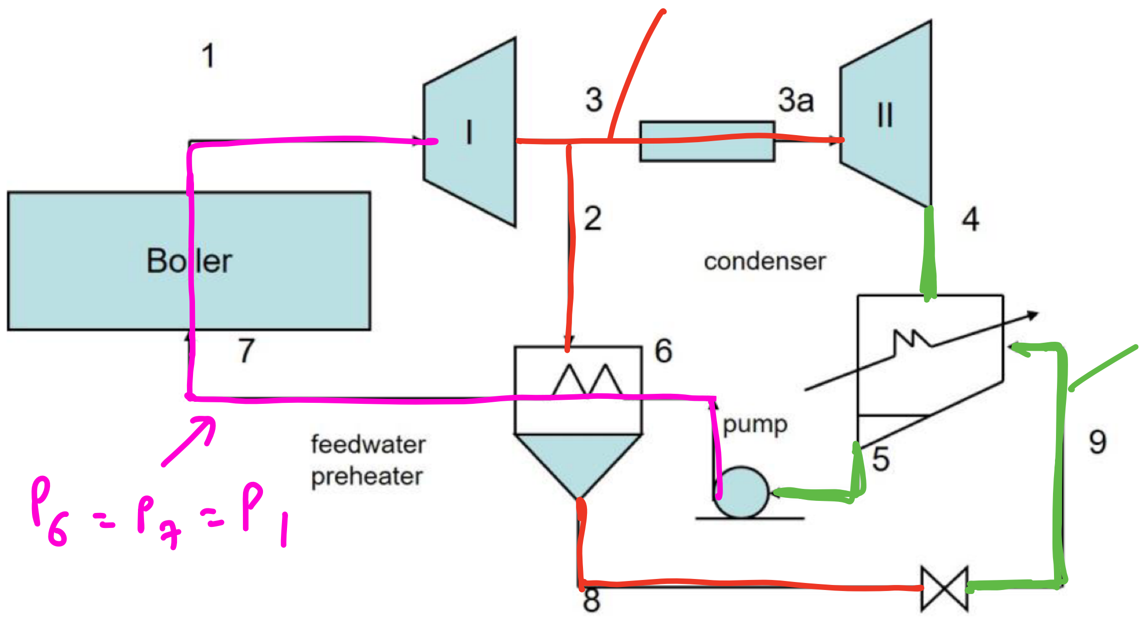
Thermo

Recitation #8 (03/28/23)

Question 5.4 & 5.14

(modified Rankine cycle) (Refrigeration process)

Q5.4



Filling the table with H & S values!!.

Stream	T [°C]	P [Mpa]	H [kJ/kg]	S [kJ/kgK]
1	500	4		
2/3		0.8		
3a	500	0.8		
4		0.01		
5	45.81	0.01		
6		4		
7	T8-5 165.41	4		
8	~~T8~~ 170.41	0.8		

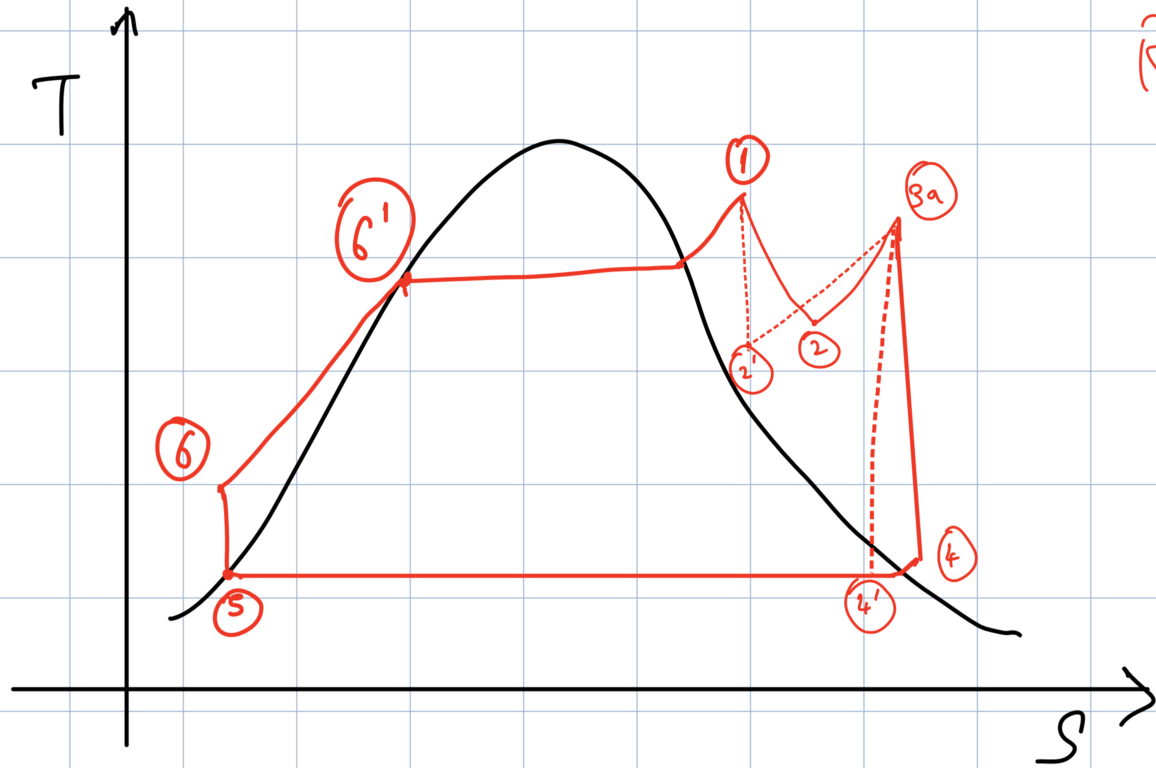
SH (1)
SH ? (2/3)
SH (3a)
? (4)
Sat. liq. (5)
Compressed liq (6, 7)
Sat. liq (8)

$P_1 = P_6 = P_7$

$P_2 = P_3 = P_8$

$P_4 = P_5 = P_9$

$T_7 = T_8 - 5°C$



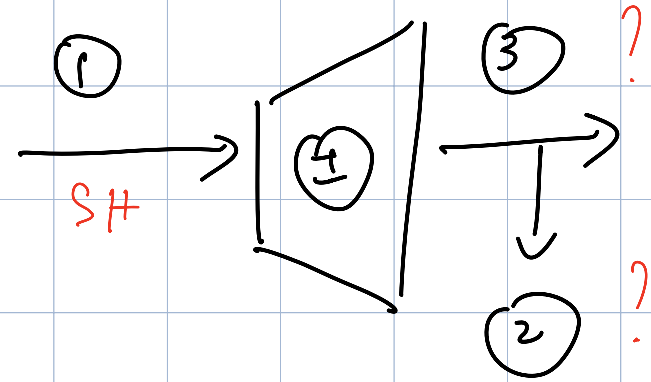
Rankine cycle for two turbine system

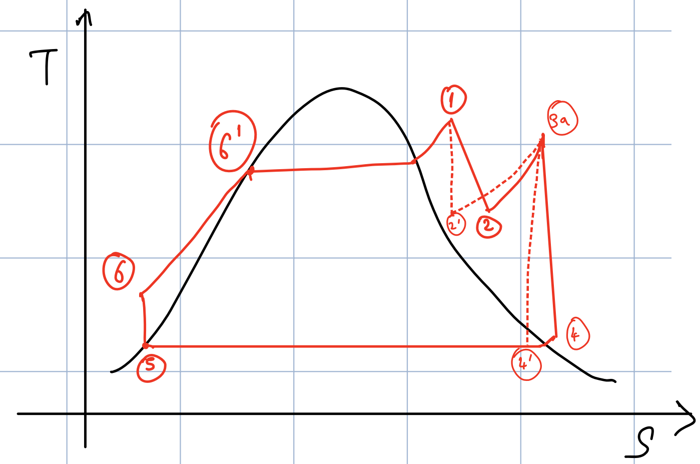
to find $\dot{m}_1$

→ Approach: we use the feedwater preheater energy balance to determine mass flow ratios of the separated streams.

→ Combine these ratios using $\dot{W}_{s,net}$ & Plant capacity.

Turbine 1





Assume ideal $\Rightarrow$ $s_1 = s_2' = 7.092$ kJ/kg K

sat. P table @ P = 0.8 MPa : $s^v = 6.66$ kJ/kg K

$s_2' > s^v$ $\Rightarrow$ S.H

interpolation to get H_2' ($\because s_2 = 7.092$ kJ/kg K)

T	H	S
250	y_1 2950.4	7.0401 x_1
	H_2' y	7.092 x
300	y_2 3056.9	7.2345 x_2

$$y = \frac{y_2 - y_1}{x_2 - x_1}(x - x_2) + y_2$$

$$y = 2978.94 \text{ kJ/kg} = H_2'$$

$$W_s' = \Delta H = H_2' - H_1 = 2978.94 - 3446.0$$

$$W_s' = -467.06 \text{ kJ/kg}$$

$$W_s = W_s' \eta = -467.06 \times 0.85$$

$$W_s = -397.09 \text{ kJ/kg} = \Delta H$$

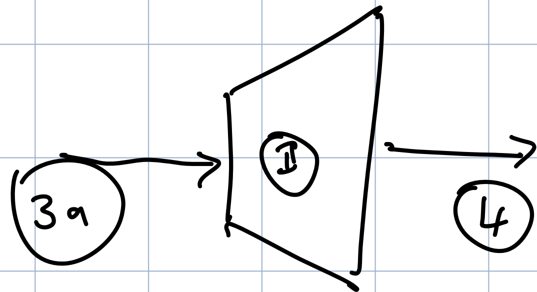
$$H_{2/3} = \Delta H + H_1 = -397.09 + 3446.0$$

$$H_{2/3} = 3049.0 \text{ kJ/kg}$$

similarly, interpolate for S ⇒ $S_{2/3} = 7.2201 \text{ kJ/kg K}$

	Stream	T [C]	P [Mpa]	H [kJ/kg]	S [kJ/kgK]
SH	1	500	4	3446.0	7.0922
	2/3		0.8	3049.0	7.2201
SH	3a	500	0.8	3481.3	7.8692
	4		0.01		
sat. liq	5	45.81	0.01	191.81	0.6492
comp. liq	6		4		
comp. liq	7	165.41	4		
sat. liq	8	170.41	0.8	720.86	2.0457

Turbine II



$S_{3a} = S_4' = 7.8692$ kJ/kgK

$P_{3a} = 0.8$ MPa

$T = 500\ ^\circ C$

$P_4 = 0.1$ MPa

Sat. P @ P_4 :

$S^L = 0.6492$ kJ/kgK

$S^V = 8.1486$ "

$H^L = 191.81$ kJ/kg

$H^V = 2583.86$ "

$\because\ S^L < S_4' < S^V \Rightarrow$ wet steam, at 4

$$q' = \frac{S_4' - S^L}{S^V - S^L} = \frac{7.8692 - 0.6492}{8.1486 - 0.6492} = 0.963$$

(@ 0.01 MPa) $\therefore H_4' = H^L + q(\Delta H^{vap})$

$= 191.81 + 0.963(2392.05)$

$H_4' = 2495.35$ kJ/kg

$W_s' = \Delta H' = 2494.68 - 3481.3 = -986.62$ kJ/kg

$W_s = \eta_{turb.} W_s' = -838.63$ kJ/kg

$\therefore H_4 = \Delta H + H_{3a} = 2642.67$ kJ/kg

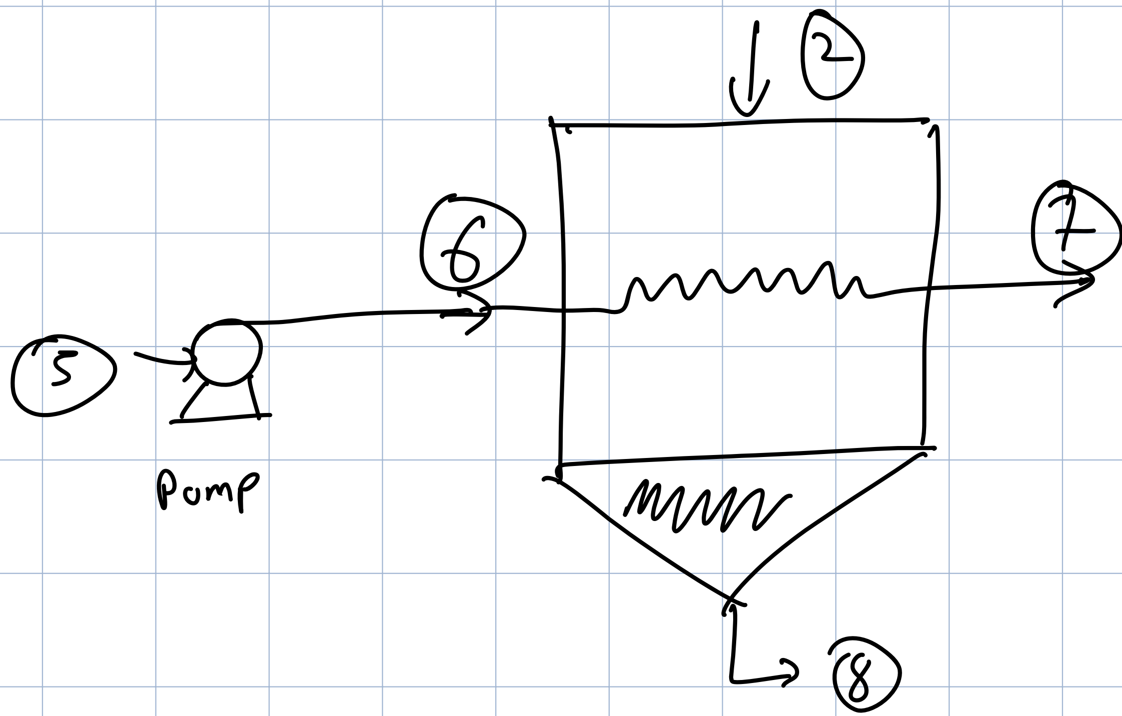
$H_4 > H^V \Rightarrow$ S.H

$\therefore$ S.H @ $P = 0.01$ MPa

interpolate for S $\Rightarrow$ $S_4 = 8.32$ kJ/kgK

Stream	T [C]	P [Mpa]	H [kJ/kg]	S [kJ/kgK]
1	500	4	3446.0	7.0922
2/3		0.8	3049.0	7.2201
3a	500	0.8	3481.3	7.8692
4		0.01	2642.67	8.3200
5		0.01	191.81	0.6492
6		4		
7	165.41	4		
8	170.41	0.8	720.86	2.0457

Feedwater pre heater



$$\Delta H'_{pump} = V_5^L (\Delta P) = 0.00101 \times (4 - 0.01) \times 10^6 \frac{Pa}{1 MPa} \times \frac{1 kJ}{10^3 J}$$

$$\Delta H'_{pump} = 4.0299 \text{ kJ/kg}$$

$$W_s = \frac{W_s'}{\eta_{pump}} = \frac{4.0299}{0.8} = 5.0374 \text{ kJ/kg} = \Delta H_{pump}$$

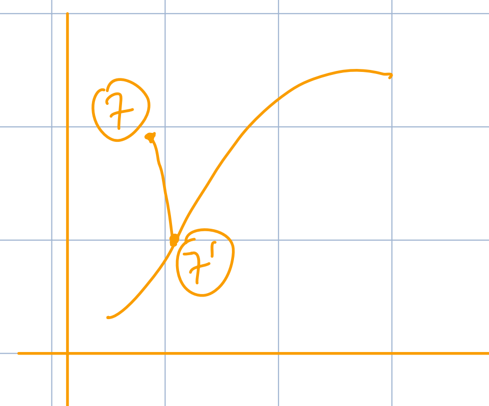
$$\therefore H_6 = \Delta H_{pump} + H_5 = 5.0374 + 191.81$$

$$H_6 = 196.85 \text{ kJ/kg}$$

Approximation: for H_7 → Taking enthalpy change from sat. liq → Compressed liq.

$$H_7 = \underbrace{H_{165}^{L} + V_{165}^{L}}_{\text{from sat. T table}} (\Delta P)$$

sat P @ 165°C = 0.7009



$$H_7 = 697.24 + 0.001108\,(4 - 0.7009) \times 10^3$$

$$H_7 = 700.895 \text{ kJ/kg}$$

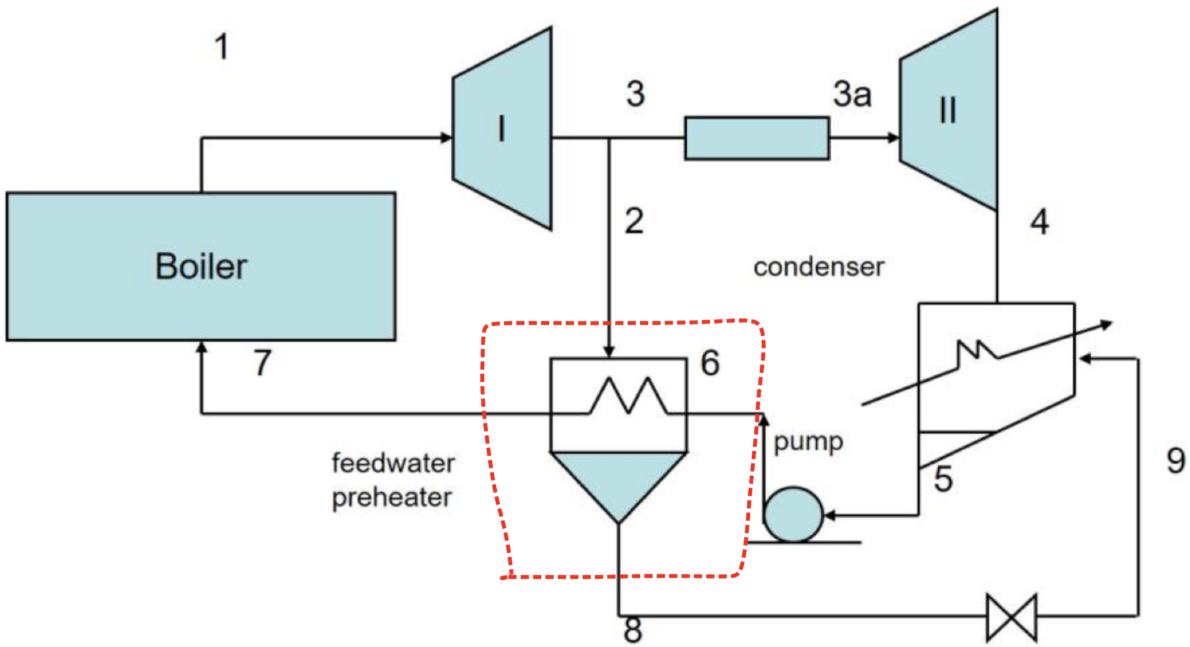
Stream	T [C]	P [Mpa]	H [kJ/kg]	S [kJ/kgK]
1	500	4	3446.0	7.0922
2/3		0.8	3049.0	7.2201
3a	500	0.8	3481.3	7.8692
4		0.01	2642.67	8.3200
5		0.01	191.81	0.6492
6		4	196.85	
7	165.41	4	700.893	
8	170.41	0.8	720.86	2.0457

(a) we have 3 mass flowrates

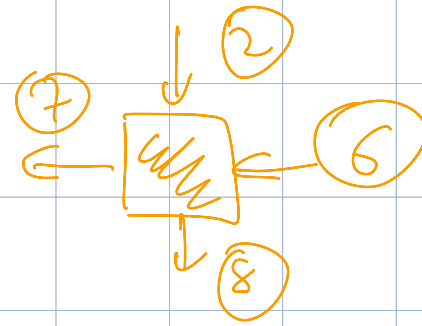
$(\dot{m}_1, \dot{m}_2, \dot{m}_{3a})$ $\rightarrow$ $\dot{m}_6 = \dot{m}_7 = \dot{m}_1$

$\dot{m}_2 = \dot{m}_8$

$\dot{m}_{3a} = \dot{m}_1 - \dot{m}_2$



Energy balance over feedwater preheater.



$$\dot{m}_1 (H_7 - H_6) = -\dot{m}_2 (H_8 - H_2)$$

$$\therefore \quad \frac{\dot{m}_2}{\dot{m}_1} = \frac{H_7 - H_6}{-(H_8 - H_2)} = \frac{700.895 - 196.85}{-(720.86 - 3049.0)} = 0.2165$$

Now, $\because \quad \dfrac{\dot{M}_{3a}}{\dot{m}_1} = \dfrac{\dot{m}_1}{\dot{m}_1} - \dfrac{\dot{m}_2}{\dot{m}_1}$ } mass bal. across Turbine 1

$$\frac{\dot{m}_{3a}}{\dot{m}_1} = \left(1 - \frac{\dot{m}_2}{\dot{m}_1}\right) = 0.7835$$

kW

$$\because \quad \dot{m}_1 = \frac{\text{plant capacity}}{w_{s,net}} = \frac{\text{Plant capacity}}{\underbrace{\dot{w}_{s,net} / \dot{m}_1}}$$

kW / kg stream of $\dot{m}_1$

Now, find $w_{s,net} = \dfrac{\dot{W}_{s,net}}{\dot{m}_1}$

$$\dot{W}_{s,net} = \dot{m}_1 (w_{s,T\,I}) + \dot{m}_{3a} (w_{s,T\,II}) + \dot{m}_1 (w_{s,pump})$$

$$\therefore \frac{w_{s,net}}{\dot{m}_1} = (w_{s,T\,I}) + \frac{\dot{m}_{3a}}{\dot{m}_1} (w_{s,T\,II}) + (w_{s,pump})$$

$$= -397.09 + 0.7835\,(-838.63) + 5.0374$$

$$\frac{\dot{w}_{s,net}}{\dot{m}_1} = -1049.12 \text{ kJ / kg of stream 1}$$

$$\Rightarrow \dot{m}_1 = \frac{\text{Plant Capacity}}{\frac{\dot{W}_{s,net}}{\dot{m}_1}} = \frac{80000}{-1049.12} = 76.25\ kg/s$$

$$\therefore \dot{m}_2 = 0.2165 \times \dot{m}_1 = 16.51\ kg/s$$

$$\therefore \dot{m}_{3a} = \dot{m}_1 - \dot{m}_2 = 59.74\ kg/s$$

b)

$$\boxed{\eta_o = \frac{W_{s,net}}{Q_{H,total}}}$$

$$Q_B = \underbrace{(H_1 - H_7)}_{kJ/kg}\ \underbrace{\dot{m}_1}_{kg/s}$$

$$= (3446 - 700.895)\ 76.25$$

$$Q_B = 209314.25 \text{ kW}$$

$$Q_{RH} = (H_{3a} - H_{2/3})\ \dot{m}_{3a}$$

$$= (3481.3 - 3049) \times 59.74$$

$$Q_{RH} = 25825.602 \text{ kW}$$

$$Q_{H,tot} = Q_B + Q_{RH} = 235139.852 \text{ kW}$$

$$\therefore\ \eta_o = \frac{W_{s,net}}{Q_{H,total}} = \frac{80000}{235139.852} = 0.34$$

c)

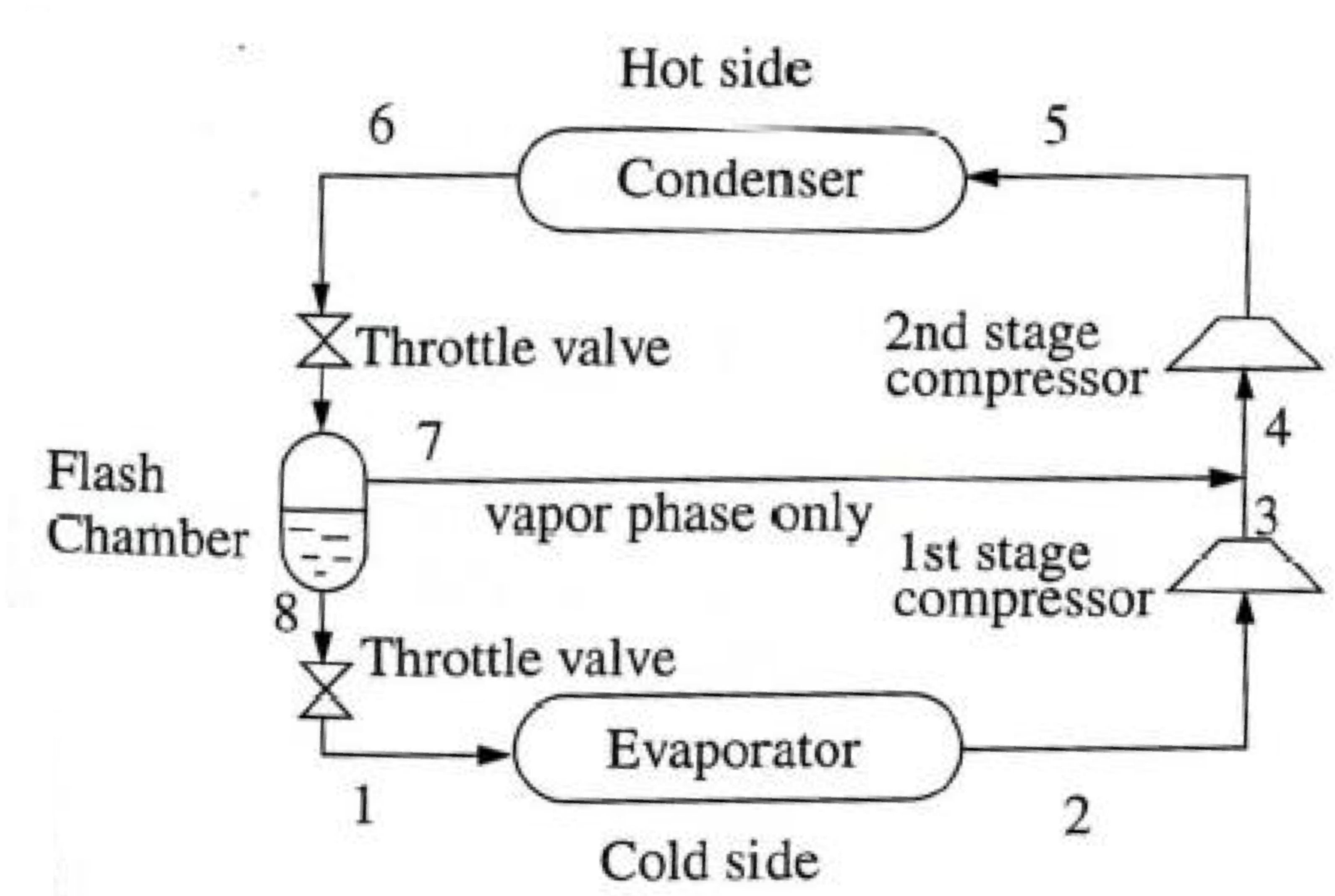
$$\dot{W}_{s,pump} = \underbrace{(H_6 - H_5)}_{\Delta H_{pump}} \dot{m},$$

$$= 5.04 \times 76.25$$

$$= 384.3 \ kJ/s$$

$$\dot{W}_{s,pump} = 384.3 \ kW$$

5.14


Hot side
6
Condenser
5
Throttle valve
2nd stage
compressor
7
4
Flash
Chamber
vapor phase only
3
1st stage
compressor
8
Throttle valve
Evaporator
1
2
Cold side

(1) Saturated fluid ($L+V$), $T_1 = -20°C$

(2) sat. vapour, $T_2 = -20°C$ (given)

(3) compressed fluid, P_3

(4) = (3) + (7), $P_4 = P_3 = P_7 = P_8 = 0.29$ MPa

(5) Compressed fluid, $T_5 = 40°C$

(6) sat. liq, $T_6 = T_5 = 40°C$

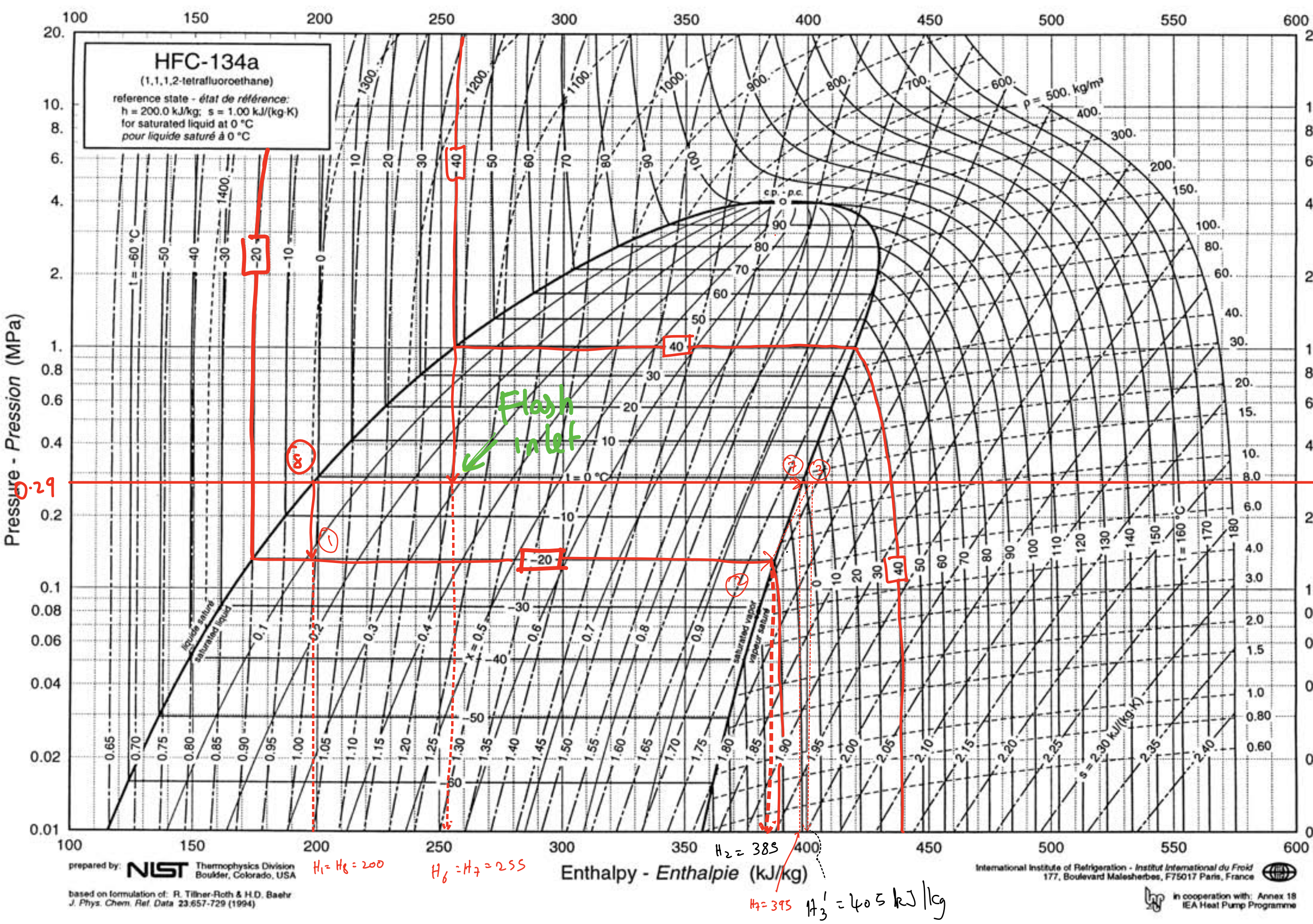
(7) Sat Vapour, $P_7 = P_3 = P_4 = P_8 = 0.29$ MPa

(8) sat liquid, $P_8 = 0.29$ MPa

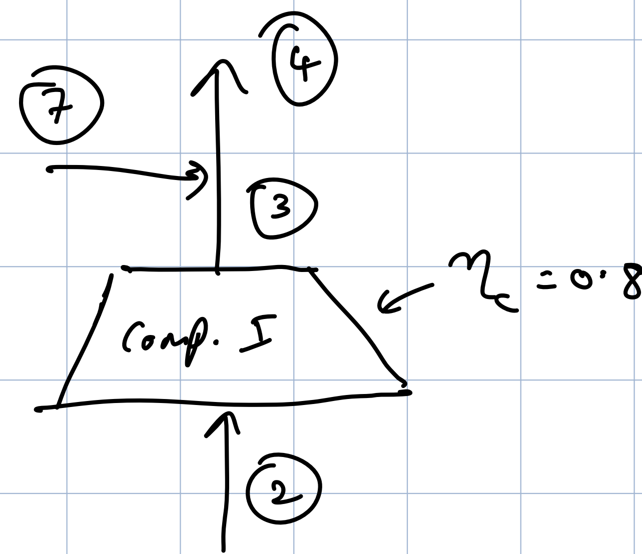
$H_8 = H_1$, $\dot{m}_1 = 23$ kg/hr

E.12 PRESSURE-ENTHALPY DIAGRAM FOR R134A (1,1,1,2-TETRAFLOUROETHANE)

(Source: NIST, Thermophysics Division, Boulder, CO, USA, used with permission.)



(a) $\dot{W}_{s, \text{compressor I}} = ?$ [kJ/hr]



Assume ideal operation initially.

$S_3' = S_2 = 1.725 \text{ kJ/kg K}$

$H_2 = 385 \text{ kJ/kg}$

Using isentropic line → $P_3 = 0.29$ MPa

$H_3' = 405$ kJ/kg ← From graph.

$W_s' = \Delta H' = H_3' - H_2 = 405 - 385$

$W_s' = 20$ kJ/kg

$$W_s = \frac{W_s'}{\eta_c} = \frac{\Delta H'}{\eta_c} = \frac{20}{0.8} = 25 \ kJ/kg = \Delta H$$

$$\dot{W}_s = W_s \cdot \dot{m}_1 = 25 \ \frac{kJ}{kg} \times 23 \ \frac{kg}{hr} = 575 \ \frac{kJ}{hr}$$

$$H_3 = \Delta H + H_2 = 25 + 385 = 410 \ kJ/kg$$

(b)

$\dot{m}_7 = ?$

$\dot{m}_6 = ?$

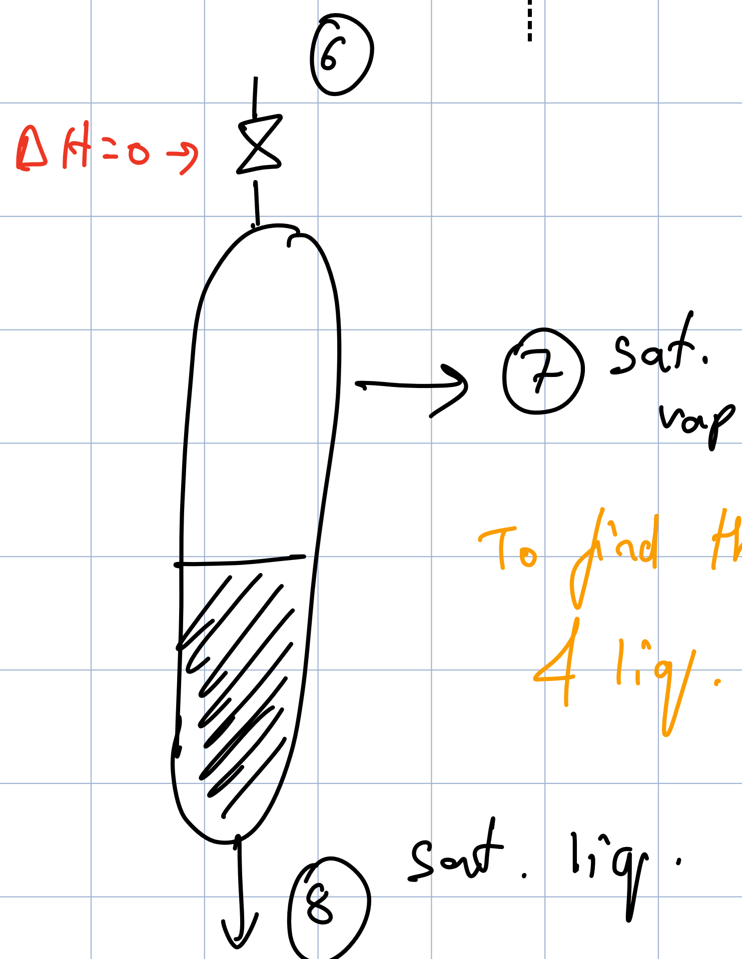
$\dot{m}_8 = \dot{m}_1 = 23$ kg/hr

$\dot{m}_6 = \dot{m}_7 + \dot{m}_8$

$H_6 = 255$ kJ/kg

$H_7 = H^{v}_{0.29} = 395$ "

$H_8 = H^{l}_{0.29} = 200$ kJ/kg



To find the quantity of vapour 7 & liq. 8 we need to find q.

$$q_{(inlet)} = \frac{H_6 - H_8}{H_7 - H_8} = 0.282 \Rightarrow \begin{array}{l} 28\% \text{ vap.} \\ 72\% \text{ liq.} \end{array}$$

$$\therefore \dot{m}_8 = 0.72 \times \dot{m}_6$$

$$\dot{m}_7 = 0.28 \times \dot{m}_6$$

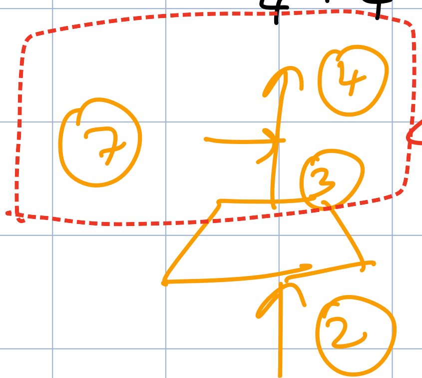
$$\therefore \dot{m}_6 = \frac{\dot{m}_8}{0.72} = \frac{23}{0.72} = 31.94 \text{ kg/hr.}$$

$$\dot{m}_7 = \dot{m}_6 - \dot{m}_8 = 31.94 - 23 = 8.94 \text{ kg/hr.}$$

(c) $④ = ③ + ⑦$

$$H_4 = H_3 + H_7$$

$$\dot{m}_4 H_4 = \dot{m}_3 H_3 + \dot{m}_7 H_7$$



mass balance here.

$\dot{m}_4 = \dot{m}_6 = 31.94$ kg/hr.

$\dot{m}_3 = \dot{m}_1 = 23$ kg/hr

$\dot{m}_7 = 8.94$ kg/hr

$H_3 = 410$ kJ/kg

$H_7 = 395$ kJ/kg.

$$H_4 = \frac{\dot{m}_3 H_3 + \dot{m}_7 H_2}{\dot{m}_4}$$

$$H_4 = \frac{23 \times 410 + 8.94 \times 395}{31.94} = 405.8 \text{ kJ/kg.}$$