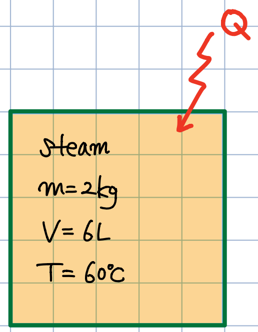
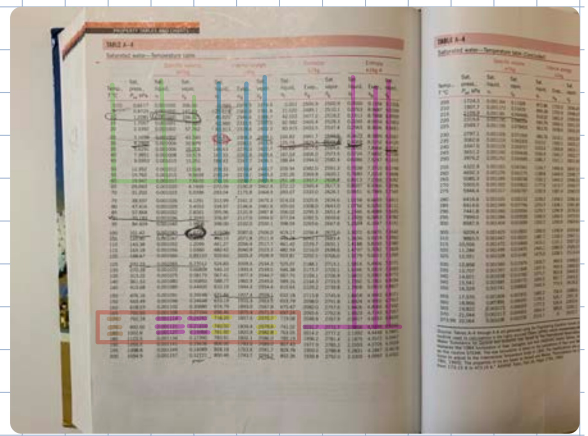
2kg of steam is contained in a 6L tank at 60°C.
If 1MJ of heat is added, calculate the final entropy.

$\hookrightarrow S_2 = m s_2$



· Steam : 증기 → water liq + vap.

Trial & Error ★★★



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

$\therefore Q = m(u_2 - u_1)$

$T_1 = 60°C$

$V_1 = 6L \cdot \frac{1\,m^3}{1000\,L} = 0.006\,m^3 \longrightarrow v_1 = 0.003\,m^3/kg$

Table A-4 → $T_1 = 60°C$ → $v_f = 0.001017\,m^3/kg$, $v_g = 7.6670\,m^3/kg$ → $v_1 = v_f + x_1(v_g - v_f)$

$\therefore x_1 = \frac{v_1 - v_f}{v_g - v_f} = \frac{0.003 - 0.001017}{7.6670 - 0.001017} = 0.000259$

$\therefore u_1 = u_f + x_1(u_g - u_f)$
$= (251.16) + (0.000259)\cdot(2204.7)$
$= 251.73\,kJ/kg$

$Q = mu_2 - mu_1$

$u_2 = Q/m + u_1 = \frac{1000\,kJ}{2\,kg} + (251.73\,kJ/kg) = 751.73\,kJ/kg$

State 2: $u_2 = 751.73\,kJ/kg$
$v_2 = 0.003\,m^3/kg$

For s_2, we need to know T_2, x_2

T(°C)	v_f	v_g	u_f	u_g
180	0.001127	0.19384	761.92	1820.9

$x_2 = \frac{v_2 - v_f}{v_g - v_f} = \frac{0.003 - 0.001127}{0.19384 - 0.001127} = 0.00972 \longrightarrow u_2 = u_f + x_2(u_g - u_f) = 779.62$

170	0.001114	0.24260	718.20	1857.5

$x_2 = 0.00781 \longrightarrow u_2 = 732.71$

175	0.001121	0.21659	740.02	1839.4

$x_2 = 0.00872 \longrightarrow u_2 = 756.06$

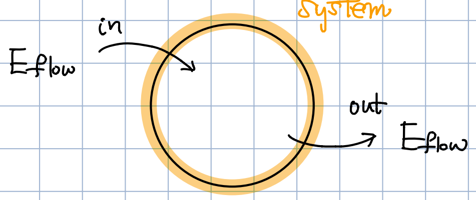
$s_g = 2.0906$
$s_{fg} = 4.5335$

$\therefore s_2 = (2.0906) + (0.00872)\cdot(4.5335)$
$= 2.13013\,kJ/kg\cdot K$

$S_2 = m s_2 = (2\,kg)\cdot(2.13013\,kJ/kg\cdot K)$
$= 4.26\,kJ/K$ Ans.

열역학 제 1법칙 (First Law of Thermodynamics)

Conservation of Energy.



$$\boxed{\Delta E_{system} = \Delta E^{in}_{flow} - \Delta E^{out}_{flow}}$$

$$\boxed{dU = \delta Q - \delta W}$$

dU : internal energy
= the change of the energy in the system

How to characterize the system?
How to write the variables?

$$\boxed{dU = \delta Q + \sum_c y_c \, dX_c}$$

X_c → extensive variables

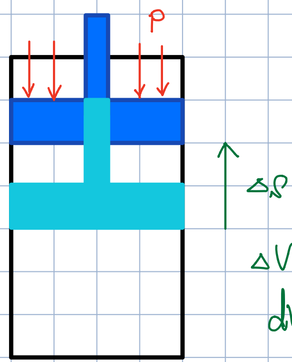
y_c → conjugate force

extensive variables (X_c)	δW		
V	$-pdV$	Mechanical Work	
l	Fdl	Mechanical Work	
E	$d\mathcal{P}$	Dielectric Work	E : the electric field $\mathcal{P}$: the total polarization of the dielectric
M	$\mathcal{H}\,dM$	Magnetic Work	
q	Φdq	Electrical Work	

1. The work term : extensive variable + conjugate force
2. The heat term : $\boxed{\delta Q = TdS}$ ← Temperature + Entropy (its conjugate)

System : $\begin{cases} \text{Closed system (밀폐계)} \\ \text{Open system (개방계)} \end{cases}$

Closed System



$\Delta V = A \times \Delta s$

$dV = A\,ds$

$$\boxed{\delta W = p\,dV}$$

경계일
(Boundary Work)

• Conservation of Energy

: $dE = \delta Q - \delta W$

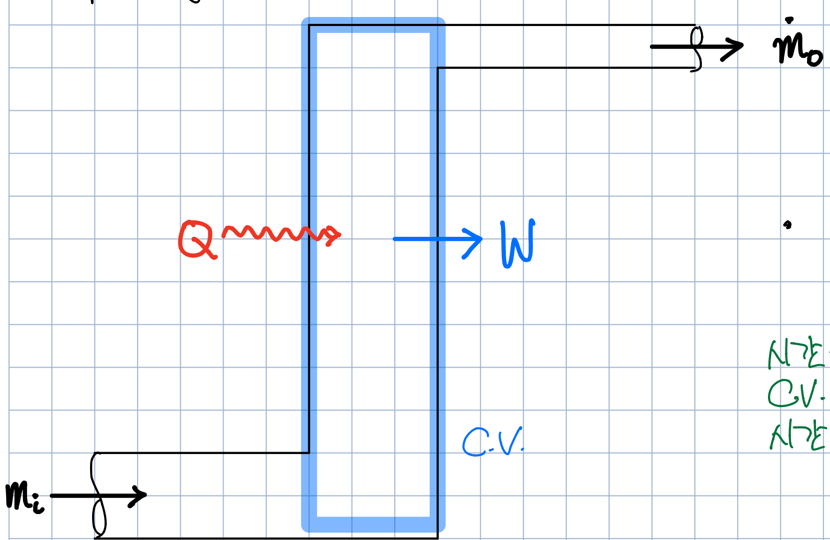
$dU = \delta Q - p\,dV$

$\therefore \delta Q = dU + p\,dV$

$\delta q = du + p\,dv$

$$\Delta E = \cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U \cdots$$

Open System



질량의 흐름에 동반되어 CV 안으로 들어가는 에너지의 시간 변화율

• Conservation of Energy

$$dE = \delta Q - \delta W + \text{◍}$$

시간 t 에서의 C.V. 안 에너지의 시간 변화율

시간 t 에서의 열전달에 의해 유입되는 에너지의 시간 변화율

시간 t 에서의 일에 의해 소모되는 에너지의 시간 변화율

작동유체가 들어오고 나간다. 시간변화율!

m $\dot{m}$

$$dE_{cv}/dt = \dot{Q} - \dot{W} + \dot{m}_i\left(u_i + V_i^2/2 + gz_i\right) - \dot{m}_o\left(u_o + V_o^2/2 + gz_o\right)$$

• 질량이 들어오거나 나갈때 발생되는 유체의 압력에 의한 일 : $\dot{W} = \dot{W}_{cv} + \dot{m}pv$

$\dot{m}pv$ [kg/s] [N/m²] [m³/kg] = [J/s]

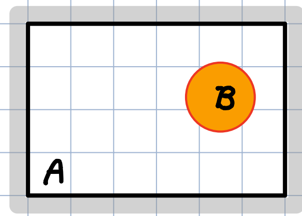
$$dE_{cv}/dt = \dot{Q} - \dot{W}_{cv} + \dot{m}_i\left(u_i + pv + V_i^2/2 + gz_i\right) - \dot{m}_o\left(u_o + pv + V_o^2/2 + gz_o\right)$$

$$dE_{cv}/dt = \dot{Q} - \dot{W}_{cv} + \dot{m}_i\left(h_i + V_i^2/2 + gz_i\right) - \dot{m}_o\left(h_o + V_o^2/2 + gz_o\right)$$

Entropy Transfer

- **Closed System** $\Sigma \frac{Q_k}{T_k} + S_{gen} = \Delta S_{system} = S_2 - S_1$

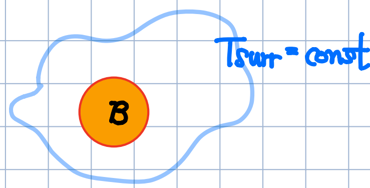
1. adiabatic : $S_{gen} = \Delta S_{system} = S_2 - S_1$
   $= \Delta S_A + \Delta S_B$



$\frac{Q_A}{T_A} + \frac{Q_B}{T_B} = 0$

$\Sigma Q_k / T_k = 0$

2. surrounding : $S_{gen} = \Delta S_{sys} + \Delta S_{surr}$
   $= \Delta S_B + \Delta S_{surr}$
   $= \Delta S_B + \frac{Q_{surr}}{T_{surr}}$



(Control Volume)

- **Open System**

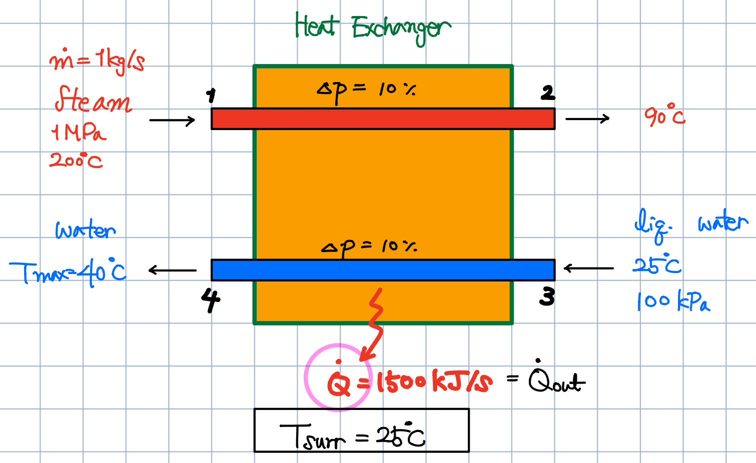
$\Sigma \frac{Q_k}{T_k} + S_{gen} + \Sigma m_i S_i - \Sigma m_e S_e = (S_2 - S_1)_{cv}$

$\Sigma \frac{\dot{Q}_k}{T_k} + \Sigma \dot{m}_i S_i - \Sigma \dot{m}_e S_e + \dot{S}_{gen} = dS_{cv}/dt$

steady-flow, single stream : $\dot{S}_{gen} = \dot{m}(S_e - S_i) - \Sigma \frac{\dot{Q}_k}{T_k}$ ← ∵ single stream : $\dot{m}_i = \dot{m}_e$

steady-flow, adiabatic : $\dot{S}_{gen} = \Sigma \dot{m}_e S_e - \Sigma \dot{m}_i S_i$

steady-flow, single stream, adiabatic : $\dot{S}_{gen} = \dot{m}(S_e - S_i)$



ΔKE, ΔPE are negligible

a) The minimum mass flow rate of the cooling water

b) assume : [$\dot{m}_w = 10 kg/s$
Heat transfer (W/ Environment) : internally reversible & isothermal

$S_{gen} = ?$

Open System → TD's 1st Law

$$\cancel{\frac{dE_{cv}}{dt}} = \dot{Q} - \cancel{\dot{W}_{cv}} + \dot{m}_i\left(h_i + \cancel{\frac{V_i^2}{2}} + \cancel{gz_i}\right) - \dot{m}_o\left(h_o + \cancel{\frac{V_o^2}{2}} + \cancel{gz_o}\right)$$

∵ steady-state

$-\dot{Q}_{out}$

$$-\dot{Q}_{out} + (\dot{m}_1 h_1 + \dot{m}_3 h_3) - (\dot{m}_2 h_2 + \dot{m}_4 h_4) = 0 \leftarrow \dot{m}_3 = \dot{m}_4,\ \dot{m}_1 = \dot{m}_2$$

$$\dot{m}_1(h_1 - h_2) + \dot{m}_3(h_3 - h_4) = \dot{Q}_{out}$$

State 1 : $\dot{m} = 1 kg/s$ Steam 1MPa 200°C

superheated ? → $T_{sat} \sim 179.88°C$ (at 1MPa) → O

★ superheated ?

∴ $h_1 = 2828.3$ kJ/kg·K , $S_1 = 6.6956$

State 2 : 90°C , 0.9MPa (900kPa)

★ subcooled ?

<Temp. Table> T = 90°C → $P_{sat} = 70.183$ kPa → ∴ subcooled liquid! → fluid 100%
<Pressure Table> P = 0.9MPa → $T_{sat} = 175.35°C$

★ temp. table ?

∴ T = 90°C (temp. table) : $\boxed{h_f = h_2 = 377.04 \text{ kJ/kg},\ S_f = S_2 = 1.1929 \text{ kJ/kg·K}}$

State 3 : liq. water 25°C 100 kPa

$\boxed{h_f = h_3 = 104.83,\ S_f = S_3 = 0.3672}$

$$\dot{m}_1(h_1 - h_2) + \dot{m}_3(h_3 - h_4) = \dot{Q}_{out}$$

State 4 : water $T_{max} = 40°C$ 90kPa

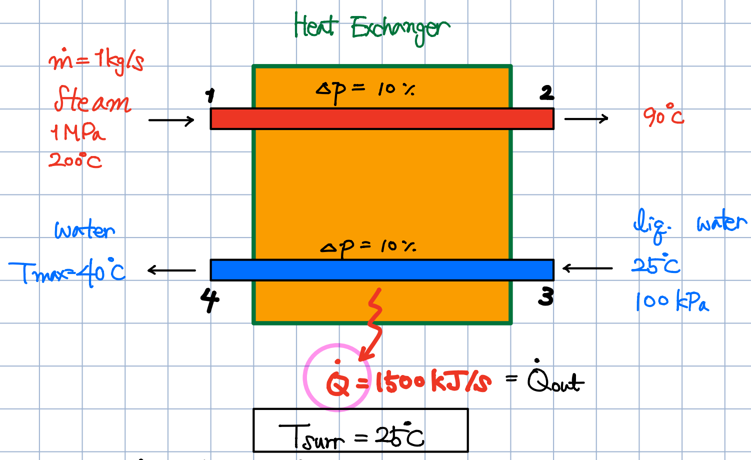
$\boxed{h_4 = 167.53,\ S_4 = 0.5724}$

$$\dot{m}_3 = \frac{\dot{Q}_{out} - \dot{m}_1(h_1 - h_2)}{h_3 - h_4} = \frac{1500 - (1)(2828.3 - 377.04)}{104.83 - 167.53}$$

$= 15.17 kg/s$ Ans. (a)

b) assume : $\left[\begin{array}{l} \dot{m}_w = 10 \text{ kg/s} \\ \text{Heat transfer : internally reversible} \\ \text{(w/ Environment)} \quad \& \\ \qquad\qquad \text{isothermal} \end{array} \right.$

$S_{gen} = ?$



$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{S}_{gen} = \cancel{\frac{dS_{cv}}{dt}}$$

∵ steady-state

$$\frac{-\dot{Q}_{out}}{T_b} + \underbrace{(\dot{m}_1 s_1 + \dot{m}_3 s_3) - (\dot{m}_2 s_2 + \dot{m}_4 s_4)}_{= \dot{m}_1 (s_1 - s_2) + \dot{m}_3 (s_3 - s_4)} + \dot{S}_{gen} = 0 \quad \leftarrow \quad \dot{m}_3 = \dot{m}_4 \ , \ \dot{m}_1 = \dot{m}_2$$

$$\dot{S}_{gen} = \dot{m}_1 (s_2 - s_1) + \dot{m}_3 (s_4 - s_3) + \frac{\dot{Q}_{out}}{T_b}$$

$$= (1 \text{kg/s}) \cdot \underbrace{(1.1929 - 6.6956 \text{ kJ/kg·K})}_{-5.5027} + (10) \cdot \underbrace{(0.5724 - 0.3672)}_{= 0.2052} + \underbrace{\frac{1500 \text{ kJ/s}}{298 \text{ K}}}_{= 5.0335}$$

$$= -5.5027 + 2.052 + 5.0335$$

$$= 1.58286 \text{ kJ/K·s}$$

Ans. (b)

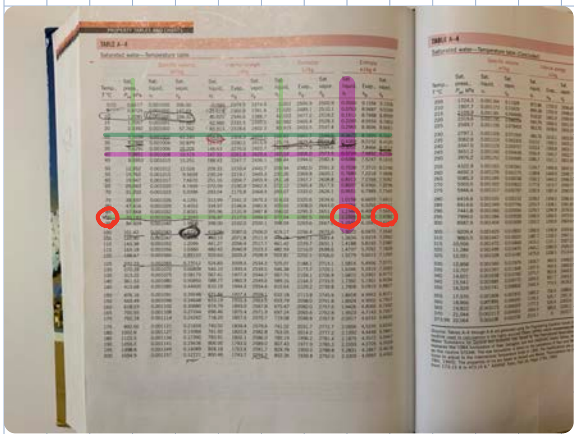


TABLE A-4
Saturated water—Temperature table

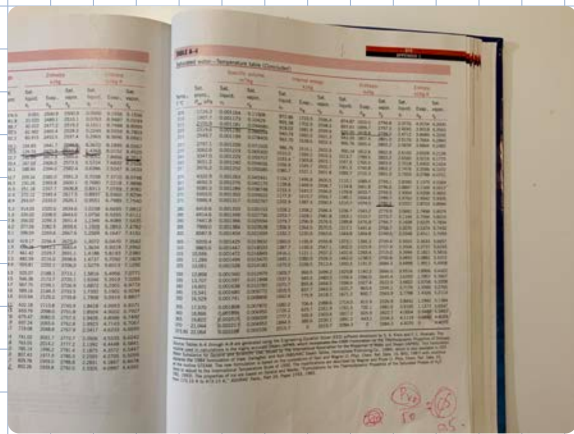


TABLE A-4
Saturated water—Temperature table (Concluded)

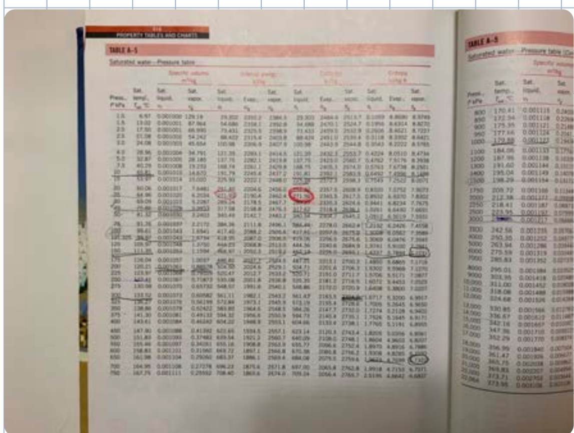


TABLE A-5
Saturated water—Pressure table

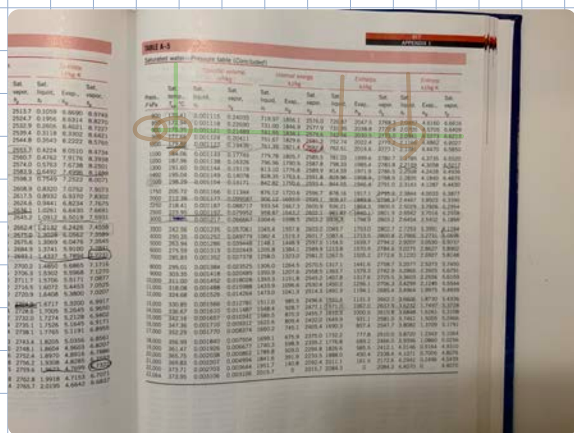


TABLE A-5
Saturated water—Pressure table (Concluded)

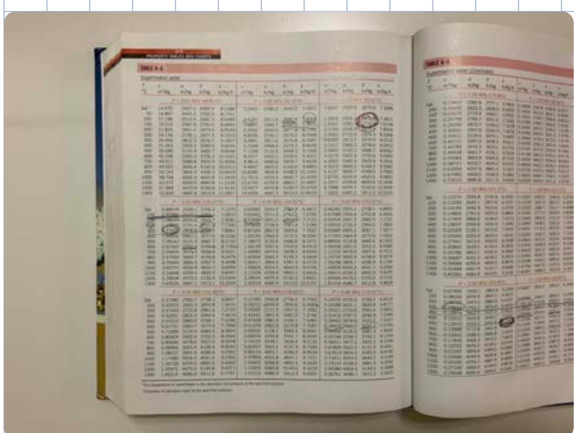


TABLE A-6
Superheated water

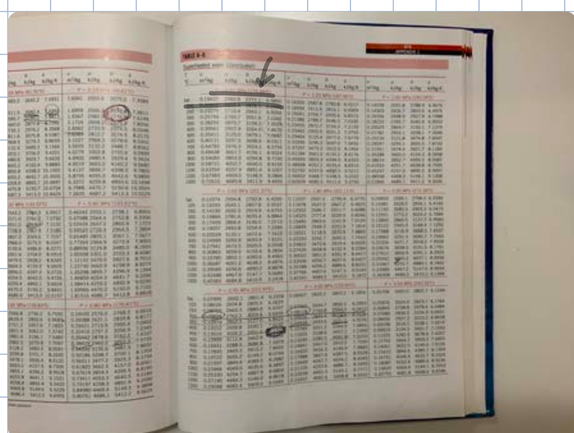


TABLE A-6
Superheated water (Continued)

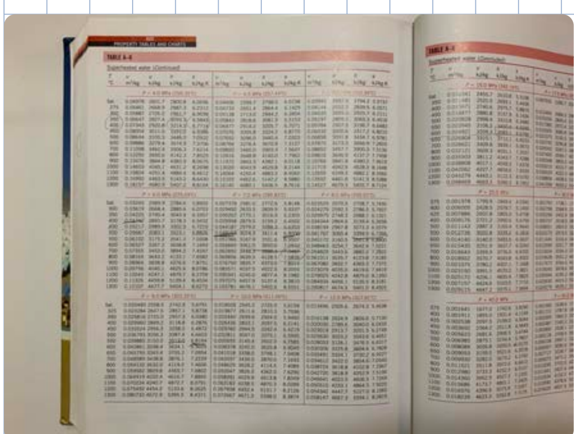


TABLE A-6
Superheated water (Continued)

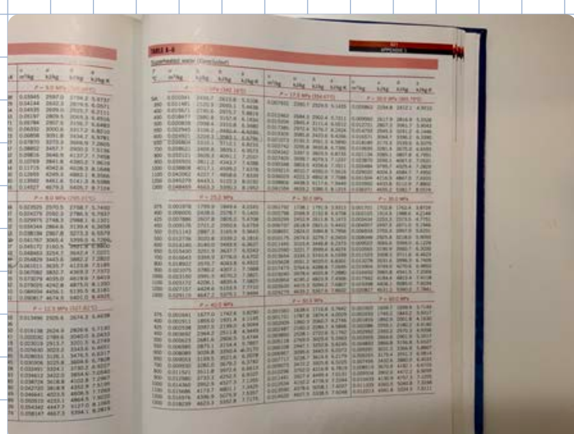
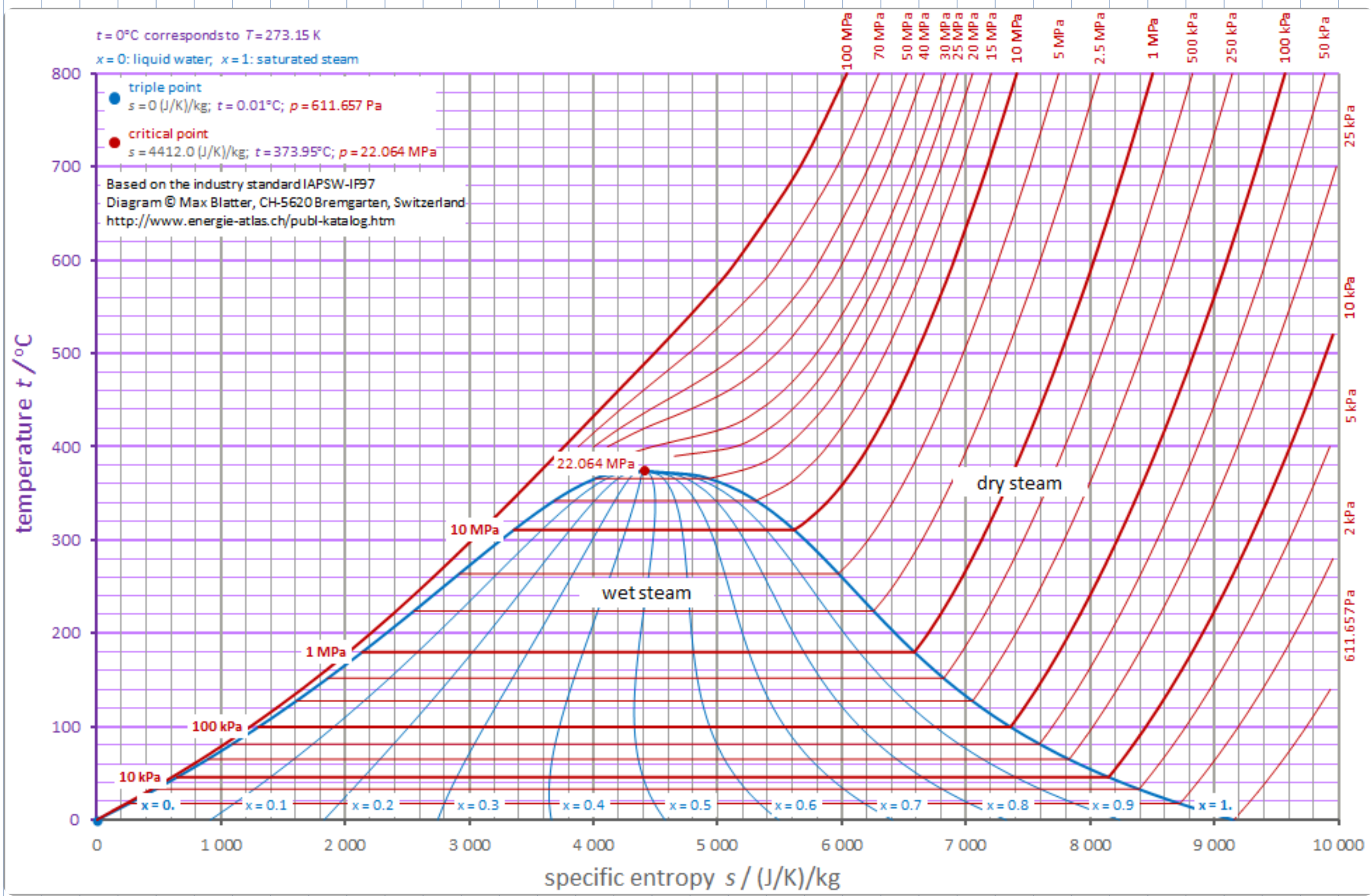
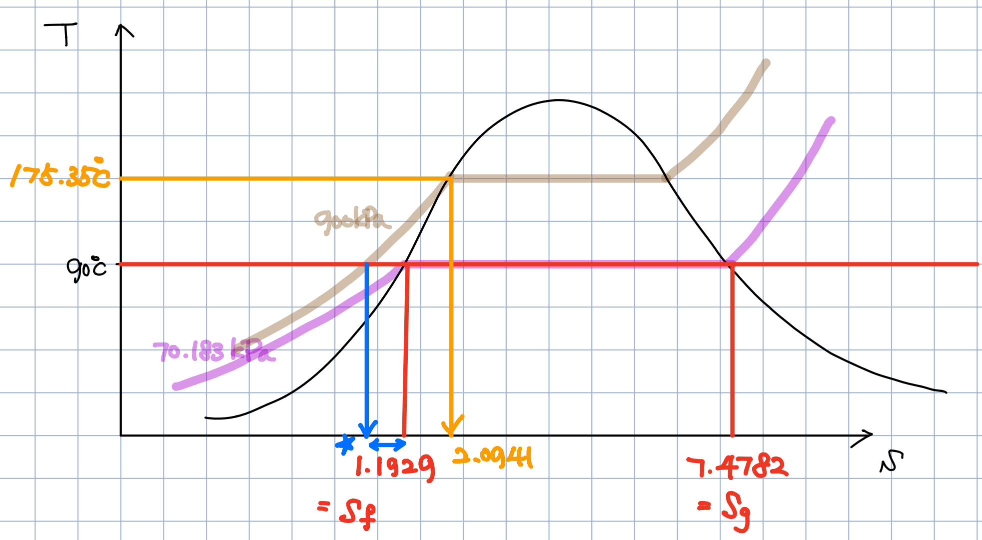


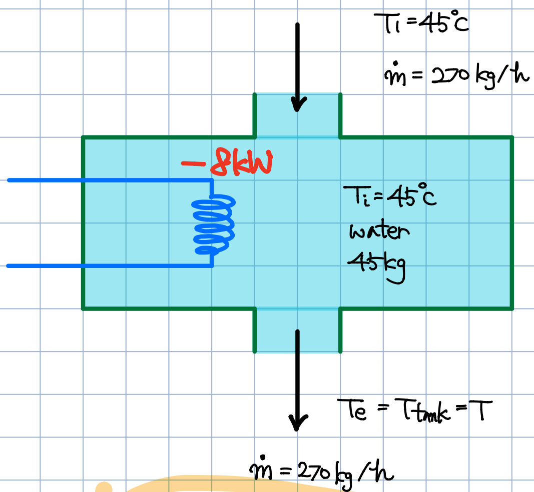
TABLE A-6
Superheated water (Concluded)



https://upload.wikimedia.org/wikipedia/commons/f/f4/T-s-diagram-steam.png

900kPa, 90°C





45kg , liq. water , 45°C

$\dot{m}$ = 270 kg/h

cooling coil = 8kW

T in tank = uniform

$P_{in} = P_{out}$

$C = 4.2$ kJ/kg·K

$\Delta pe = \Delta ke = 0$

Determine the variation of the tank water temp.

$$\frac{dE_{cv}}{dt} = \dot{Q} - \cancel{\dot{W}_{cv}} + \dot{m}_i\left(h_i + \cancel{\frac{V_i^2}{2}} + \cancel{gz_i}\right) - \dot{m}_o\left(h_o + \cancel{\frac{V_o^2}{2}} + \cancel{gz_o}\right)$$

$Q = E = (m)CT$

CV안에서의 질량

$$\frac{dE_{cv}}{dt} = \dot{Q} + \dot{m}(h_i - h_e) \quad \leftarrow \quad dh = CdT \quad , \quad \frac{dE_{cv}}{dt} = mC\left(\frac{dT}{dt}\right)_{cv}$$

$$mC\left(\frac{dT}{dt}\right)_{cv} = \dot{Q} + \dot{m}C(T_i - T)$$

$$\frac{dT}{dt} = \frac{\dot{Q}}{mC} + \frac{\dot{m}\cancel{C}}{m\cancel{C}}(T_i - T)$$

[K/s]

$$= \frac{-8\,kJ/s}{(45kg)\cdot(4.2kJ/kg\cdot K)} + \frac{(270kg/h)\cdot\frac{1h}{3600s}}{(45kg)}(318 - T)K$$

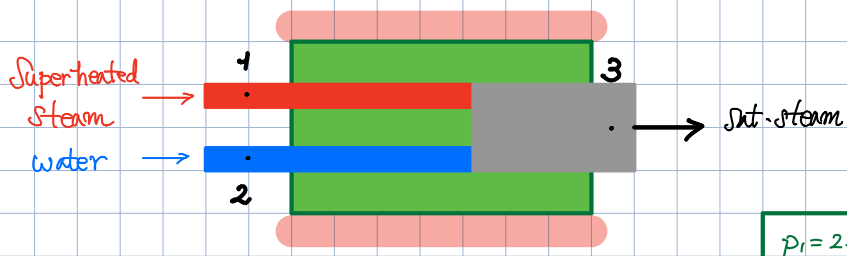
[K/s] [K/s]

$$= -0.0423 + 0.0017(318 - T)$$

$$\frac{dT}{dt} = 0.4983 - 0.0017T$$

Ans.

adiabatic desuperheater
steady state



water + superheated steam $\rightarrow$ sat. steam

$p_1 = 2.7\,MPa$, $T_1 = 300°C$
$h_1 = 3002.7\ kJ/kg$, $s_1 = 6.6019\ kJ/kg\cdot K$
$\dot{m}_1 = 1000\ kg/h = 1000\ kg/h \cdot \frac{1\,h}{3600\,s} = 0.278\ kg/s$

$p_2 = 2.7\,MPa$, $T_2 = 40°C$
$h_2 = 174\ kJ/kg$, $s_2 = 0.571\ kJ/kg\cdot K$

$p_3 = 2.5\,MPa$, $T_3 = 223.99°C$ (sat.)
$h_3 = 2803.1\ kJ/kg$ $s_3 = 6.2575\ kJ/kg\cdot K$

a) $\dot{m}_{water}$
b) the change in entropy of C.V.
c) reversible? $\dot{S}_{gen}$

<Energy Balance - Open System>

$$\cancel{\frac{dE_{cv}}{dt}}^{\,0} = \cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} + \dot{m}_i(h_i) - \dot{m}_e(h_e)$$

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \quad \leftarrow \quad \dot{m}_3 = \dot{m}_1 + \dot{m}_2$$
$$= (\dot{m}_1 + \dot{m}_2)\, h_3$$

$$\dot{m}_2 (h_2 - h_3) = \dot{m}_1 (h_3 - h_1)$$

$$\therefore \dot{m}_2 = \frac{\dot{m}_1 (h_3 - h_1)}{h_2 - h_3} = \frac{(0.278)\cdot(2803.1 - 3002.7)}{(174 - 2803.1)} = \underline{0.0211\ kg/s}$$ Ans. (a)

<Entropy - Open System>

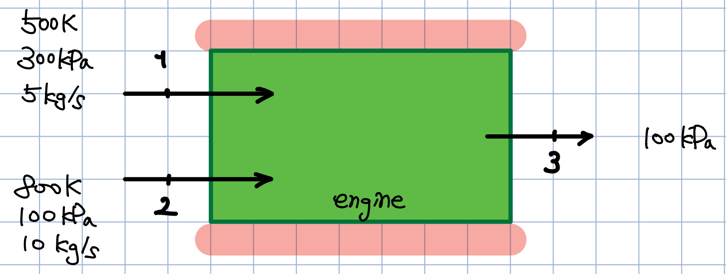
$$\cancel{\frac{dS_{cv}}{dt}} = \cancel{\Sigma \frac{\dot{Q}_b}{T_b}} + \dot{m}_i s_i - \dot{m}_e s_e + \dot{S}_{gen}$$

$\dot{m}_1 = 0.278$
$\dot{m}_2 = 0.0211$
$\dot{m}_3 = 0.2991$

$$\dot{S}_{gen} = \dot{m}_e s_e - \dot{m}_i s_i$$
$$= \dot{m}_3 s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2 \quad \leftarrow$$

$$= (0.2991)\cdot(6.2575) - (0.278)\cdot(6.6019) - (0.0211)\cdot(0.571)$$
$$= \underline{0.02424\ kJ/K\cdot s}$$ Ans. (b)

$\dot{S}_{gen} \neq 0 \rightarrow$ $\underline{\text{irreversible}}$ Ans. (c)



Two air streams

- steady-state
- adiabatic
- $\Delta ke = \Delta pe = 0$
- ideal gas with const C
  ($R = 0.287$ kJ/kg·K, $C = 1$ kJ/kg·K)

Determine the maximum power output of the engine.

$$\cancel{\frac{dE_{cv}}{dt}} = \cancel{\dot{Q}_{cv}} - \dot{W}_{cv} + \sum \dot{m}_i (h_i) - \sum \dot{m}_e (h_e)$$

$\dot{W}_{engine}$

$$\dot{W}_{engine} = \sum \dot{m}_i h_i - \sum \dot{m}_e h_e$$
$$= \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3$$

5kg/s, 10kg/s, $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$, 15kg/s

$h_1 = (1\ \text{kJ/kg·K}) \cdot (500\text{K}) = 500$ kJ/kg

$h_2 = (1) \cdot (800) = 800$ kJ/kg

$h_3 = (1) \cdot T_3 = 615.75$ kJ/kg

in order to have maximum work out,

isentropic / reversible $\longrightarrow$ no entropy change!

$$C_p = \left(\frac{\partial Q}{\partial T}\right)_p = \left(\frac{dH}{dT}\right) \leftarrow \delta q = dh - \cancel{v\,dp}$$

$\therefore H = mC_pT$

$$\dot{W}_{engine} = (5)(500) + (10)\cdot(800) + (15)\cdot(615.75)$$
$$= 1263.75\ \text{kJ/s}$$

Ans.

$$\cancel{\frac{dS_{cv}}{dt}} = \cancel{\sum \frac{Q_k}{T_b}} + \dot{m}_i s_i - \dot{m}_e s_e + \cancel{\dot{S}_{gen}}$$

$$\dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 = 0$$

$$\Delta S_{13} + \Delta S_{23} = 0 \longleftarrow$$

$$\delta q = dh - v\,dp$$
$$T\,ds = C_p\,dT - \frac{RT}{p}\,dp$$
$$\boxed{\Delta s = C_p \ln \frac{T_3}{T_1} - R \ln \frac{P_3}{P_1}}$$

$$\Delta S_{13} = \dot{m}_1 s_{13}$$
$$= \dot{m}_1 \left\{ C_p \ln \frac{T_3}{T_1} - R \ln \frac{P_3}{P_1} \right\}$$

$$\Delta S_{23} = \dot{m}_2 \left\{ C_p \ln \frac{T_3}{T_2} - R \ln \frac{P_3}{P_2} \right\}$$

-0.3153

$$(5)\cdot\left\{ (1) \ln \frac{T_3}{500} - \boxed{(0.287)\cdot \ln \frac{100}{300}} \right\}$$
$$+$$
$$(10)\cdot\left\{ (1) \ln \frac{T_3}{800} + \cancel{(0.287)\cdot \ln \frac{100}{100}} \right\}$$

$$5\cdot\{\ln T_3 - \ln 500 + 0.3153\} + \{10 \ln T_3 - 10 \ln 800\} = 0$$

$$15 \ln T_3 = 5 \ln 500 - 1.5765 + 10 \ln 800$$
$$= 31.073 - 1.5765 + 66.846$$
$$= 96.3425$$

$$\ln T_3 = 6.423$$

$$\therefore T_3 = e^{6.423} = 615.75\ \text{K}$$

adiabatic, reversible, steady-state

$C_p = 1.87\ kJ/kg\cdot K$, $k=1.3$, $v = 0.001\ m^3/kg$

(ideal gas)

$v = 0.001\ m^3/kg$

1~2 : incompressible

a) pump : 100 kPa, 20°C $\rightarrow$ 1000 kPa $\rightarrow$ $W_{pump} = \int_1^2 v\,dp = (0.001\ m^3/kg)(1000-100\ kPa)$

(liq. water)

$= \underline{0.9\ kJ/kg}$ Ans. (a)

b) Compressor : 100 kPa, 500°C $\rightarrow$ 1000 kPa $\rightarrow$ $W_{comp} = \int_1^2 v\,dp$

(steam)

<isentropic, ideal gas>

$$T_2/T_1 = (v_1/v_2)^{k-1} = (P_2/P_1)^{k-1/k}$$

$$T_2 = T_1 \cdot (P_2/P_1)^{k-1/k}$$

$$= (773K)\cdot(1000/100)^{\frac{1.3-1}{1.3}} = \underline{1315.1K}$$

$$\cancel{\delta q} - \delta w = dh + \cancel{dke} + \cancel{dpe}$$

$-\delta W_{in}$

$$\delta W_{in} = dh = C_p dT$$

$$W_{in} = C_p(T_2-T_1) = (1.87\ kJ/kg\cdot K)\cdot(1315.1-773\ K) = \underline{1013.73\ kJ/kg}$$ Ans. (b)

$\boxed{\delta W_p = v\,dp}$

initial final

$$\cancel{dE_{cv}/dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}(h_1 + V_1^2/2 + gz_1) - \sum_e \dot{m}(h_2 + V_2^2/2 + gz_2)$$

$Q_{cv} - W_{cv}$ = final − initial

$Q_{cv} - W_{cv} = \Delta H + \Delta KE + \Delta PE$

↓

Reversible, Steady-flow work

↓

$$\delta q_{rev} - \delta W_{rev} = dh + dke + dpe$$

$\delta q_{rev} = Tds$

$Tds = dh - v\,dp$ $\rightarrow$ $\delta q_{rev} = dh - v\,dp$

$$(\cancel{dh} - v\,dp) - \delta W_{rev} = \cancel{dh} + \cancel{dke} + \cancel{dpe}$$

$-\delta W_{rev} = v\,dp$

$\boxed{W_b = \int_1^2 P\,dV}$ ↔ $\boxed{W_{rev} = -\int_1^2 v\,dp}$ ... system이 하는 일

↕

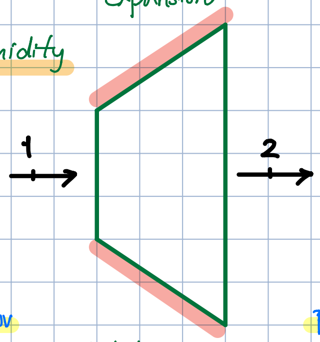
$\boxed{W_{rev,in} = \int_1^2 v\,dp}$ system이 받는 일

expansion

air + 50 % humidity

steam
air , water vapors : ideal gas

$T_1 = 100°C$
$p_1 = 200\,kPa$
air
wv
$p_1 = p_{1,air} + p_{1,wv}$



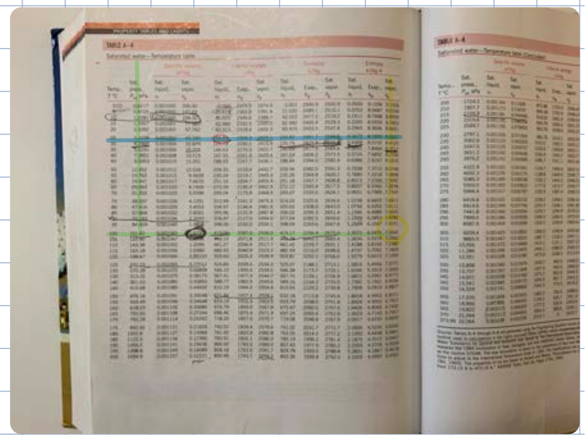
$T_2 = 25°C$
$p_2 = ?$
air
wv
$p_2 = p_{2,air} + p_{2,wv}$

$k_{air} = 1.4$
$k_w = 1.327$ } const

$R_{air} = 0.287\,kJ/kg\,K$
$R_{wv} = 0.4615$

$p_2 = ?$

adiabatic
reversible



ϕ : relative humidity = $\dfrac{\text{water vapor pressure}}{\text{equilibrated vapor pressure}}$

State 1 :

WV $\quad T_1 = 100°C \rightarrow p_1 = 101.42\,kPa$

$p_{wv,1} = (0.5)\cdot(101.42) = 50.7\,kPa$

Air $\quad p_1 = 200\,kPa \rightarrow p_{1,air} = p_1 - p_{1,wv}$

$= 200 - 50.7 = 149.3\,kPa$

State 2 :

Air $\quad$ adiabatic $\rightarrow$ $T_2/T_1 = (v_1/v_2)^{k-1} = (p_2/p_1)^{k-1/k}$

$p_{2,air} = (p_{1,air})\cdot(T_2/T_1)^{k/k-1}$

$= (149.3\,kPa)\cdot\left(\dfrac{298\,K}{373\,K}\right)^{1.4/0.4}$

$= 68.05\,kPa$

WV $\quad$ adiabatic / reversible $\rightarrow$ isentropic !
$\Delta s = 0$

$p_2 = (68.05) + (3.17)$
$= 71.22$ Ans.

$T_1 = 100°C \rightarrow s_1 = s_g = 7.3542\,kJ/kg\cdot K \quad (s_1 = s_2)$

$T_2 = 25°C \rightarrow$
$s_f = 0.3672$
$s_{fg} = 8.1895 \longrightarrow s_2 = s_f + x_2(s_g - s_f)$
$s_g = 8.5567$

$\therefore x_2 = \dfrac{(7.3542) - (0.3672)}{8.1895} = 0.8532$

$p_{2,wv} = P_{sat}$ (at $T = 25°C$)
$= 3.17\,kPa$

A system : 1 kg (sat. water vapor) at 100°C

$\downarrow$ condensed (isobaric) $\longleftrightarrow$ heat transfer ($T_{res} = 25°C$)

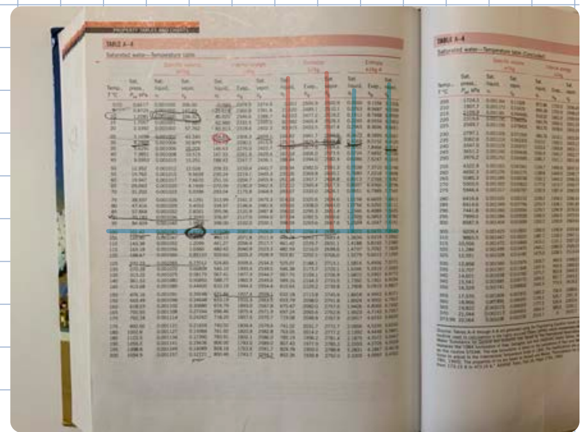
Sat. liquid at 100°C

$\Delta S = ?$

(the net increase in entropy)

(system = water + surrounding)

$\Delta S_{system} = \Delta S_{water} + \Delta S_{surr} = ?$



Water

$T_1 = 100°C \longrightarrow S_1 = S_g = 7.3542 \ kJ/kg \cdot K$

$S_2 = S_f = 1.3072$

$\Delta S_{water} = S_2 - S_1$

$= (1.3072) - (7.3542)$

$= \underline{-6.047 \ kJ/kg \cdot K}$

Heat

$$\boxed{\Delta S_{surr} = \frac{Q_b}{T_b}}$$

$\Delta E = Q - \cancel{W} = \Delta H = \boxed{m(h_1 - h_2)} = (1 kg) \cdot (2675.6 - 419.17 \ kJ/kg)$

$= 2256.4 \ kJ$

$\therefore \Delta S_{surr} = \frac{2256.4 kJ}{298 K} = \underline{7.572 \ kJ/K}$

$\therefore \Delta S_{system} = (-6.047) + (7.572) = \underline{1.53 \ kJ/K}$ Ans.

High Pressure Water jet (adiabatic & reversible) $\rightarrow$ isentropic

Compress $\boxed{\text{liq. water} \quad 100\,kPa,\ 20^\circ C} \rightarrow \boxed{2000\,kPa} \rightarrow$ $P_{atm} = 100\,kPa = 1\,bar = 10^5\,Pa$

tank jet

Assume steady-state

water $(20^\circ C, 100\,kPa)$: $C_v = 4.18\ kJ/kg \cdot K$

$v = 0.001\ m^3/kg$

$h = 2675\ kJ/kg$

$\rho = 997\ kg/m^3$

a) $\dot{W}/Q$, the energy per unit volume flow rate

b) $V_{water\,jet}$

$$\boxed{\delta w_p = v\,dp}$$

$$\cancel{\frac{dE_{cv}}{dt}} = \dot{Q}_{cv} - \dot{W}_{cv} + \underbrace{\sum_i \dot{m}\left(h_1 + \frac{V_1^2}{2} + gz_1\right)}_{initial} - \underbrace{\sum_e \dot{m}\left(h_2 + \frac{V_2^2}{2} + gz_2\right)}_{final}$$

$$Q_{cv} - W_{cv} = \text{final} - \text{initial}$$

$$Q_{cv} - W_{cv} = \Delta H + \Delta KE + \Delta PE$$

$\downarrow$

Reversible, Steady-flow work

$\downarrow$

$$\delta q_{rev} - \delta w_{rev} = dh + dke + dpe$$

$$\begin{cases} \delta q_{rev} = T\,ds \\ T\,ds = dh - v\,dp \end{cases} \rightarrow \delta q_{rev} = dh - v\,dp$$

$$(\cancel{dh} - v\,dp) - \delta w_{rev} = \cancel{dh} + \cancel{dke} + \cancel{dpe}$$

$$-\delta w_{rev} = v\,dp$$

$\boxed{W_b = \int_1^2 P\,dV}$ $\leftrightarrow$ $\boxed{w_{rev} = -\int_1^2 v\,dp}$ ... system이 하는 일

$\updownarrow$

$\boxed{w_{rev,in} = \int_1^2 v\,dp}$ system이 받는 일

$$w_{rev} = -\int_1^2 v\,dp \leftarrow \text{system이 하는 일}$$

$$\boxed{w_{rev,in} = \int_1^2 v\,dp}$$

$$\dot{W}_{rev,in} = \dot{m}\int_1^2 v\,dp$$

$$\frac{\dot{W}_{rev,in}}{\dot{m}} = \int_1^2 v\,dp \leftarrow v = f(p)$$

incompressible $v_1 = v_2 = const$ (specific volume)

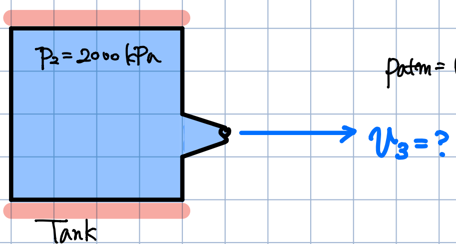
$$= v \cdot (p_2 - p_1)$$

$*$ $Q = AV$ $\quad$ $[m^3/s]\ [m^2]\cdot[m/s]$ $\qquad$ $\dot{m} = \rho A V = \rho Q$

$$\frac{\dot{W}_{rev,in}}{\rho Q} = v \cdot (p_2 - p_1)$$

$$\therefore \frac{\dot{W}_{rev,in}}{Q} = \rho v (p_2 - p_1) = (997\ kg/m^3)\cdot(0.001\ m^3/kg)\cdot(2000\,kPa - 100\,kPa)$$

$$= \underline{1900\ kJ/m^3}$$ **Ans. (a)**



$P_{atm} = 100\,kPa$

< Energy Balance >

$$\cancel{\frac{dE_{cv}}{dt}} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}(h_i + ke + pe) - \sum_e \dot{m}(h_e + ke + pe)$$

$\because$ steady-state

$$\cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} = \text{final (exit)} - \text{initial (i)}$$

$\because$ adiabatic

$$= \Delta H + \Delta KE + \cancel{\Delta PE}$$

$v_2 \approx 0$ (stationary) $\quad$ $v_3 \gg 0$ (very fast) $\Big\}$ velocity

$\downarrow$

$$0 = \Delta H + \Delta KE$$

$$0 = \Delta h + \Delta ke \leftarrow \Delta ke = \frac{1}{2}(v_3^2 - \cancel{v_2^2}) \quad (v_2 \approx 0)$$

$$\Delta h = h_3 - h_2$$

$$\therefore 0 = (h_3 - h_2) + \frac{1}{2}v_3^2$$

$T = 20^\circ C$, $p_1 = 100\,kPa \rightarrow h_1 = 2675\ kJ/kg$

? $\quad p_2 = 2000\,kPa \rightarrow h_2 = ?$

? $\quad p_3 = 100\,kPa \rightarrow h_3 = ?$

ΔH ?

$1 \rightarrow 2$

$$\cancel{Q} - W = \Delta H + \cancel{\Delta KE} + \cancel{\Delta PE}$$

$\downarrow$

$$w_{in} = \int_1^2 v\,dp = h_2 - h_1$$

$$\therefore v_3 = \sqrt{2(h_2 - h_3)} \leftarrow h_1 \approx h_3$$

$$= \sqrt{2(h_2 - h_1)}$$

$$= \sqrt{2 \cdot v(p_2 - p_1)}$$

$$= \sqrt{2 \times (0.001\ m^3/kg)\cdot(2000 - 100\,kPa)\cdot\frac{1000\,Pa}{1\,kPa}}\ [m^2/s^2]$$

$$= \underline{61.6\ m/s}$$ **Ans. (b)**

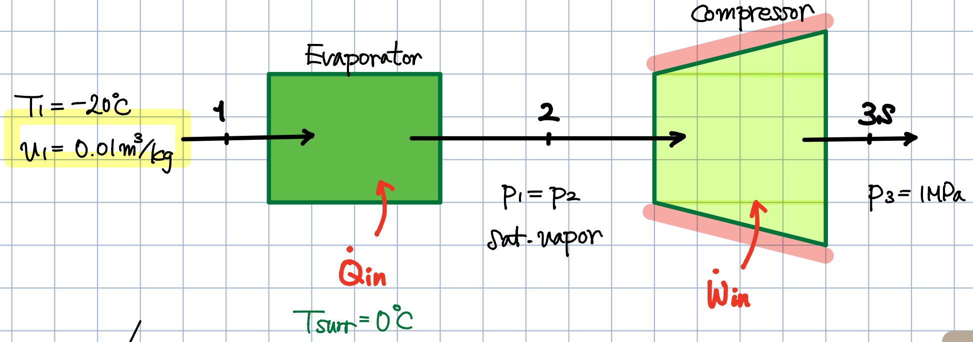
$F = ma$: $N = kg \cdot m/s^2$

$$\frac{m^3}{kg}\cdot\frac{N}{m^2} = \frac{N\cdot m}{kg} = \frac{\cancel{kg}\cdot m/s^2 \cdot m}{\cancel{kg}}$$

Ref-134a
$\dot{m} = 1\ kg/s$

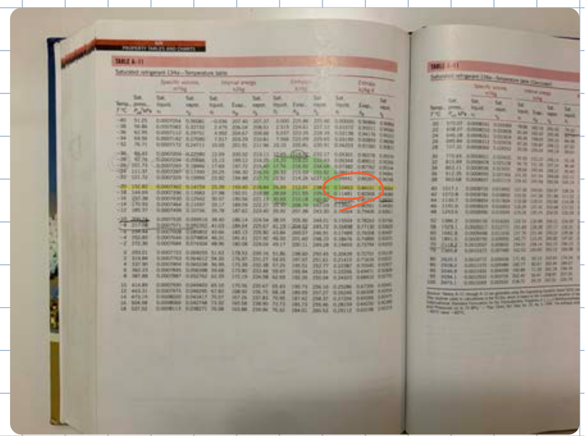
$\eta_c = 0.8$

a) $\dot{Q}_{in}$
b) $\dot{W}_{in}$
c) S_{gen}



(a) $Q - \cancel{W} = \Delta H$

$\dot{Q}_{in} = \dot{m}(h_2 - h_1)$



State 1: $T_1 = -20°C$, $v_1 = 0.01\ m^3/kg$ $\longrightarrow$ $v_f = 0.0007362$, $v_g = 0.14729$; $h_f = 25.49$, $h_{fg} = 212.91$

$$v_1 = v_f + x_1(v_g - v_f) \rightarrow x_1 = \frac{v_1 - v_f}{v_g - v_f}$$

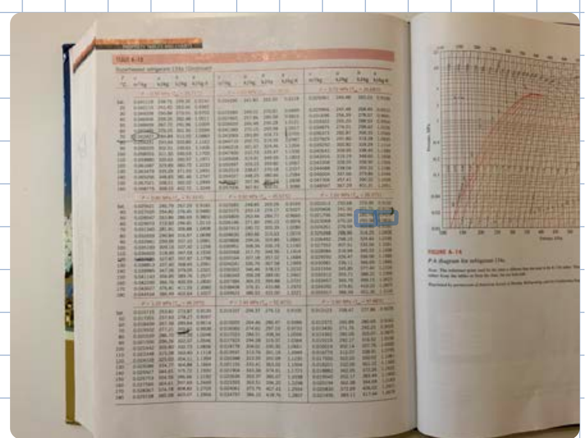
$$= \frac{(0.01) - (0.0007362)}{(0.14729) - (0.0007362)}$$

0.0092638

0.1465538

$$= \boxed{0.0632}$$

$$\therefore h_1 = h_f + x_1(h_{fg})$$
$$= (25.49) + (0.06) \cdot (212.91)$$
$$= 38.26\ kJ/kg$$



State 2: sat. vapor, $P_1 = P_2$

$h_2 = h_g = 238.41\ kJ/kg$

$s_2 = s_g = 0.94564$

$$\therefore \dot{Q}_{in} = \dot{m}(h_2 - h_1)$$
$$= (1\ kg/s) \cdot (238.41 - 38.26\ kJ/kg)$$
$$= 200.15\ kW$$

Ans.(a)

(b) $Q - W = \Delta H$

$\cancel{\dot{Q}} - \dot{W} = \dot{m}\Delta h$

$-(-\dot{W}_{in}) = \dot{m}\Delta h$

$\therefore \dot{W}_{in} = \dot{m}(h_3 - h_2)$

State 3s: $P_3 = 1MPa$, ideal $\rightarrow$ isentropic

$s_2 = s_3 = 0.94564$

h	s
271.71	0.9179
h_{3s}	0.94564
282.74	0.9525

$$\frac{271.71 - h_{3s}}{271.71 - 282.74} = \frac{0.9179 - 0.94564}{0.9179 - 0.9525} = \frac{-0.02774}{-0.0346} = 0.80173$$

-11.03

$$271.73 - h_{3s} = (-11.03) \cdot (0.80173)$$

$$\therefore h_{3s} = (271.73) + (11.03) \cdot (0.80173) = 280.57\ kJ/kg$$

$$\dot{W}_{in,ideal} = (1\ kg/s) \cdot (280.57 - 238.41)$$
$$= 42.16\ kW$$

$$\boxed{\eta_c = \frac{\dot{W}_{in,ideal}}{\dot{W}_{in,real}}} \longrightarrow \dot{W}_{in,real} = \frac{\dot{W}_{in,ideal}}{\eta_c} = \frac{42.16}{(0.8)} = \underline{52.7\ kW}$$ Ans. (b)

(c) < entropy generation >

$$\cancel{dS_{cv}/dt} = \Sigma \frac{\dot{Q}_b}{T_b} + \Sigma \dot{m}_i s_i - \Sigma \dot{m}_e s_e + \dot{S}_{gen} \longleftarrow \dot{m} = \dot{m}_i = \dot{m}_e$$

$$\dot{S}_{gen} = \dot{m}(\Sigma s_e - \Sigma s_i) - \Sigma \frac{\dot{Q}_b}{T_b}$$

$$= \dot{m}(s_3 + \cancel{s_2} - s_1 - \cancel{s_2}) - \frac{\dot{Q}_b}{T_b} \longrightarrow (1 kg/s)\cdot(0.9786 - 0.1550\ kJ/kg\cdot K) - \frac{200.15}{273 K}$$

$$= 0.8236 - 0.73315$$

$$= \underline{0.09045\ kW/K}$$ Ans. (c)

State 1: $T_1 = -20°C \longrightarrow v_f = 0.0007362$, $h_f = 25.49$

$v_1 = 0.01\ m^3/kg$, $v_g = 0.14729$, $h_{fg} = 212.91$

$x_1 = 0.06$ $s_f = 0.10463$, $s_{fg} = 0.84101$ $\rightarrow s_1 = s_f + x_1 \cdot s_{fg}$

$= (0.10463) + (0.06)\cdot(0.84101)$

$= \underline{0.1550}$

State 3s: $P_3 = 1MPa$, $\underline{ideal \rightarrow isentropic}$

$s_2 = s_3 = 0.94564$ ★

h	s
271.71	0.9179
h_{3s}	0.94564
282.74	0.9525

$$\eta_c = \frac{\dot{W}_{in,ideal}}{\dot{W}_{in,real}} = \frac{\cancel{\dot{m}}(h_{3s} - h_2)}{\cancel{\dot{m}}(h_3 - h_2)} = \frac{\overbrace{(280.57) - (238.41)}^{42.16}}{h_3 - (238.4)} = 0.8$$

$$(h_3 - 238.4)\cdot(0.8) = 42.16$$

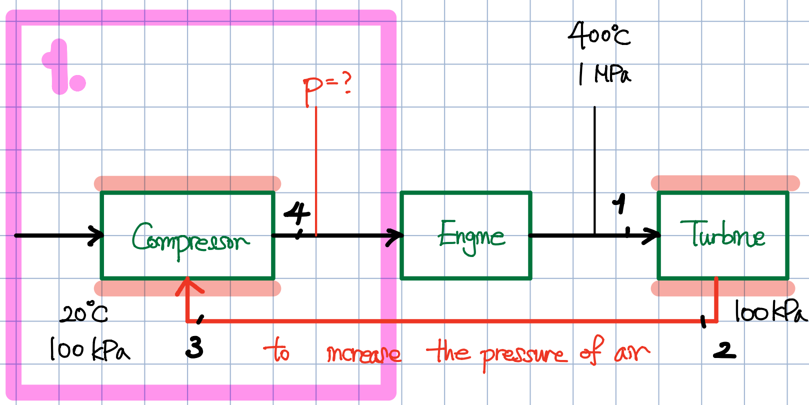
$$\therefore h_3 = 238.4 + 42.16/0.8 = 291.1$$

	h	s
	282.74	0.9525
$(=h_3)$	291.1	s_3
	293.38	0.9858

$$\frac{0.9525 - s_3}{\underbrace{0.9525 - 0.9858}_{-0.0333}} = \frac{\overbrace{282.74 - 291.1}^{-8.36}}{\underbrace{282.74 - 293.38}_{-10.64}} = 0.7857$$

$$0.9525 - s_3 = -0.02616 \qquad \therefore s_3 = 0.9786$$

Diesel turbocharger: Turbin → Compressor



$\Delta ke = \Delta pe = 0$

adiabatic, ideal (reversible)

$C_p = 0.28\ kJ/kg\cdot K$, $k = 1.4$

Calculate the air pressure at the compressor exit (engine intake)

$T_1 = 400°C$, $p_1 = 1MPa$

6.

<adiabatic>

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} = \left(\frac{P_2}{P_1}\right)^{k-1/k}$$

$$\therefore T_2 = T_1 \cdot (P_2/P_1)^{k-1/k}$$

$$= (673K)\cdot\left(\frac{100}{1000}\right)^{0.4/1.4}$$

$$= 348.58K$$

5.

$$Q - W = \Delta H$$

$$q - w = \Delta h$$

$$\cancel{\delta q} - \delta w = dh \leftarrow dh = C_p dT$$

$\because$ adiabatic

W_T

$$-W_T = \int_1^2 dh = \int_1^2 C_p dT$$

$$= C_p(T_2 - T_1)$$

4.

$$\therefore W_T = C_p(T_1 - T_2)$$

$$= (0.28\ kJ/kg\cdot K)\cdot(673 - 348.58K)$$

$$= 90.84\ kJ/kg$$

3.

$$\cancel{Q} - W = \Delta H$$

$-W_C$

$$W_C = \Delta H = C_p(T_4 - T_3) \longrightarrow W_T = C_pT_4 - C_pT_3$$

$$\parallel$$

W_T

$$\therefore T_4 = T_3 + W_T/C_p$$

$$= (293K) + \frac{(90.84\ kJ/kg)}{(0.28\ kJ/kg\cdot K)}$$

$$= 617.43K$$

2.

< adiabatic >

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{k-1} = \left(\frac{P_4}{P_3}\right)^{k-1/k}$$

$$\left(\frac{T_4}{T_3}\right)^{k/k-1} = P_4/P_3$$

$$\therefore P_4 = P_3 \cdot (T_4/T_3)^{k/k-1}$$

$$= (100\ kPa)\cdot\left(\frac{617.43K}{293K}\right)^{1.4/0.4}$$

$$= 1358.4\ kPa$$

Ans.