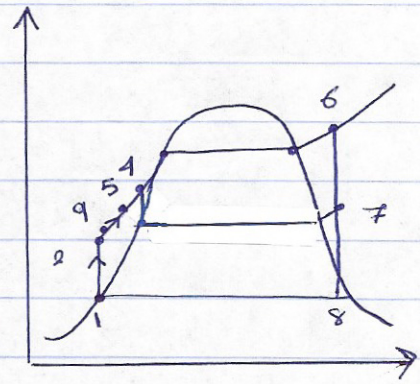
$W_p = (1-y)\, \underbrace{W_{pump_I}}_{(v_1(P_2-P_1))} + \underbrace{W_{pump_{II}}}_{(v_3(P_4-P_3))}$

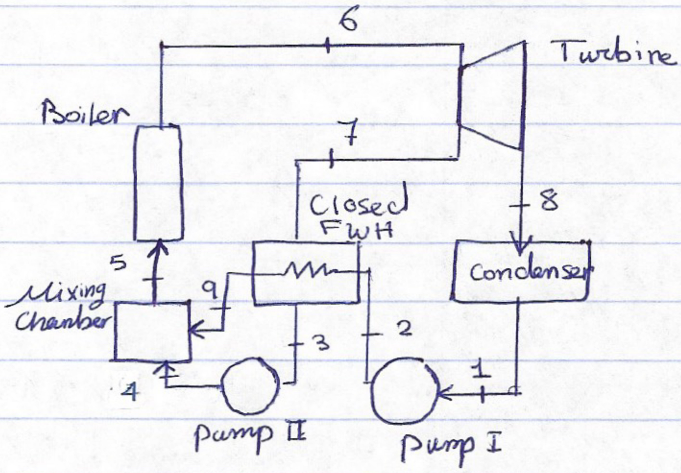
6, 2 have same pressure

$y = \frac{\dot{m}_6}{\dot{m}_5}$ $\quad 0 < y < 0.2$

- water coming out of 2 mixes with steam making a sat liq

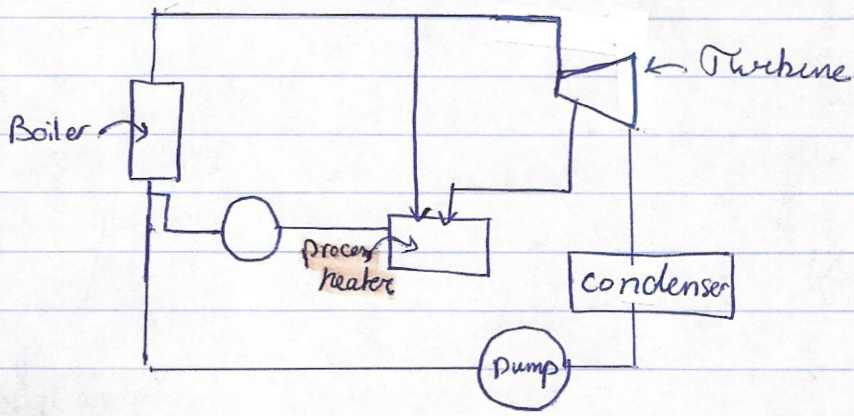
2- Closed FWH
No mixing occurs, so two streams can have diff pressures
$P_{73} \neq P_{29}$ But $P_4 = P_9$


6
4
5
9
7
2
1
8


6
Turbine
Boiler
7
Closed FWH
8
Condenser
5
Mixing Chamber
9
3
2
1
4
Pump II
Pump I

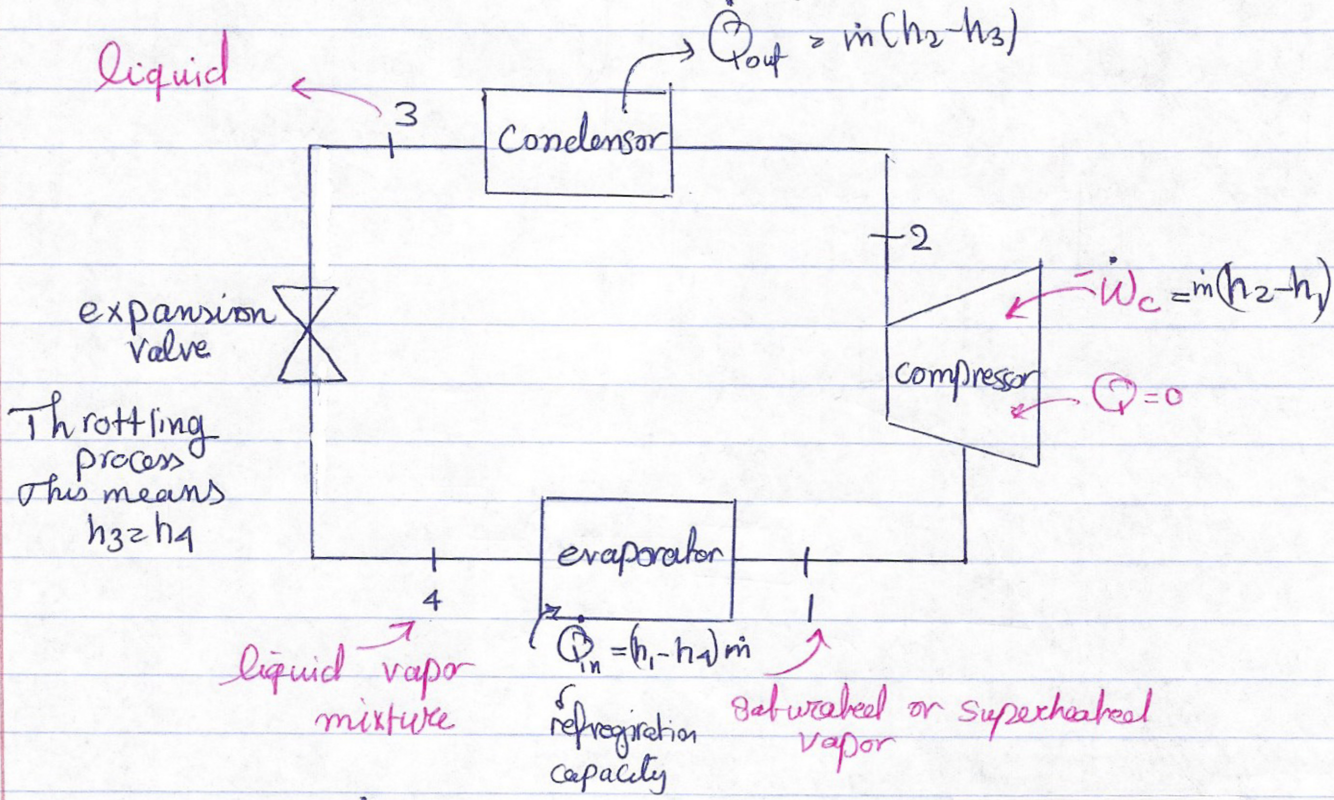
Cogeneration:

- We use the already existing work potential as a process heat
  - ↳ energy input in the form of heat



Combined Gas – Vapor power cycle
- operates at higher temp than steam cycle
- can achieve high thermal efficiencies up to 60%

9.9 vapor-compression Refrigeration cycle



$$\text{CoP}: \beta = \frac{\dot{Q}_{in}}{\dot{W}_c} = \frac{h_1 - h_4}{h_2 - h_1}$$

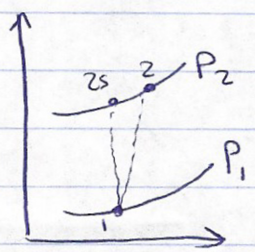
ton of refregeration
$= 211$ KJ/min
(power unit)

$$\beta_{max} = \frac{T_c}{T_H - T_c} \Rightarrow \text{carenot coefficient of preformance}$$

- Actual vapor-compression Cycle

$W_{act} > W_s$ in compresser

- Isentropic efficiency of the compressor $\quad \eta_c = \dfrac{h_{2s} - h_1}{h_2 - h_1}$



The vapor-compression heat pump cycle

coefficient of preformance

$$\gamma = \frac{h_2 - h_3}{h_2 - h_1} = \frac{\dot{Q}_{out}}{\dot{W}_c}$$

Carnet " " "

$$\gamma_{max} = \frac{T_H}{T_H - T_C} \quad T_L$$