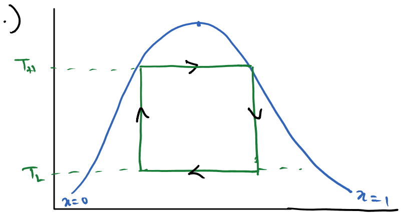
Thursday, December 16, 2021 10:16 AM

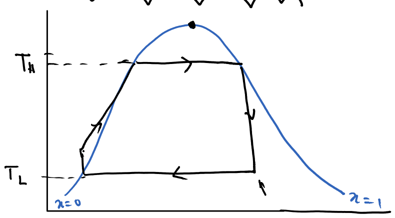
Vapor power cycles

Carnot Cycle

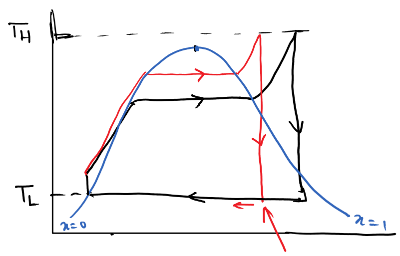
All cycles are Internally Reversible
(No friction, unresisted expansion, Joule heating, etc.)



Rankine Cycle



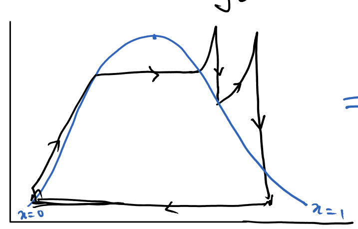
Rankine Cycle with Superheat



Better η_w, SSC
Poorer η, η_{II}

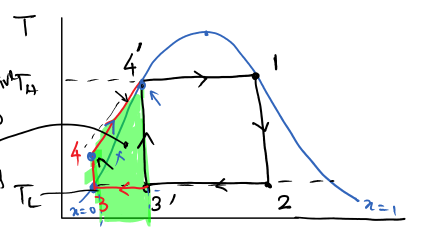
with increasing P_{boiler}, $\eta \uparrow$ but
x @ Turbine ext $\downarrow$
$\Rightarrow$ Turbine blade erosion

Reheat Cycle



$\Rightarrow$ Better specific work output (w_{net})
(lower SSC, $\because$ SSC $= \frac{1}{w_{net}}$)
η may $\uparrow$ or $\downarrow$, depending on $p_{boil.}$
@ $P_{Reheat} \approx 0.25\, p_b$, η is max.

Regenerative Feed Heating

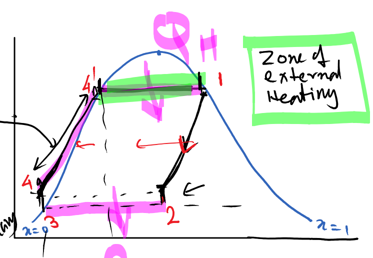


We do regenerative feed heating to minimize the subcooled heating regime, thus improving $\bar{T}_H$

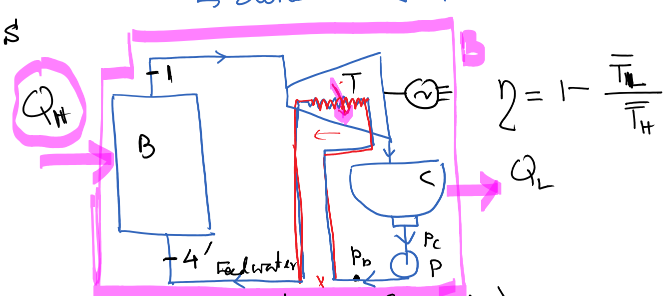
$\eta_R < \eta_C$

$\eta \approx 1 - \frac{\bar{T}_L}{\bar{T}_H}$

Carnot cycle $\bar{T}_H = T_H$
4 – 4' Subcooled liquid heating
↳ done at $< T_H$



Heat is added only from another part of the cycle which is within the System Boundary



$\eta = 1 - \frac{\bar{T}_L}{\bar{T}_H}$

$\dot{Q}_L = \dot{m}(h_{4'} - h_4)$

$\eta = 1 - \frac{\bar{T}_L}{\bar{T}}$

$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}(h_i - h_e)$

$\frac{dS}{dt} = \int \delta\dot{Q}/T_b + \dot{S}_{gen} + \dot{m}(s_i - s_e)$ ←

(if $\dot{Q} = -\dot{Q}_L$)

$Q_L = m(h_{4'} - h_4)$

$\eta = 1 - \frac{\bar{T}_L}{\bar{T}_H}$

$= 1 - T_L / T_H$

$\frac{dS}{dt} = \int \delta Q / T_b + S_{gen} + m(s_i - s_e)$

$\dot{W} = \dot{m}(h_i - h_e) - \dot{Q}_L$ (if $\dot{Q} = -\dot{Q}_L$)

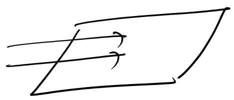
$= \boxed{\dot{m}(h_1 - h_3)} - \boxed{\dot{m}(h_{4'} - h_4)}$

$s_g = s_1 - \int_4^{4'} \frac{\delta Q_L}{T_b}$ $s_2 < s_1$

Regenerative Heating

- → reduces work output
- → reduces heat input
- → improves the $\bar{T}_H \Rightarrow \eta \uparrow$

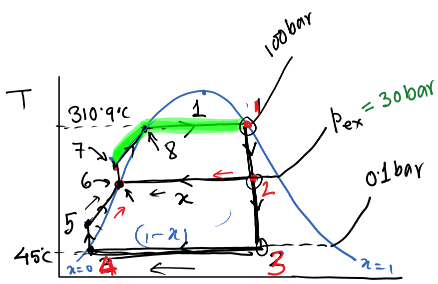
Practical Difficulty of the above schematic:

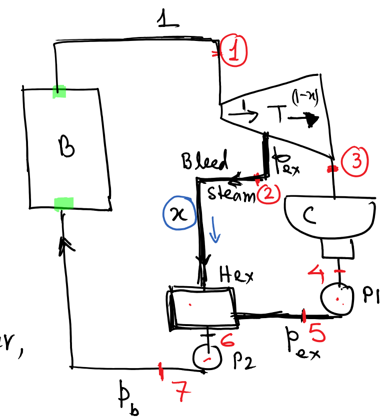


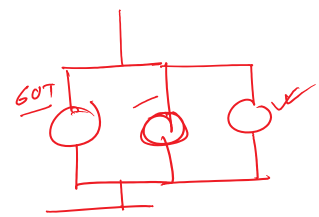
$F = \tau A = \boxed{\mu \frac{du}{dy}} \cdot A$

i) Turbine cannot work well as a heat exchanger

ii) LPT wetness problem







Per kg of steam generated from boiler,

$w_T = (h_1 - h_2) + (1-x)(h_2 - h_3)$

$w_p = (1-x)(h_5 - h_4) + 1\,(h_7 - h_6)$

$\approx v_4 (P_{ex} - P_c)$ $\approx v_6 (P_b - P_{ex})$

For Rankine, R/H & Reg. cycles, the pump work is often neglected.

$q_H = (h_1 - h_7)$

$\eta = \frac{w_T - w_p}{q_H}$

We need to know

$h_1 = 2730$ kJ/kg $h_4 = h_f$ @ 0.1 bar

$h_2 = 2420$ "

$h_3 = 1780$ "

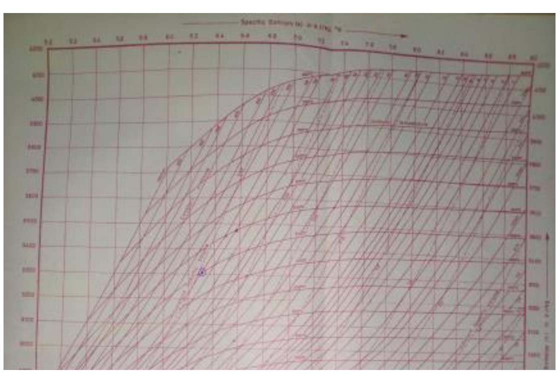
$h_4 = 192$ kJ/kg

$h_5 = h_4 + v_4 (P_{ex} - P_c) = 200$ kJ/kg.

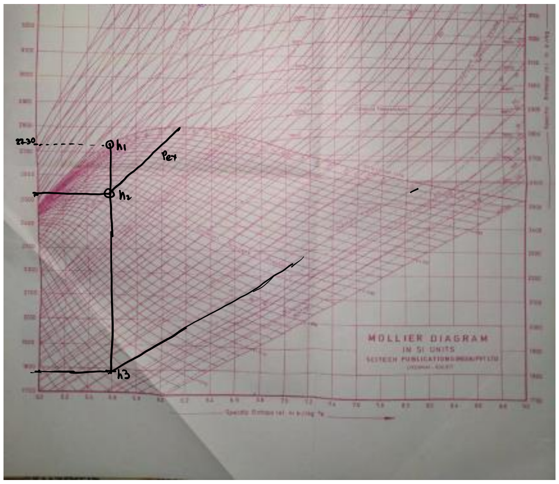
$h_6 = h_f$ at $P_{ex} = 1008.2$ kJ/kg.

$h_7 = h_6 + v_6 \times (P_b - P_{ex}) \approx 1005$ kJ/kg

$x = (h_6 - h_5) / (h_2 - h_5) = (1008.2 - 200) / (2420 - 200) = 0.3640$



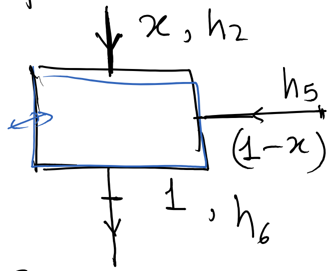
Which ... feedwater heater



$h_7 = h_6 + v_6 \times (P_b - P_{ex}) \approx 1005$ kJ/kg

$x = (h_6 - h_5)/(h_2 - h_5) = (1008.2 - 200)/(2420 - 200) = 0.3640$

1st Law for the feedwater heater



SFEE ⇒

$$\frac{dE}{dt}^{\to 0} = \dot{Q}^{\to 0} - \dot{W}^{\to 0} + \sum \dot{m}_i h_i - \sum \dot{m}_e h_e$$

$$x h_2 + (1-x) h_5 = h_6$$

$$\Rightarrow \quad x = \frac{(h_6 - h_5)}{(h_2 - h_5)} = 0.364$$

$$w_T = (h_1 - h_2) + (1-x)(h_2 - h_3)$$

$$= (2730 - 2420) + (1 - 0.364)(2420 - 1780) = 717 \text{ kJ/kg}$$

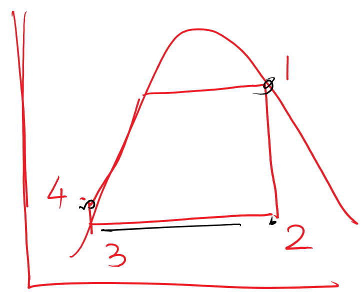
$w_p = 13$ kJ , $w_{net} = 704$ kJ/kg ←

$$q_H = (h_1 - h_7) = (2730 - 1005) = 1725 \text{ kJ/kg}$$

$$\eta = 40.811 \ \%$$

Higher than the corresponding Rankine cycle

What was the corresponding Rankine cycle



$h_1 = 2730$ kJ/kg

$h_2 = 1780$ "

$h_3 = 191$ "

$h_4 = 201$ "

$q_H = 2539$ kJ/kg

$w_T - w_p = 940$ kJ/kg ↑

$$\eta = 1 - \frac{q_L}{q_H} = 1 - \frac{(h_2 - h_3)}{h_1 - h_4} = 1 - \frac{1780 - 191}{2730 - 191}$$

$$\eta = 1 - \frac{q_L}{q_H} = 1 - \frac{\quad}{h_1 - h_4} \qquad 2730 - 191$$

$$= 1 - \frac{1589}{?} = 37.4\ \%$$

500 MW, ⇒ 8760 hrs, 1% $\Delta\eta$,

Coal ⇒ CV = 12000 kJ/kg, Rs = 2/kg.

Calculat the financial impact of 1% $\Delta\eta$ about a base value of 40%

Effects of Regeneration

1) η increases (→ $\overline{T}_H$ ↑, $\overline{T}_L$ remains same)

2) W_{net} decreases, SSC increases

⇒ For the same plant capacity (MW) we need to circulate more steam

⇒ Boiler should be bigger,

3) q_H dereases

4) Condenser heat rejection decreases

In a practical Regenerative cycle