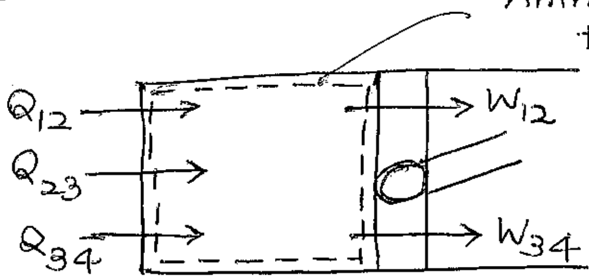
Given Ammonia inside a closed piston-cylinder device undergoing three processes

Find
(a) Entropy generation $\left(\frac{kJ}{K}\right)$ for each process
(b) T-s diagram

System

Ammonia substance inside the cylinder is the system



Assumptions
- Closed system (m = constant)
- Quasi-equilibrium process
- Neglect friction between piston and cylinder wall
- Ignore change in KE and PE

Basic Equations

$$W_{boundary} = \int P\,dV$$

$$Q - W = \Delta E = \Delta U + \cancel{\Delta KE}^{\,no} + \cancel{\Delta PE}^{\,no}$$

$$W \hookrightarrow (W_{boundary} + \cancel{W_{other}}^{\,0})$$

$$\frac{Q}{T_{boundary}} + \sigma_{generation} = \Delta S$$

Solution

See HW-10

$Q_{12} = +7262$ kJ

$Q_{23} = +3276$ kJ

$Q_{34} = +1148.9$ kJ

State 1 $P_1 = 20$ bar, $T_1 = 40°C$

$T_1 < T_{sat}(P_1) \Rightarrow$ sub-cooled (compressed) liquid

$$s_1 = 1.3556\ \frac{kJ}{kg\sim K}$$

State 2: $P_2 = 20\ \text{bar},\ v_2 = 0.042174\ \frac{m^3}{kg}$

$v_f(P_2) < v_2 < v_g(P_2) \Rightarrow$ saturated liquid-vapor mixture

$$x_2 = 0.645 = \frac{s_2 - s_f(P_2)}{s_g(P_2) - s_f(P_2)} = \frac{s_2 - 1.5023}{4.7697 - 1.5023}$$

$$s_2 = 3.6098\ \frac{kJ}{kg-K}$$

State 3: $v_3 = v_2 = 0.042174\ \frac{m^3}{kg}$, sat. vapor

$P_3 = 30\ \text{bar}$

$$s_3 = s_g(P_3) = 4.5996\ \frac{kJ}{kg-K}$$

State 4: $P_4 = 20\ \text{bar},\ T_4 = 65.725^\circ C$

$T_4 > T_{sat}(P_4) \Rightarrow$ superheated vapor

Interpolating: $$\frac{s_4 - 4.8861}{5.0709 - 4.8861} = \frac{65.725 - 60}{80 - 60}$$

$$s_4 = 4.9390\ \frac{kJ}{kg-K}$$

(a) Considering entropy balance, entropy generation during the process: $\sigma_{generation} = \Delta S - \frac{Q}{T_{boundary}}$

$$\sigma_{12} = (S_2 - S_1) - \frac{Q_{12}}{T_{boundary}}$$

$$= (m_1 = m_2)(s_2 - s_1) - \frac{Q_{12}}{T_{boundary}}$$

$$= 10\ kg * (3.6098 - 1.3556)\frac{kJ}{kg-K} - \frac{7262\ kJ}{(100+273.15)\ K}$$

$$\boxed{\sigma_{12} = +3.0807\ \frac{kJ}{K}}$$

$\sigma_{generation} > 0$ ✓

$$\sigma_{23} = (S_3 - S_2) - \frac{Q_{23}}{T_{boundary}}$$

$$= (m_2 = m_3)(s_3 - s_2) - \frac{Q_{23}}{T_{boundary}}$$

$$= 10\,kg * (4.5996 - 3.6098)\frac{kJ}{kg-K} - \frac{3276\ kJ}{(100+273.15)\,K}$$

$$\boxed{\sigma_{23} = +1.1187\ \frac{kJ}{K}}$$ $\sigma_{generation} > 0$ ✓

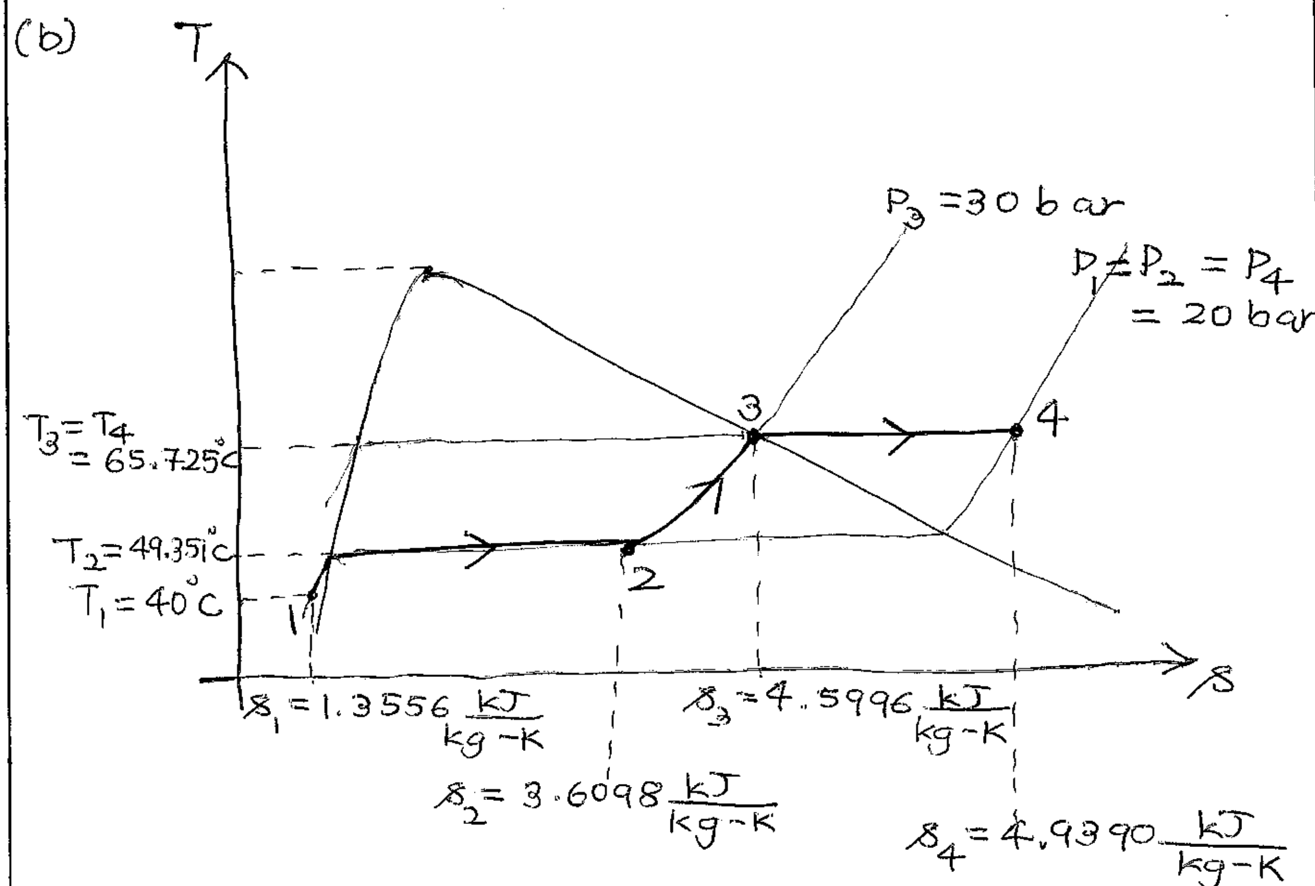
$$\sigma_{34} = (S_4 - S_3) - \frac{Q_{34}}{T_{boundary}}$$

$$= (m_3 = m_4)(s_4 - s_3) - \frac{Q_{34}}{T_{boundary}}$$

$$= 10\,kg * (4.9390 - 4.5996) - \frac{1148.9\ kJ}{(100+273.15)\,K}$$

$$\boxed{\sigma_{34} = +0.31508\ \frac{kJ}{K}}$$ $\sigma_{generation} > 0$ ✓

(b)



Given

Air inside a closed, rigid tank

Find

(a) Entropy generation $\left(\frac{kJ}{K}\right)$ during the process

(b) T-s diagram

System

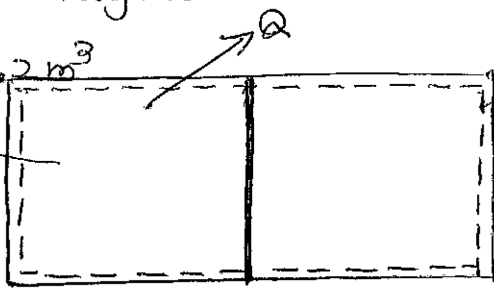
$P_1 = 5$ bar, $V_1 = 0.2\ m^3$

$T_1 = 500$ K

$\downarrow$

$P_2 = 1.25$ bar

$V_2 = 0.4\ m^3$



Air inside the tank is the system

Assumptions

- Closed system (m = constant)
- Rigid tank: $W_{boundary} = 0$
- Ignore change in KE and PE
- Air behaves as an ideal gas
- Specific heat constant with temperature change

Basic Equations

$$Q - \cancel{W}^{0} = \Delta E = \Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0}$$

$$\hookrightarrow (\cancel{W_{boundary}}^{0} + \cancel{W_{other}}^{0})$$

$$\frac{Q}{T_{boundary}} + \sigma_{generation} = \Delta S$$

Solution

See HW-12(i)

$m_1 = m_2 = 0.697$ kg

$P_1 = 5$ bar, $T_1 = 500$ K

$P_2 = 1.25$ bar, $T_2 \cong 250$ K

$Q = -127.2$ kJ

(a) Considering entropy balance, entropy generation during the process: $\sigma_{generation} = \Delta S - \dfrac{Q}{T_{boundary}}$

$$\sigma_{generation} = (S_2 - S_1) - \frac{Q}{T_{boundary}}$$

$$= (m_1 = m_2)(s_2 - s_1) - \frac{Q}{T_{boundary}}$$

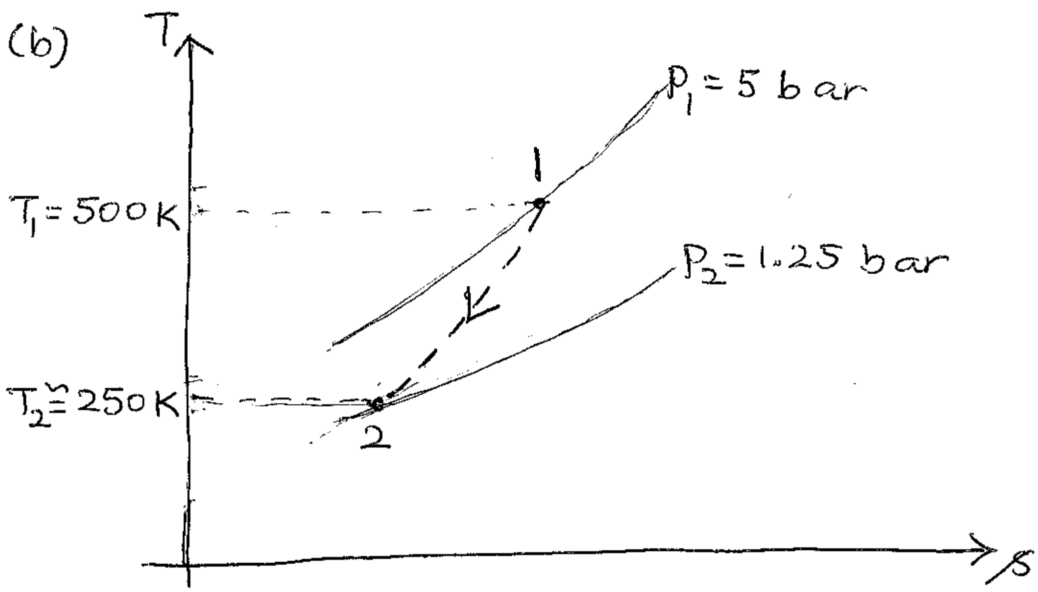
$$= (m_1 = m_2)\left(C_{P_{air}} \ln \frac{T_2}{T_1} - R_{air} \ln \frac{P_2}{P_1}\right) - \frac{Q}{T_{boundary}}$$

$$= 0.697\,kg * \left(1.017 \frac{kJ}{kg-K} \ln \frac{250\,K}{500\,K} - 0.287 \frac{kJ}{kg-K} \ln \frac{1.25\,bar}{5\,bar}\right)$$

$$- \frac{-127.2\,kJ}{300\,K}$$

$$\boxed{\sigma_{generation} = +0.20998\,\frac{kJ}{K}} \qquad \sigma_{generation} > 0 \checkmark$$

(b)



Given

Condenser in a thermal power plant

Find

Rate of entropy generation $\left(\frac{kW}{K}\right)$

System

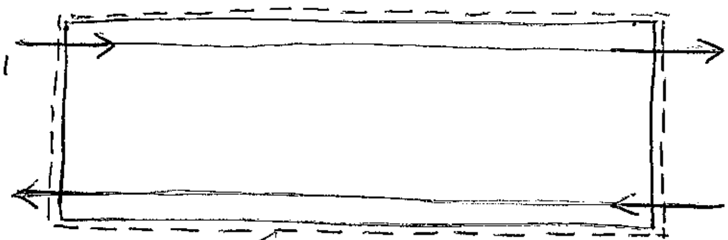
$\dot{m}_{steam} = 3.4\times10^5 \frac{kg}{hr}$

$P_1 = 0.08$ bar
$x_1 = 0.932$ $\quad \dot{m}_1$

$P_2 = 0.08$ bar
$\dot{m}_2$ sat. liquid

$P_4 = 1$ bar $\quad \dot{m}_4$
$T_4 = 35°C$

$\dot{m}_3 \quad P_3 = 1$ bar
$T_3 = 15°C$



Flow of steam and cooling water through the condenser is the system

Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Ignore change in KE and PE
- Insulated (overall) : $\dot{Q} = 0$
- Passive : $\dot{W} = 0$

Basic Equations

$$\cancel{\left.\frac{dm}{dt}\right|_{system}}^{0} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\cancel{\left.\frac{dE}{dt}\right|_{system}}^{0} = \sum_{in} \dot{m}_{in}(h+\cancel{ke}+\cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h+\cancel{ke}+\cancel{pe})_{out} + \cancel{\dot{Q}} - \cancel{\dot{W}}$$

$$\cancel{\left.\frac{dS}{dt}\right|_{system}}^{0} = \sum_{in} \dot{m}_{in} s_{in} - \sum_{out} \dot{m}_{out} s_{out} + \cancel{\sum_j \frac{\dot{Q}_j}{T_{j,boundary}}} + \dot{\sigma}_{generation}$$

Solution

See HW-16 (ii)

$$\dot{m}_{\substack{cooling\\water}} = 9.1\times10^6 \frac{kg}{hr}$$

Mass balance: $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}_{steam}$

$0 = \dot{m}_3 - \dot{m}_4 \Rightarrow \dot{m}_3 = \dot{m}_4 = \dot{m}_{\substack{cooling\\water}}$

Entropy balance: $0 = (\dot{m}_1 s_1 + \dot{m}_3 s_3) - (\dot{m}_2 s_2 + \dot{m}_4 s_4) + 0 + \dot{\sigma}_{generation}$

Rate of entropy generation for the condenser:

$$\dot{\sigma}_{generation} = \dot{m}_{steam}(s_2 - s_1) + \dot{m}_{cooling\ water}(s_4 - s_3)$$

State 1 $P_1 = 0.08$ bar, $x_1 = 0.932$

$$s_1 = s_f(P_1) + x_1(s_g(P_1) - s_f(P_1))$$
$$= 0.59249 \frac{kJ}{kg\text{-}K} + 0.932 * (8.2273 - 0.59249) \frac{kJ}{kg\text{-}K}$$
$$= 7.7081 \frac{kJ}{kg\text{-}K}$$

State 2 $P_2 = 0.08$ bar, sat. liquid

$$s_2 = s_f(P_2) = 0.59249 \frac{kJ}{kg\text{-}K}$$

State 3 $P_3 = 1$ bar, $T_3 = 15°C$

$T_3 < T_{sat}(P_3) \Rightarrow$ compressed (sub-cooled) liquid

$$s_3 \simeq s_f(T_3) = 0.22446 \frac{kJ}{kg\text{-}K}$$

State 4 $P_4 = 1$ bar, $T_4 = 35°C$

$T_4 < T_{sat}(P_4) \Rightarrow$ compressed (sub-cooled) liquid

$$s_4 \simeq s_f(T_4) = 0.50513 \frac{kJ}{kg\text{-}K}$$

$$\dot{\sigma}_{generation} = 3.4 \times 10^5 \frac{kg}{hr} * (0.59249 - 7.7081) \frac{kJ}{kg\text{-}K} + 9.1 \times 10^6 \frac{kg}{hr} * (0.50513 - 0.22446) \frac{kJ}{kg\text{-}K}$$

$$= 1.348 \times 10^5 \frac{kJ/hr}{K}$$

$$\boxed{\dot{\sigma}_{generation} = +37.4 \frac{kW}{K}}$$

$\dot{\sigma}_{generation} > 0$ ✓

Given

A power cycle operating at steady state

Find

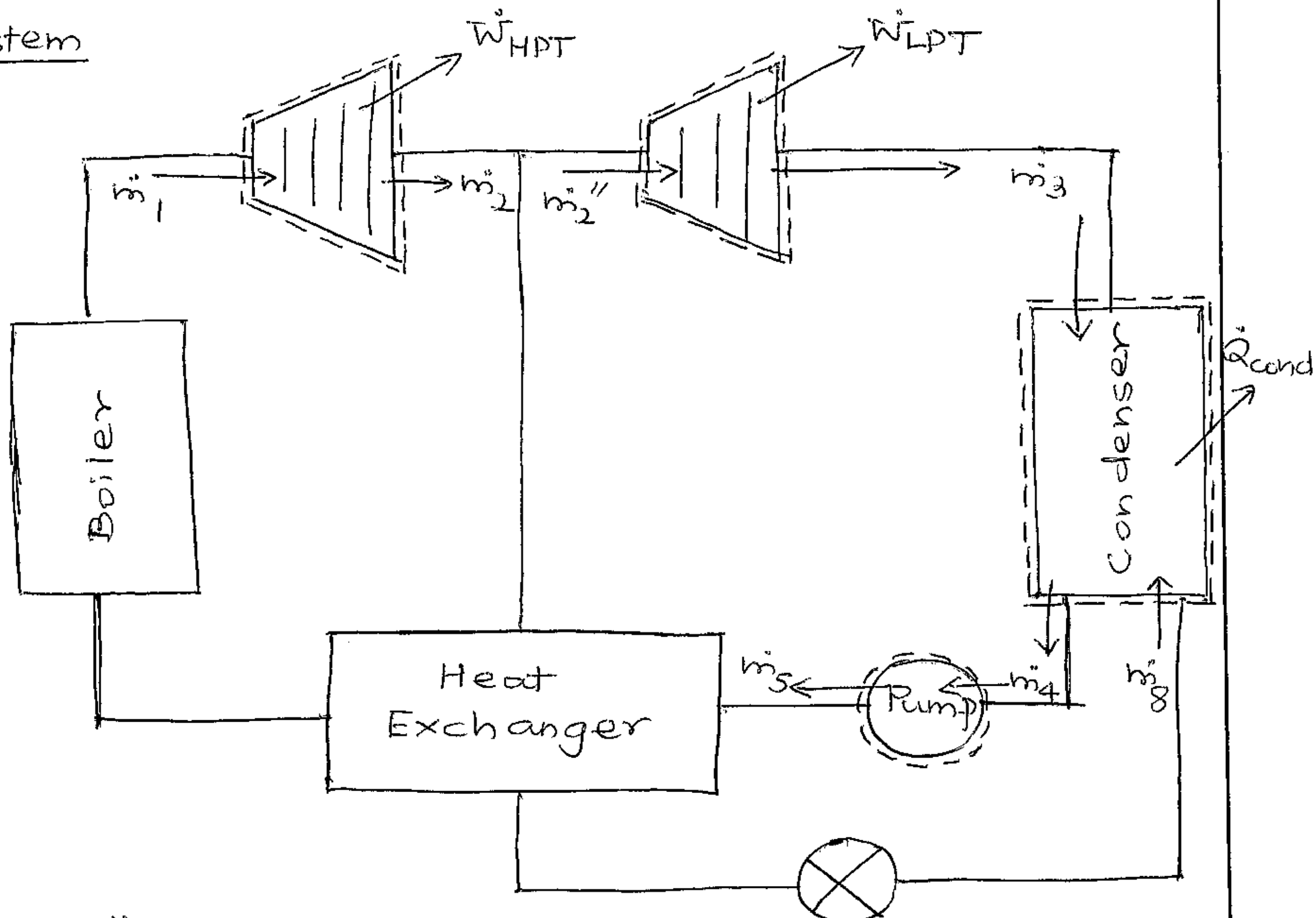
(a) Specific entropy generation $\left(\frac{kJ}{kg-K}\right)$ for HPT and LPT

(b) Specific entropy generation $\left(\frac{kJ}{kg-K}\right)$ for pump

(c) Specific entropy generation $\left(\frac{kJ}{kg-K}\right)$ for condenser

(d) T-s diagram

System



Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Ignore change in KE and PE
- Condenser : $\dot{W} = 0$
- Turbines and pump : $\dot{Q} = 0$

Flow of water/steam through various components is the system

Basic Equations

$$\cancel{\left.\frac{dm}{dt}\right|_{system}}^{\,0} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\cancel{\left.\frac{dE}{dt}\right|_{system}}^{\,0} = \sum_{in} \dot{m}_{in}(h+\cancel{ke}+\cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h+\cancel{ke}+\cancel{pe})_{out} + \dot{Q} - \dot{W}$$

$$\cancel{\left.\frac{ds}{dt}\right|_{system}}^{\,0} = \sum_{in} \dot{m}_{in} s_{in} - \sum_{out} \dot{m}_{out} s_{out} + \cancel{\sum_j \frac{\dot{Q}_j}{T_{j,boundary}}} + \dot{\sigma}_{generation}$$

Solution

See HW-17

$y = 0.265$

$q_{condenser} = -1600.1 \ \frac{kJ}{kg}$

State 1 $P_1 = 100$ bar, $T_1 = 480°C$

$T_1 > T_{sat}(P_1) \Rightarrow$ superheated vapor

$s_1 = 6.5311 \ \frac{kJ}{kg-K}$

State 2 $P_2 = 7$ bar, $x_2 = 0.985$

$$s_2 = s_f(P_2) + x_2(s_g(P_2) - s_f(P_2))$$
$$= 1.9918 \ \frac{kJ}{kg-K} + 0.985 * (6.7071 - 1.9918) \frac{kJ}{kg-K}$$
$$= 6.6364 \ \frac{kJ}{kg-K}$$

State 3 $P_3 = 0.06$ bar, $x_3 = 0.82$

$$s_3 = s_f(P_3) + x_3(s_g(P_3) - s_f(P_3))$$
$$= 0.52082 \ \frac{kJ}{kg-K} + 0.82 * (8.3290 - 0.52082) \frac{kJ}{kg-K}$$
$$= 6.9235 \ \frac{kJ}{kg-K}$$

State 4 $P_4 = 0.06$ bar, sat. liquid

$$s_4 = s_f(P_4) = 0.52082 \ \frac{kJ}{kg-K}$$

State 5 $P_5 = 100$ bar, $T_5 = 36.8°C$

$T_5 < T_{sat}(P_5) \Rightarrow$ sub-cooled (compressed) liquid

Interpolating: $s_5 = 0.52464 \ \frac{kJ}{kg-K}$

State 8 $P_8 = 0.06$ bar, $h_8 = h_7 = 697.00 \ \frac{kJ}{kg}$
(Throttling)

$h_f(P_8) < h_8 < h_g(P_8) \Rightarrow$ saturated liquid-vapor mixture

$$x_8 = \frac{h_8 - h_f(P_8)}{h_g(P_8) - h_f(P_8)} = \frac{697.00 - 151.48}{2566.6 - 151.48} = 0.226$$

$$x_8 = \frac{s_8 - s_f(P_8)}{s_g(P_8) - s_f(P_8)} \Rightarrow 0.226 = \frac{s_8 - 0.52082}{8.3290 - 0.52082}$$

$$s_8 = 2.2855 \frac{kJ}{kg-K}$$

State 6 $P_6 = 100$ bar, $T_6 = 164.95°C$

$T_6 < T_{sat}(P_6) \Rightarrow$ sub-cooled (compressed) liquid

Interpolating: $s_6 = 1.9774 \frac{kJ}{kg-K}$

State 7 $P_7 = 7$ bar, sat. liquid

$$s_7 = s_f(P_7) = 1.9918 \frac{kJ}{kg-K}$$

(a) HPT

Mass balance: $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}$

Entropy balance: $0 = \dot{m}_1 s_1 - \dot{m}_2 s_2 + 0 + \dot{\sigma}_{\underset{HPT}{generation}}$

$$\dot{\sigma}_{\underset{HPT}{generation}} = \dot{m}(s_2 - s_1)$$

Specific entropy generation for HPT:

$$\sigma_{\underset{HPT}{generation}} = \frac{\dot{\sigma}_{\underset{HPT}{generation}}}{\dot{m}} = s_2 - s_1$$

$$\boxed{\sigma_{\underset{HPT}{generation}} = +0.1053 \frac{kJ}{kg-K}} \qquad \sigma_{generation} > 0 \ \checkmark$$

LPT

Mass balance: $0 = \dot{m}_2'' - \dot{m}_3 \Rightarrow \dot{m}_2'' = \dot{m}_3 = (1-y)\dot{m}$

Entropy balance: $0 = \dot{m}_2'' s_2 - \dot{m}_3 s_3 + 0 + \dot{\sigma}_{\underset{LPT}{generation}}$

$$\dot{\sigma}_{\underset{LPT}{generation}} = \dot{m}(1-y)(s_3 - s_2)$$

Specific entropy generation for LPT:

$$\sigma_{\underset{LPT}{generation}} = \frac{\dot{\sigma}_{\underset{LPT}{generation}}}{\dot{m}} = (1-y)(s_3 - s_2)$$

$$\boxed{\sigma_{\substack{generation\\LPT}} = +0.2110 \frac{kJ}{kg-K}} \qquad \sigma_{generation} > 0 \checkmark$$

(b) Pump

Mass balance : $0 = \dot{m}_4 - \dot{m}_5 \Rightarrow \dot{m}_4 = \dot{m}_5 = \dot{m}$

Entropy balance : $0 = \dot{m}_4 s_4 - \dot{m}_5 s_5 + 0 + \dot{\sigma}_{\substack{generation\\pump}}$

Specific entropy generation for pump :

$$\sigma_{\substack{generation\\pump}} = \frac{\dot{\sigma}_{\substack{generation\\pump}}}{\dot{m}} = s_5 - s_4$$

$$\boxed{\sigma_{\substack{generation\\pump}} = +0.00382 \frac{kJ}{kg-K}} \qquad \sigma_{generation} > 0 \checkmark$$

(c) Condenser

Mass balance : $0 = (\dot{m}_3 + \dot{m}_8) - \dot{m}_4$

$\dot{m}_3 = (1-y)\dot{m}$, $\dot{m}_8 = y\dot{m}$, $\dot{m}_4 = \dot{m}$

Entropy balance : $0 = (\dot{m}_3 s_3 + \dot{m}_8 s_8) - \dot{m}_4 s_4 + \cancel{\frac{\dot{Q}_{condenser}}{}}\ \cancel{0} + \dot{\sigma}_{\substack{generation\\condenser}} + \frac{\dot{Q}_{condenser}}{T_{condenser}}$

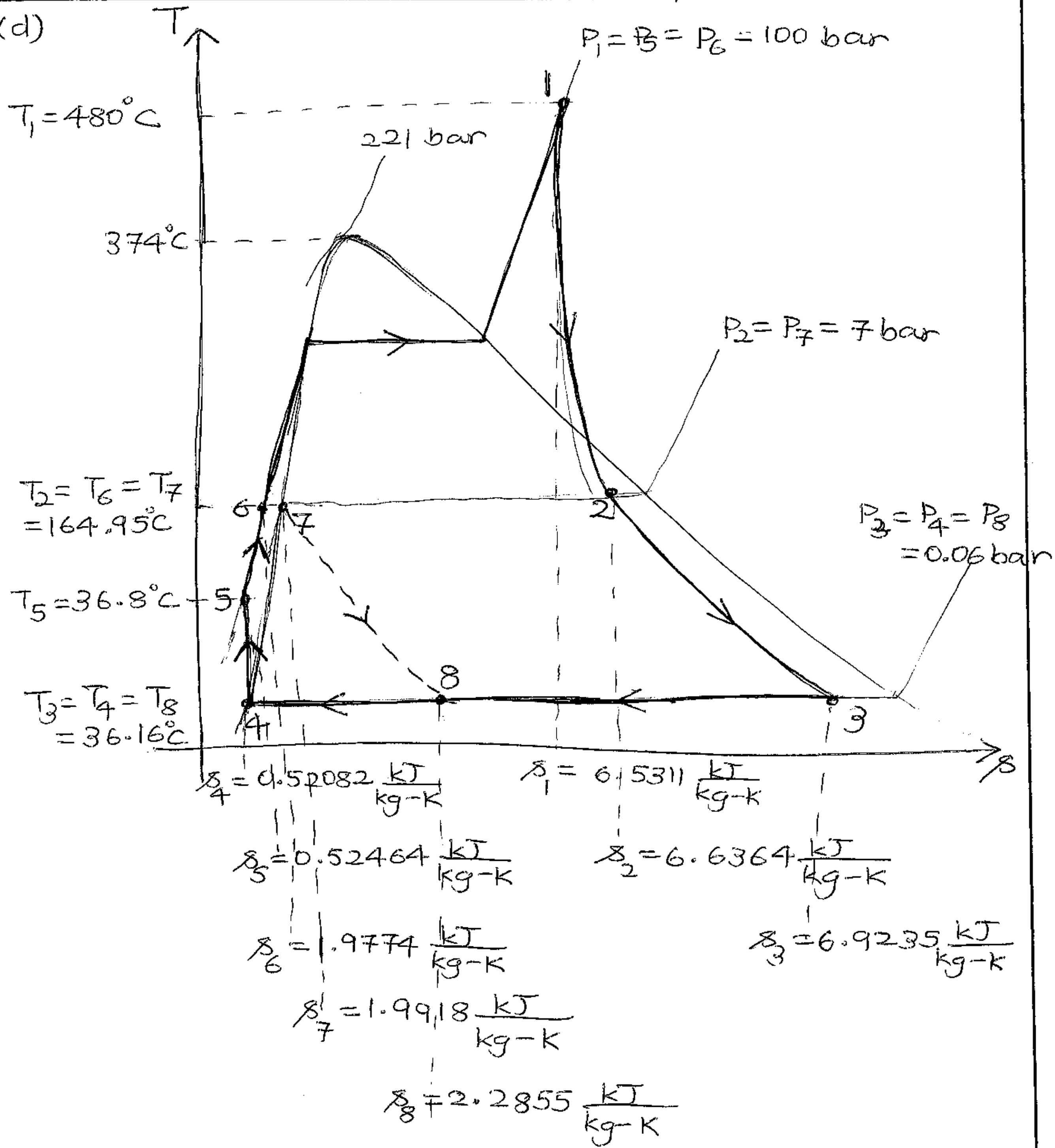
$$\dot{\sigma}_{\substack{generation\\condenser}} = \dot{m}s_4 - \dot{m}(1-y)s_3 - \dot{m}y s_8 - \frac{\dot{Q}_{condenser}}{T_{condenser}}$$

Specific entropy generation for condenser :

$$\sigma_{\substack{generation\\condenser}} = \frac{\dot{\sigma}_{\substack{generation\\condenser}}}{\dot{m}} = s_4 - (1-y)s_3 - y s_8 - \frac{q_{condenser}}{T_{condenser}}$$

$$\boxed{\sigma_{\substack{generation\\condenser}} = +0.16 \frac{kJ}{kg-K}} \qquad \sigma_{generation} > 0 \checkmark$$

(d)


T
$P_1 = P_5 = P_6 = 100$ bar
1
$T_1 = 480°C$
221 bar
374°C
$P_2 = P_7 = 7$ bar
$T_2 = T_6 = T_7$
$= 164.95°C$
6
7
2
$P_3 = P_4 = P_8$
$= 0.06$ bar
$T_5 = 36.8°C$
5
8
$T_3 = T_4 = T_8$
$= 36.16°C$
4
3
s
$s_4 = 0.52082 \frac{kJ}{kg-K}$
$s_1 = 6.5311 \frac{kJ}{kg-K}$
$s_5 = 0.52464 \frac{kJ}{kg-K}$
$s_2 = 6.6364 \frac{kJ}{kg-K}$
$s_6 = 1.9774 \frac{kJ}{kg-K}$
$s_3 = 6.9235 \frac{kJ}{kg-K}$
$s_7 = 1.9918 \frac{kJ}{kg-K}$
$s_8 = 2.2855 \frac{kJ}{kg-K}$

Given

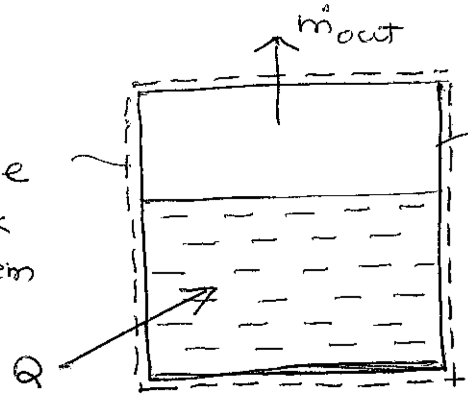
A rigid tank containing R-134a with a leak

Find

Entropy generation $\left(\frac{kJ}{K}\right)$ during the process

System

R-134a in the rigid tank is the system



$T_{out} = 20^\circ C$, sat. vapor

$V = 0.0189\ m^3$

$T_1 = 20^\circ C,\ x_1 = 0.10$

$\downarrow$

$T_2 = 20^\circ C$, sat. vapor

Assumptions

- Open system
- Unsteady state, steady flow
- 1-D, uniform flow at outlet
- Ignore KE and PE effects
- Rigid tank: $\dot{W} = 0$

Basic Equations

$$\left.\frac{dm}{dt}\right|_{system} = \cancel{\sum_{in} \dot{m}_{in}} - \sum_{out} \dot{m}_{out}$$

$$\left.\frac{dE}{dt}\right|_{system} = \cancel{\sum_{in} \dot{m}_{in}(h+ke+pe)_{in}} - \sum_{out} \dot{m}_{out}(h+\cancel{ke}+\cancel{pe})_{out} + \dot{Q} - \cancel{\dot{W}}$$

$$\frac{d}{dt}(U+\cancel{KE}+\cancel{PE})$$

$$\left.\frac{dS}{dt}\right|_{system} = \cancel{\sum_{in} \dot{m}_{in} s_{in}} - \sum_{out} \dot{m}_{out} s_{out} + \cancel{\sum_j} \frac{\dot{Q}_j}{T_{j,boundary}} + \dot{\sigma}_{generation}$$

Solution

See HW-20

$m_1 = 4.36$ kg, $m_2 = 0.525$ kg, $m_{out} = 3.84$ kg

$Q = +716.4$ kJ

State 1 $\quad T_1 = 20^\circ C,\ x_1 = 0.10$

$$x_1 = \frac{s_1 - s_f(T_1)}{s_g(T_1) - s_f(T_1)} \Rightarrow 0.10 = \frac{s_1 - 0.30063}{0.92243 - 0.30063}$$

$$s_1 = 0.36281\ \frac{kJ}{kg-K}$$

State 2 $T_2 = 20°C$, sat. vapor

$$s_2 = s_g(T_2) = 0.92243 \frac{kJ}{kg-K}$$

Outlet $T_{out} = 20°C$, sat. vapor

$$s_{out} = s_g(T_{out}) = 0.92243 \frac{kJ}{kg-K}$$

Integrating entropy balance: $S_2 - S_1 = -m_{out} s_{out} + \frac{Q}{T_{boundary}} + \sigma_{generation}$

Entropy generation during the process:

$$\sigma_{generation} = m_2 s_2 - m_1 s_1 + m_{out} s_{out} - \frac{Q}{T_{boundary}}$$

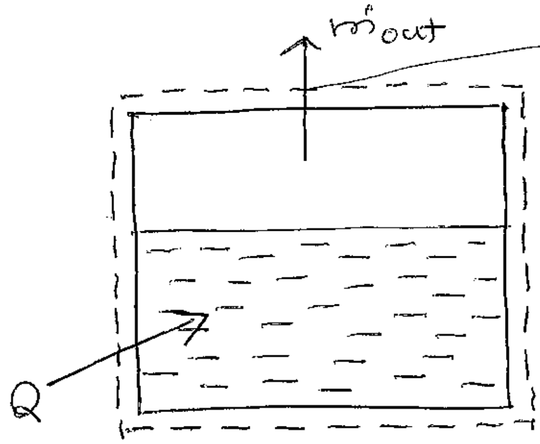
$$= 0.525\ kg * 0.92243 \frac{kJ}{kg-K} - 4.36\ kg * 0.36281 \frac{kJ}{kg-K} + 3.84\ kg * 0.92243 \frac{kJ}{kg-K} - \frac{716.4\ kJ}{(27+273)\ K}$$

$$\boxed{\sigma_{generation} = +0.0566 \frac{kJ}{K}}$$

$\sigma_{generation} > 0$ ✓

In this analysis, we have only considered R-134a entering the leak from the tank (sat. vapor at 20 C) and entropy generation is due to heat transfer into the tank

System



$\hat{h}_{out} = 261.60 \frac{kJ}{kg}$

$\hat{P}_{out} \cong 1$ bar

(1 atm = 1.01325 bar)

$T_1 = 20^\circ C$, $x_1 = 0.10$

$\downarrow$

$T_2 = 20^\circ C$, sat. vapor

State 1 $\quad m_1 = 4.36\ kg$, $s_1 = 0.36281 \frac{kJ}{kg-K}$

State 2 $\quad m_2 = 0.525 kg$, $s_2 = 0.92243 \frac{kJ}{kg-K}$

Outlet $\quad \hat{h}_{out} = 261.60 \frac{kJ}{kg}$, $\hat{P}_{out} = 1$ bar

(Throttling across the leak) $\quad \hat{m}_{out} = 3.84\ kg$

$h_{out} > h_g(P_{out}) \Rightarrow$ superheated vapor

Interpolating: $\hat{s}_{out} = 1.0548 \frac{kJ}{kg-K}$

"Total" entropy generation during the process:

$$\sigma_{total} = m_2 s_2 - m_1 s_1 + \hat{m}_{out} \hat{s}_{out} - \frac{Q}{T_{boundary}}$$

$$= 0.525\ kg * 0.92243 \frac{kJ}{kg-K} - 4.36\ kg * 0.36281 \frac{kJ}{kg-K}$$
$$+ 3.84\ kg * 1.0548 \frac{kJ}{kg-K} - \frac{716.4\ kJ}{(27+273)\ K}$$

$$\boxed{\sigma_{total} = +0.565 \frac{kJ}{K}}$$

$\sigma_{total} > 0$ ✓

Note

Significant entropy generation occurs due to pressure drop across the leak where R-134a expands to ambient pressure

In this analysis, we have considered R-134a exiting the leak from the tank into the surrounding and entropy generation is due to heat transfer into the tank as well as pressure drop across the leak