

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

Steam
 $m=2\text{kg}$
 $V=6\text{L}$
 $T=60^\circ\text{C}$



$$\Delta S_2 = mS_2$$

Steam : $\xrightarrow{\text{Cond}} \text{water lq} + \text{vap.}$

Trial & Error

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

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

$$T_1 = 60^\circ\text{C}$$

$$V_1 = 6\text{L} \cdot \frac{1\text{m}^3}{1000\text{L}} = 0.006\text{m}^3 \rightarrow \rho_1 = 0.003\text{m}^3/\text{kg}$$

$$\text{Table A-4} \rightarrow T_1 = 60^\circ\text{C} \rightarrow u_f = 0.001017\text{ m}^3/\text{kg} \rightarrow u_l = u_f + x_1(u_g - u_f)$$

$$u_g = 7.6670\text{ m}^3/\text{kg}$$

$$\therefore x_1 = \frac{u_l - u_f}{u_g - u_f} = \frac{0.003 - 0.001017}{7.6670 - 0.001017} = 0.000259$$

$$\therefore u_1 = u_f + x_1(u_g - u_f)$$

$$= (251.16) + (0.000259) \cdot (2204.7)$$

$$= \underline{\underline{251.73\text{ kJ/kg}}}$$

$$Q = m u_2 - m u_1$$

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

State 2:

$$u_2 = 751.73\text{ kJ/kg}$$

$$u_2 = 0.003\text{ m}^3/\text{kg}$$

$$\Delta S_2 = mS_2 = (2\text{kg}) \cdot (2.13013\text{ kJ/kg-K})$$

$$= \underline{\underline{4.26\text{ kJ/K}}} \quad \text{Ans.}$$

For S_2 , we need to know T_2, x_2

$T(\text{C}^\circ)$	u_f	u_g	u_f	u_g
180	0.001027	0.19384	761.92	1820.9

$$x_2 = \frac{u_2 - u_f}{u_g - u_f} = \frac{0.003 - 0.001027}{0.19384 - 0.001027} = 0.00972 \rightarrow u_2 = u_f + x_2(u_g - u_f) = 779.62$$

$$170 \quad 0.00114 \quad 0.24260 \quad 718.20 \quad 1857.5$$

$$x_2 = 0.00781 \rightarrow u_2 = 732.71$$

$$175 \quad 0.001121 \quad 0.21659 \quad 740.02 \quad 1839.4$$

$$x_2 = 0.00872 \rightarrow u_2 = \underline{\underline{756.06}}$$

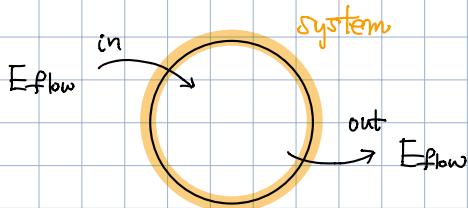
$$S_g = 2.0906$$

$$x_{fg} = 4.5335$$

$$\therefore \Delta S_2 = (2.0906) + (0.00872) \cdot (4.5335) = 2.13013\text{ kJ/kg-K}$$

열역학 제 1 법칙 (First Law of Thermodynamics)

Conservation of Energy.



$$\Delta E_{\text{system}} = \Delta E_{\text{flow}}^{\text{in}} - \Delta E_{\text{flow}}^{\text{out}}$$

$$dU = dQ - dW$$

dU : internal energy

= the change of the energy
in the system

How to characterize the system?

How to write the variables?

$$dU = dQ + \sum y_i dX_i$$

Conjugate force

extensive variables (X_c)

$-pdV$

Mechanical Work

V

Fdl

Mechanical Work

I

dP

Dielectric Work

E

$H dM$

Magnetic Work

M

ϕdg

Electrical Work

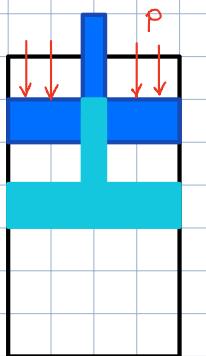
1. The work term : extensive variable + conjugate force

2. The heat term : $dQ = TdP \leftarrow$ Temperature + Entropy
(its conjugate)

E : the electric field
 P : the total polarization
of the dielectric

System = { Closed system (폐쇄계계)
Open system (개방계계)

Closed System



$$\delta W = pdV$$

경계일
(Boundary Work)

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

$$ds = Ads$$

$$\Delta E = \Delta KE + \Delta PE + \Delta U \dots$$

• Conservation of Energy

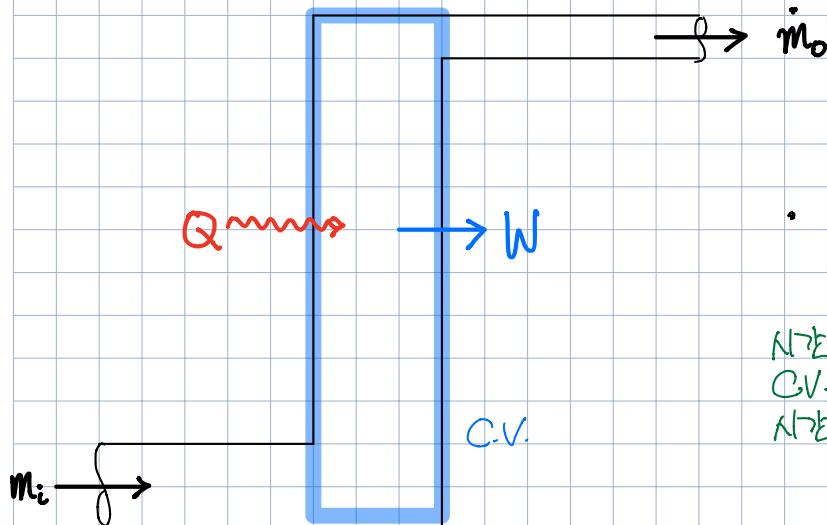
$$dE = \delta Q - \delta W$$

$$dU = \delta Q - pdV$$

$$\therefore \delta Q = dU + pdV$$

$$\delta q = du + pdv$$

Open System



장치의 소음과 통반화
CV 안으로 들어가는
에너지의 일부 변화도

• Conservation of Energy

$$dE = \delta Q - \delta W + \text{[Red circle]}$$

시간 + 미시의
CV. 안 미니자의
시간 변화도

시간 + 미시의
열전달에 의해
유입하는 미니자의
시간 변화도

시간 + 미시의
일기 의해
소모하는 미니자의
시간 변화도

작동유체가 들어오고 나간다.

시간변화도!

$$m \quad \dot{m}$$

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}_i (h_i + \frac{V_i^2}{2} + gz_i) - \dot{m}_o (h_o + \frac{V_o^2}{2} + gz_o)$$

• 진동이 들어오거나 나갈 때 발생되는 유체의 운동학적 의한 일 = $\dot{W} = \dot{W}_{av} + \dot{m} \rho v u$

$$\dot{m} \rho v [kg/s] [N/m^2] [m^3/kg] = [J/s]$$

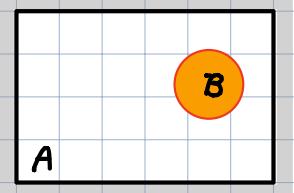
$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{av} + \dot{m}_i (h_i + \cancel{\rho v} + \frac{V_i^2}{2} + gz_i) - \dot{m}_o (h_o + \cancel{\rho v} + \frac{V_o^2}{2} + gz_o)$$

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{av} + \dot{m}_i (h_i + \frac{V_i^2}{2} + gz_i) - \dot{m}_o (h_o + \frac{V_o^2}{2} + gz_o)$$

Entropy Transfer

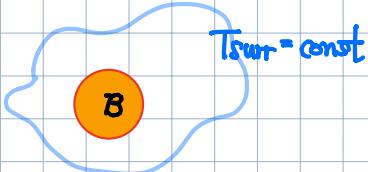
• Closed System $\sum \frac{Q_k}{T_k} + \dot{S}_{gen} = \Delta S_{system} = S_2 - S_1$

4. Adiabatic : $\dot{S}_{gen} = \Delta S_{system} = S_2 - S_1$
 $= \Delta S_A + \Delta S_B$



$\leftarrow \frac{\dot{Q}_A}{T_A} + \frac{\dot{Q}_B}{T_B} = 0$
 $\sum \frac{Q_k}{T_k} = 0$

2. Surrounding : $\dot{S}_{gen} = \Delta S_{sys} + \Delta S_{sur}$
 $= \Delta S_B + \Delta S_{sur}$
 $= \Delta S_B + \frac{\dot{Q}_{sur}}{T_{sur}}$



(Control Volume)

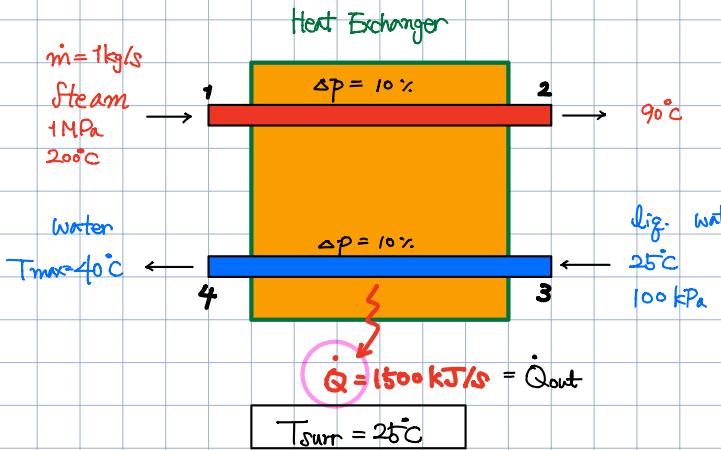
• Open System $\sum \frac{Q_k}{T_k} + \dot{S}_{gen} + \sum \dot{m}_i \dot{s}_i - \sum \dot{m}_e \dot{s}_e = (\dot{S}_2 - \dot{S}_1)_{cv}$

$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i \dot{s}_i - \sum \dot{m}_e \dot{s}_e + \dot{S}_{gen} = \frac{dP_{cv}}{dt}$

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

Steady-flow, adiabatic : $\dot{S}_{gen} = \sum \dot{m}_e \dot{s}_e - \sum \dot{m}_i \dot{s}_i$

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



$\Delta KE, \Delta PE$ are negligible

a) The minimum mass flow rate of the cooling water

b) Assume: $\dot{m}_{in} = 10 \text{ kg/s}$
Heat transfer: internally reversible (w/ Environment)
& isothermal
 $S_{gen} = ?$

Open System \rightarrow TD's 1st Law

$$\frac{dE_{sys}}{dt} = \dot{Q} - \dot{W}_{ext} + \dot{m}_1(h_1 + \frac{V^2}{2} + gz_1) - \dot{m}_2(h_2 + \frac{V^2}{2} + gz_2)$$

\therefore steady state
 $-\dot{Q}_{out}$

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

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

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

Superheated? $\rightarrow T_{sat} \sim 179.88^\circ\text{C}$ (at 1 MPa) $\rightarrow 0$

* Superheated?

$$\therefore h_1 = 2828.3 \text{ kJ/kg.K}, s_1 = 6.6956$$

State 2: 90°C, 0.9 MPa (900 kPa)

* Subcooled?

<Temp. Table> $T = 90^\circ\text{C} \rightarrow P_{sat} = 70.183 \text{ kPa}$

$\rightarrow \therefore$ subcooled liquid! \rightarrow fluid 100%

<Pressure Table> $P = 0.9 \text{ MPa} \rightarrow T_{sat} = 175.35^\circ\text{C}$

* Temp. table?

$$\therefore T = 90^\circ\text{C} \text{ (temp. table)} : h_f = h_2 = 377.04 \text{ kJ/kg}$$

$$s_f = s_2 = 1.1929 \text{ kJ/kg.K}$$

State 3: liq. water 25°C 100 kPa

$$h_f = h_3 = 104.83$$

$$s_f = s_3 = 0.3672$$

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

State 4: Water $T_{water} = 40^\circ\text{C}$ 90 kPa

$$h_f = 167.53$$

$$s_f = 0.5724$$

$$\dot{m}_3 = \frac{\dot{Q}_{out} - \dot{m}_1 (h_1 - h_2)}{h_3 - h_f} = \frac{1500 - (1)(2828.3 - 377.04)}{104.83 - 167.53} = 15.17 \text{ kg/s}$$

Ans. (a)

b) Assume: $\dot{m}_w = 10 \text{ kg/s}$

Heat transfer: internally reversible
(w/ Environment)
&
isothermal

$$\dot{S}_{\text{gen}} = ?$$

$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i s_i - \sum \dot{m}_o s_o + \dot{S}_{\text{gen}} = \frac{dS_{\text{sys}}}{dt}$$

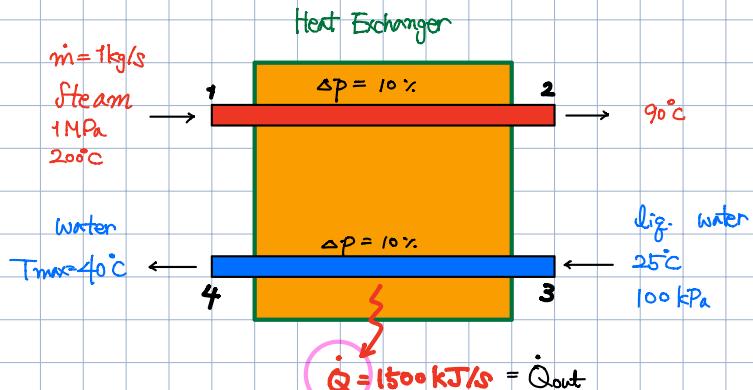
.. steady-state

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

$$= \dot{m}_1 (s_1 - s_2) + \dot{m}_2 (s_3 - s_4)$$

$$\begin{aligned} \dot{S}_{\text{gen}} &= \dot{m}_1 (s_1 - s_2) + \dot{m}_2 (s_3 - s_4) + \frac{\dot{Q}_{\text{out}}}{T_b} \\ &= (1 \text{ kg/s}) \cdot (1.1929 - 6.6956 \text{ kJ/kg.K}) + (10) \cdot (0.5724 - 0.3672) + \frac{1500 \text{ kJ/s}}{298 \text{ K}} \\ &= -5.5027 + 2.052 + 5.0335 \\ &= 1.58286 \text{ kJ/K.s} \end{aligned}$$

Ans. (b)



$$\frac{1500 \text{ kJ/s}}{298 \text{ K}} = 5.0335$$

TABLE A-4
Saturated water - Temperature table (Continued)

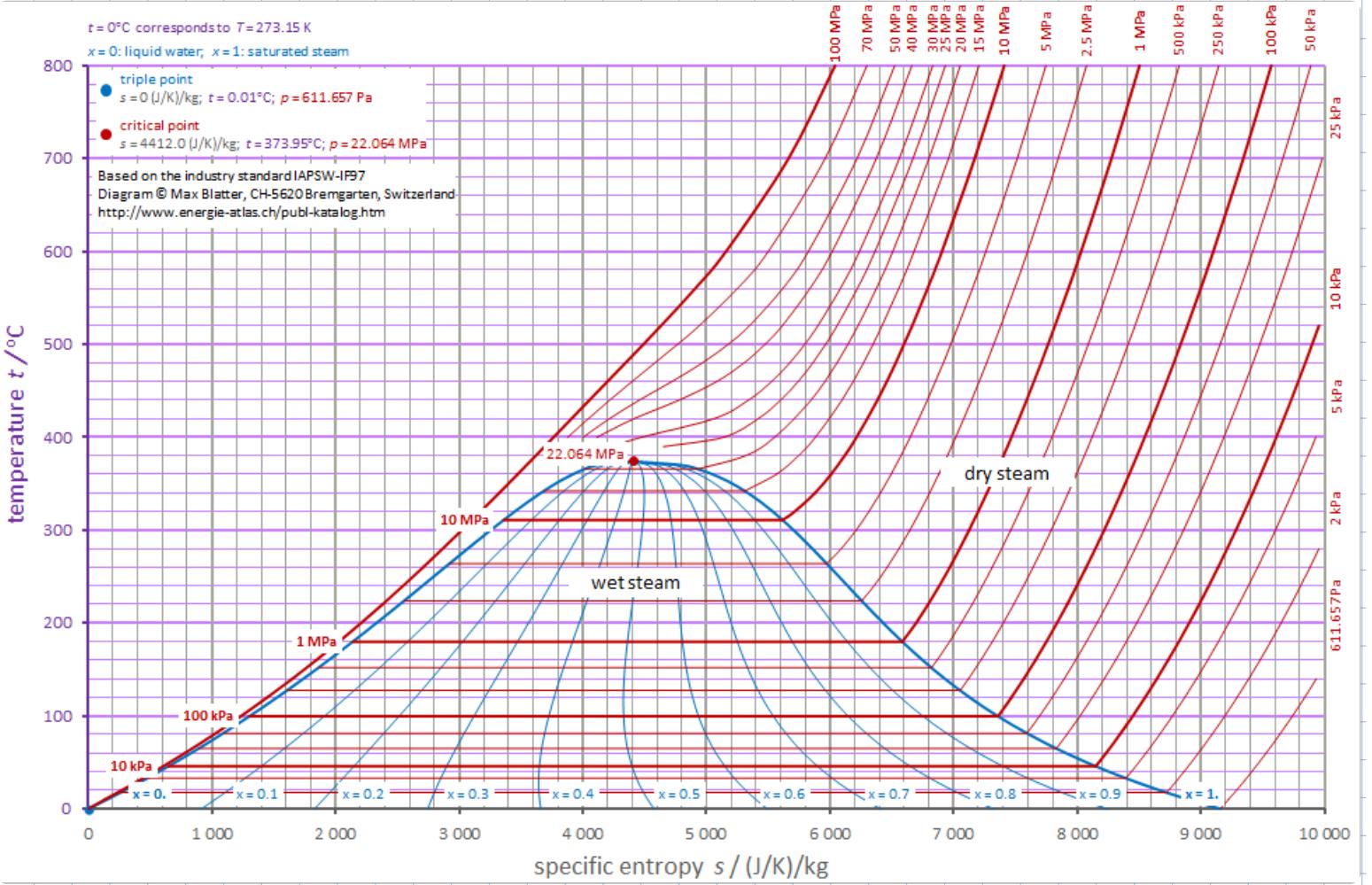
This table provides saturation properties for water at temperatures from 0°C to 100°C. It includes columns for Pressure (P), Specific volume (v), Enthalpy (h), Entropy (s), and other thermodynamic properties.

T (°C)	P (kPa)	v (m³/kg)	h (kJ/kg)	s (kJ/kg K)
0	0.000000000000000	0.000000000000000	0.000000000000000	0.000000000000000
10	0.010000000000000	0.000999999999998	40.6300000000000	0.000000000000000
20	0.036600000000000	0.001999999999996	80.5600000000000	0.000000000000000
30	0.100000000000000	0.002999999999994	120.590000000000	0.000000000000000
40	0.200000000000000	0.003999999999992	160.620000000000	0.000000000000000
50	0.333333333333333	0.004999999999990	200.650000000000	0.000000000000000
60	0.500000000000000	0.005999999999988	239.680000000000	0.000000000000000
70	0.700000000000000	0.006999999999986	278.710000000000	0.000000000000000
80	0.923907000000000	0.007999999999984	317.740000000000	0.000000000000000
90	1.16666666666667	0.008999999999982	356.770000000000	0.000000000000000
100	1.43333333333333	0.009999999999980	395.800000000000	0.000000000000000
110	1.71666666666667	0.010999999999978	434.830000000000	0.000000000000000
120	2.01666666666667	0.011999999999976	473.860000000000	0.000000000000000
130	2.32333333333333	0.012999999999974	512.890000000000	0.000000000000000
140	2.63666666666667	0.013999999999972	551.920000000000	0.000000000000000
150	3.05666666666667	0.014999999999970	590.950000000000	0.000000000000000
160	3.48222222222222	0.015999999999968	629.980000000000	0.000000000000000
170	3.91444444444444	0.016999999999966	668.010000000000	0.000000000000000
180	4.35222222222222	0.017999999999964	706.040000000000	0.000000000000000
190	4.80555555555555	0.018999999999962	744.070000000000	0.000000000000000
200	5.26444444444444	0.019999999999960	782.100000000000	0.000000000000000
210	5.73000000000000	0.020999999999958	820.130000000000	0.000000000000000
220	6.20222222222222	0.021999999999956	858.160000000000	0.000000000000000
230	6.68144444444444	0.022999999999954	896.190000000000	0.000000000000000
240	7.16722222222222	0.023999999999952	934.220000000000	0.000000000000000
250	7.65055555555555	0.024999999999950	972.250000000000	0.000000000000000
260	8.13144444444444	0.025999999999948	1010.280000000000	0.000000000000000
270	8.61000000000000	0.026999999999946	1048.310000000000	0.000000000000000
280	9.08622222222222	0.027999999999944	1086.340000000000	0.000000000000000
290	9.55999999999999	0.028999999999942	1124.370000000000	0.000000000000000
300	10.03144444444444	0.029999999999940	1162.400000000000	0.000000000000000
310	10.50055555555555	0.030999999999938	1200.430000000000	0.000000000000000
320	10.96744444444444	0.031999999999936	1238.460000000000	0.000000000000000
330	11.43200000000000	0.032999999999934	1276.490000000000	0.000000000000000
340	11.89422222222222	0.033999999999932	1314.520000000000	0.000000000000000
350	12.35414444444444	0.034999999999930	1352.550000000000	0.000000000000000
360	12.81176666666667	0.035999999999928	1390.580000000000	0.000000000000000
370	13.26718888888889	0.036999999999926	1428.610000000000	0.000000000000000
380	13.72040000000000	0.037999999999924	1466.640000000000	0.000000000000000
390	14.17141111111111	0.038999999999922	1504.670000000000	0.000000000000000
400	14.61999999999999	0.039999999999920	1542.700000000000	0.000000000000000
410	15.06622222222222	0.040999999999918	1580.730000000000	0.000000000000000
420	15.50999999999999	0.041999999999916	1618.760000000000	0.000000000000000
430	15.95200000000000	0.042999999999914	1656.790000000000	0.000000000000000
440	16.39222222222222	0.043999999999912	1694.820000000000	0.000000000000000
450	16.83055555555555	0.044999999999910	1732.850000000000	0.000000000000000
460	17.26700000000000	0.045999999999908	1770.880000000000	0.000000000000000
470	17.70144444444444	0.046999999999906	1808.910000000000	0.000000000000000
480	18.13388888888889	0.047999999999904	1846.940000000000	0.000000000000000
490	18.56422222222222	0.048999999999902	1884.970000000000	0.000000000000000
500	18.99244444444444	0.049999999999900	1922.000000000000	0.000000000000000
510	19.41855555555555	0.050999999999898	1959.030000000000	0.000000000000000
520	19.84266666666667	0.051999999999896	1996.060000000000	0.000000000000000
530	20.26477777777778	0.052999999999894	2033.090000000000	0.000000000000000
540	20.68500000000000	0.053999999999892	2070.120000000000	0.000000000000000
550	21.09933333333333	0.054999999999890	2107.150000000000	0.000000000000000
560	21.50866666666667	0.055999999999888	2144.180000000000	0.000000000000000
570	21.91400000000000	0.056999999999886	2181.210000000000	0.000000000000000
580	22.31533333333333	0.057999999999884	2218.240000000000	0.000000000000000
590	22.71266666666667	0.058999999999882	2255.270000000000	0.000000000000000
600	23.10700000000000	0.059999999999880	2292.300000000000	0.000000000000000
610	23.49833333333333	0.060999999999878	2329.330000000000	0.000000000000000
620	23.88666666666667	0.061999999999876	2366.360000000000	0.000000000000000
630	24.27200000000000	0.062999999999874	2403.390000000000	0.000000000000000
640	24.65533333333333	0.063999999999872	2440.420000000000	0.000000000000000
650	25.03666666666667	0.064999999999870	2477.450000000000	0.000000000000000
660	25.41599999999999	0.065999999999868	2514.480000000000	0.000000000000000
670	25.79333333333333	0.066999999999866	2551.510000000000	0.000000000000000
680	26.16866666666667	0.067999999999864	2588.540000000000	0.000000000000000
690	26.54199999999999	0.068999999999862	2625.570000000000	0.000000000000000
700	26.91333333333333	0.069999999999860	2662.600000000000	0.000000000000000
710	27.28266666666667	0.070999999999858	2700.630000000000	0.000000000000000
720	27.64999999999999	0.071999999999856	2738.660000000000	0.000000000000000
730	28.01533333333333	0.072999999999854	2776.690000000000	0.000000000000000
740	28.37866666666667	0.073999999999852	2814.720000000000	0.000000000000000
750	28.74000000000000	0.074999999999850	2852.750000000000	0.000000000000000
760	29.09933333333333	0.075999999999848	2890.780000000000	0.000000000000000
770	29.45666666666667	0.076999999999846	2928.810000000000	0.000000000000000
780	29.81299999999999	0.077999999999844	2966.840000000000	0.000000000000000
790	30.16833333333333	0.078999999999842	3004.870000000000	0.000000000000000
800	30.52266666666667	0.080999999999840	3042.900000000000	0.000000000000000
810	30.87599999999999	0.081999999999838	3080.930000000000	0.000000000000000
820	31.22833333333333	0.082999999999836	3118.960000000000	0.000000000000000
830	31.57966666666667	0.083999999999834	3156.990000000000	0.000000000000000
840	31.92999999999999	0.084999999999832	3194.020000000000	0.000000000000000
850	32.27933333333333	0.085999999999830	3231.050000000000	0.000000000000000
860	32.62766666666667	0.086999999999828	3269.080000000000	0.000000000000000
870	32.97499999999999	0.087999999999826	3307.110000000000	0.000000000000000
880	33.32133333333333	0.088999999999824	3345.140000000000	0.000000000000000
890	33.66666666666667	0.089999999999822	3383.170000000000	0.000000000000000
900	34.01100000000000	0.090999999999820	3421.200000000000	0.000000000000000
910	34.35433333333333	0.091999999999818	3459.230000000000	0.000000000000000
920	34.69666666666667	0.092999999999816	3497.260000000000	0.000000000000000
930	35.03800000000000	0.093999999999814	3535.290000000000	0.000000000000000
940	35.37833333333333	0.094999999999812	3573.320000000000	0.000000000000000
950	35.71766666666667	0.095999999999810	3611.350000000000	0.000000000000000
960	36.05599999999999	0.096999999999808	3649.380000000000	0.000000000000000
970	36.39333333333333	0.097999999999806	3687.410000000000	0.000000000000000
980	36.72966666666667	0.098999999999804	3725.440000000000	0.000000000000000
990	37.06500000000000	0.099999999999802	3763.470000000000	0.000000000000000
1000	37.39933333333333	0.099999999999800	3801.500000000000	0.000000000000000

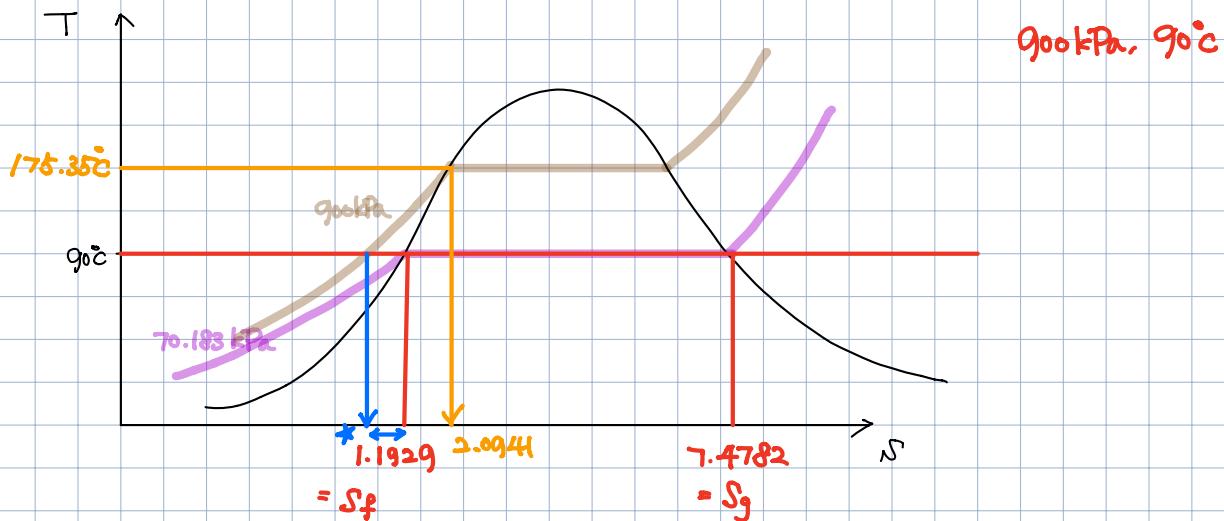
TABLE A-4
Saturated water - Temperature table (Continued)

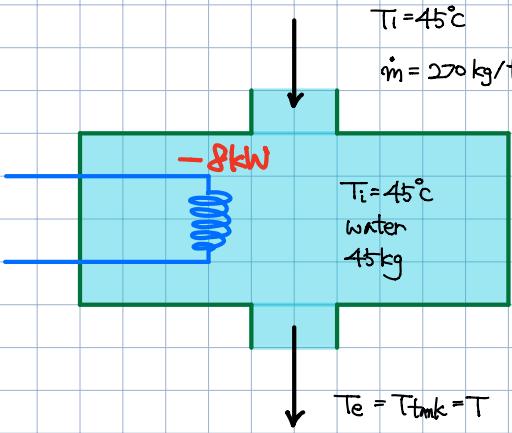
This table provides saturation properties for water at temperatures from 0°C to 100°C. It includes columns for Pressure (P), Specific volume (v), Enthalpy (h), Entropy (s), and other thermodynamic properties.

T (°C)	P (kPa)	v (m³/kg)	h (kJ/kg)	s (kJ/kg K)
0	0.000000000000000	0.000000000000000	0.000000000000000	0.000000000000000
10	0.036600000000000	0.001999999999996	40.6300000000000	0.000000000000000
20	0.100000000000000	0.002999999999994	80.5600000000000	0.000000000000000
30	0.200000000000000	0.003999999999992	120.490000000000	0.000000000000000
40	0.333333333333333	0.004999999999990	160.420000000000	0.000000000000000
50	0.500000000000000	0.005999999999988	200.350000000000	0.000000000000000
60	0.700000000000000	0.006999999999986	239.280000000000	0.000000000000000
70	0.923907000000000	0.007999999999984	278.210000000000	0.000000000000000
80	1.16666666666667	0.008999999999982	317.140000000000	0.000000000000000
90	1.43333333333333	0.009999999999980	356.070000000000	0



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





45kg, liq. water, 45°C

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

cooling coil = $\delta \text{ kW}$

T in tank = uniform

$P_{in} = P_{out}$

$C = 4.2 \text{ kJ/kg}\cdot\text{K}$

$\Delta p_e = \Delta k_e = 0$

Determine the variation of the tank water temp.

$$\frac{dE_{sys}}{dt} = \dot{Q} - \dot{W}_a + \dot{m}_i(h_i + \frac{V^2}{2} + gz) - \dot{m}_o(h_o + \frac{V^2}{2} + gz)$$

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

$$\leftarrow \frac{dE}{dt} = C dT, \quad \frac{dE_{sys}}{dt} = \dot{m} C \left(\frac{dT}{dt} \right)_{air}$$

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

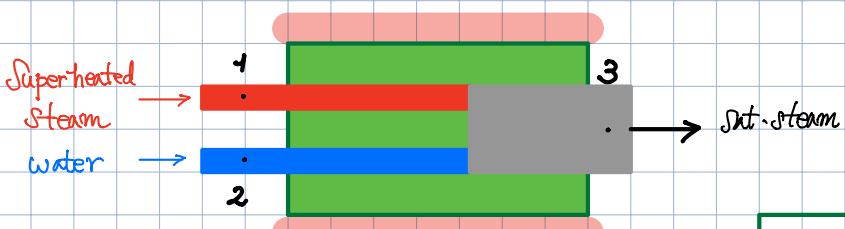
$$Q = E = \dot{m} T$$

CV 열전달의 질량

$$\begin{aligned} \frac{dT}{dt} &= \frac{\dot{Q}}{\dot{m} C} + \frac{\dot{m}_e}{\dot{m} C} (T_i - T) \\ &= \frac{-\delta \text{ kJ/s}}{(45 \text{ kg}) \cdot (4.2 \text{ kJ/kg}\cdot\text{K})} + \frac{(270 \text{ kg/h}) \cdot \frac{1 \text{ h}}{3600 \text{ s}}}{(45 \text{ kg})} (318 - T) \text{ K} \\ &= -0.0423 + 0.0017(318 - T) \end{aligned}$$

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

Ans.



adiabatic desuperheater
steady state

water + superheated steam \rightarrow sat. steam

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

$$p_1 = 2.7 \text{ MPa}, T_1 = 300^\circ\text{C}$$

$$h_1 = 3002.7 \text{ kJ/kg}, s_1 = 6.6019 \text{ kJ/kg}\cdot\text{K}$$

$$\dot{m}_1 = 1000 \text{ kg/h} = \frac{1000 \text{ kg/h}}{3600 \text{ s}} = 0.278 \text{ kg/s}$$

$$p_2 = 2.7 \text{ MPa}, T_2 = 40^\circ\text{C}$$

$$h_2 = 174 \text{ kJ/kg}, s_2 = 0.571 \text{ kJ/kg}\cdot\text{K}$$

$$p_3 = 2.5 \text{ MPa}, T_3 = 223.99^\circ\text{C} (\text{sat.})$$

$$h_3 = 2803.1 \text{ kJ/kg}, s_3 = 6.2575 \text{ kJ/kg}\cdot\text{K}$$

<Energy Balance - Open System>

$$\cancel{\frac{dE_{\text{sys}}}{dt}} = \dot{Q}_{\text{ar}} - \dot{W}_{\text{ar}} + \dot{m}_1(h_1) - \dot{m}_2(h_2)$$

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

$$= (\dot{m}_1 + \dot{m}_2) h_3$$

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

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

<Entropy - Open System>

$$\cancel{\frac{dS_{\text{sys}}}{dt}} = \sum \frac{\dot{m}_i}{T_i} + \dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{S}_{\text{gen}}$$

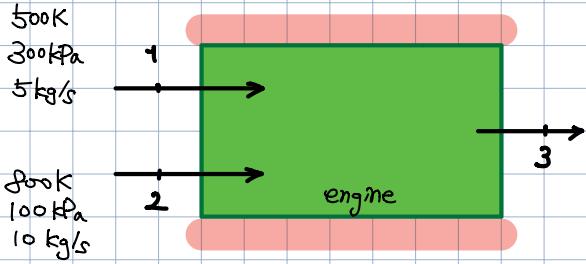
$$\dot{S}_{\text{gen}} = \dot{m}_2 s_2 - \dot{m}_1 s_1$$

$$= \dot{m}_3 s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2 \quad \leftarrow \quad \dot{m}_3 = 0.2991$$

$$= (0.2991) \cdot (6.2575) - (0.278) \cdot (6.6019) - (0.0211) \cdot (0.571)$$

$$= 0.02424 \text{ kJ/K.s} \quad \text{Ans.(b)}$$

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



Two air streams
 steady-state
 adiabatic
 $\Delta h_e = \Delta p_e = 0$
 ideal gas with const C
 $(R = 0.287 \text{ kJ/kg.K}, C = 1 \text{ kJ/kg.K})$

Determine the maximum power output of the engine.

$$\frac{dE_{av}}{dt} = \dot{Q}_v - \dot{W}_{av} + \sum m_i(h_i) - \sum m_e(h_e)$$

$$\begin{aligned} W_{\text{engine}} &= \sum m_i h_i - \sum m_e h_e \\ &= m_1 h_1 + m_2 h_2 - m_3 h_3 \end{aligned}$$

$m_1 + m_2 = m_3$
 $5 \text{ kg/s} + 10 \text{ kg/s} = 15 \text{ kg/s}$

$$C_p = \left(\frac{\partial Q}{\partial T} \right)_P = \left(\frac{\partial H}{\partial T} \right) \leftarrow \delta q = dh - vdp$$

$$\therefore H = mC_p T$$

$$\frac{dS_{tot}}{dt} = \sum \frac{\dot{Q}_i}{T_i} + \dot{m}_1 s_1 - \dot{m}_e s_e + \dot{S}_{gen}$$

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

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

$$\delta q = dh - vdp$$

$$\delta T_{de} = C_p dT - \frac{R}{P} dP$$

$$\Delta S = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

$$\begin{aligned} (5) \cdot \left\{ (1) \ln \frac{T_3}{500} - (0.287) \cdot \ln \frac{100}{300} \right\} \\ + (10) \cdot \left\{ (1) \ln \frac{T_3}{800} + (0.287) \cdot \ln \frac{100}{100} \right\} \\ 5 \cdot \left\{ \ln T_3 - \ln 500 + 0.3153 \right\} + [10 \ln T_3 - 10 \ln 800] = 0 \end{aligned}$$

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

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

$$\begin{aligned} 15 \ln T_3 &= 5 \ln 500 - 1.5765 + 10 \ln 800 \\ &= 31.073 - 1.5765 + 66.846 \\ &= 96.3425 \end{aligned}$$

$$\ln T_3 = 6.423$$

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

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

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

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

in order to have maximum work out,
 isentropic reversible → no entropy change!

$$W_{\text{engine}} = (5)(500) + (10) \cdot (800) + (15) \cdot (615.75)$$

$$= 1263.75 \text{ kJ/s}$$

Ans.

adiabatic, reversible, steady-state

$$C_p = 1.87 \text{ kJ/kg.K}, k = 1.3, \nu = 0.001 \text{ m}^3/\text{kg}$$

(ideal gas)

$$\nu = 0.001 \text{ m}^3/\text{kg}$$

$\gamma = 1.3$: incompressible

a) pump: $100 \text{ kPa}, 20^\circ\text{C} \rightarrow 1000 \text{ kPa}$ $\rightarrow W_{\text{pump}} = \int_1^2 u dp = (0.001 \text{ m}^3/\text{kg}) (1000 - 100 \text{ kPa}) = 0.9 \text{ kJ/kg}$ Ans.(a)

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

< isentropic, ideal gas >

$$\frac{T_2}{T_1} = (\nu \frac{P_2}{P_1})^{\frac{1}{k-1}} = (P_2 \frac{P_1}{P_1})^{\frac{1}{k-1}}$$

$$T_2 = T_1 \cdot (P_2 \frac{P_1}{P_1})^{\frac{1}{k-1}} = (773 \text{ K}) \cdot (1000 / 100)^{\frac{1-1}{1.3-1}} = 1315.1 \text{ K}$$

$$\delta Q - \delta W = dh + dk_e + dp_e$$

$$\delta W_{\text{in}} = dh$$

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

Ans.(b)

$$\delta W_p = u dp$$

$$\frac{dF_{\text{ext}}}{dt} = \dot{Q}_{\text{av}} - \dot{W}_{\text{av}} + \sum_i m (h_i + \frac{V_i^2}{2} + gz_i) - \sum_i m (h_{i2} + \frac{V_{i2}^2}{2} + gz_{i2})$$

$$\dot{Q}_{\text{av}} - \dot{W}_{\text{av}} = \text{final} - \text{initial}$$

$$\dot{Q}_{\text{av}} - \dot{W}_{\text{av}} = \Delta H + \Delta KE + \Delta PE$$

Reversible, Steady-flow work

$$\delta_{\text{rev}} Q - \delta_{\text{rev}} W = dh + dk_e + dp_e$$

$$\left\{ \begin{array}{l} \delta_{\text{rev}} Q = T ds \\ T ds = dh - u dp \end{array} \right. \rightarrow \delta_{\text{rev}} Q = dh - u dp$$

$$(dh - u dp) - \delta_{\text{rev}} W = dh + dk_e + dp_e$$

$$W_b = \int_1^2 P dV$$

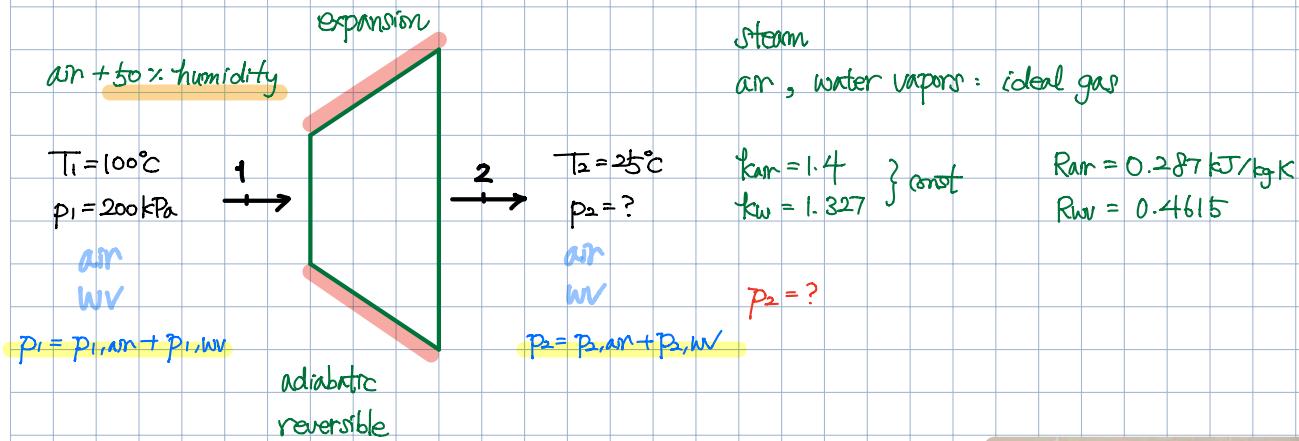
$$-\delta_{\text{rev}} W = u dp$$

$$W_{\text{rev}} = - \int_1^2 u dp$$

... system 1 $\frac{\partial T}{\partial S} \neq 0$

$$W_{\text{rev,in}} = \int_1^2 u dp$$

System 1 $\frac{\partial T}{\partial S} \neq 0$



$$\phi = \frac{\text{water vapor pressure}}{\text{equilibrated vapor pressure}}$$

State 1:

(WV) $T_1 = 100^\circ\text{C} \rightarrow p_1 = 101.42 \text{ kPa}$
 $p_{\text{wv},1} = (0.5) \cdot (101.42) = 50.7 \text{ kPa}$

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

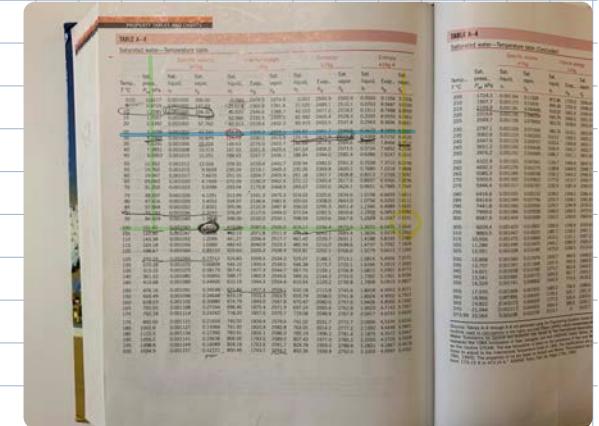
$$= 200 - 50.7 = 149.3 \text{ kPa}$$

State 2:

(Air) adiabatic $\rightarrow \frac{T_2}{T_1} = \left(\frac{p_1}{p_2}\right)^{\frac{k-1}{k}} = \left(\frac{p_1}{p_2}\right)^{\frac{1.4}{1.4}}$

$$p_{2,\text{air}} = (p_{1,\text{air}}) \cdot \left(\frac{T_2}{T_1}\right)^{\frac{1.4}{1.4}} = (149.3 \text{ kPa}) \cdot \left(\frac{298 \text{ K}}{373 \text{ K}}\right)^{\frac{1.4}{1.4}} = 68.05 \text{ kPa}$$

(WV) adiabatic/reversible \rightarrow isentropic!
 $\Delta S = 0$



$$p_2 = (68.05) + (3.17) \\ = 71.22 \text{ Ans.}$$

$$T_1 = 100^\circ\text{C} \rightarrow S_1 = S_g = 7.3542 \text{ kJ/kg}\cdot\text{K} \quad (S_f = S_i)$$

$$T_2 = 25^\circ\text{C} \rightarrow S_f = 0.3672$$

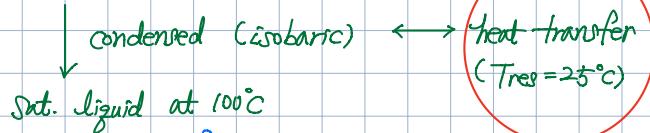
$$S_{fg} = 0.1895 \longrightarrow S_i = S_f + X_2(S_f - S_f)$$

$$S_g = 0.5567$$

$$\therefore X_2 = \frac{(7.3542) - (0.3672)}{0.1895} = 0.8532$$

$$p_{2,\text{wv}} = p_{\text{sat}} (\text{at } T=25^\circ\text{C}) \\ = 3.17 \text{ kPa}$$

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



$$\Delta S = ?$$

(the net increase in entropy)
(system = water + surrounding)

$$\Delta S_{\text{system}} = \Delta S_{\text{water}} + \Delta S_{\text{sur}} = ?$$

Water

$$T_1 = 100^\circ\text{C} \rightarrow S_1 = S_g = 7.3542 \text{ kJ/kg·K}$$

$$S_2 = S_f = 1.3072$$

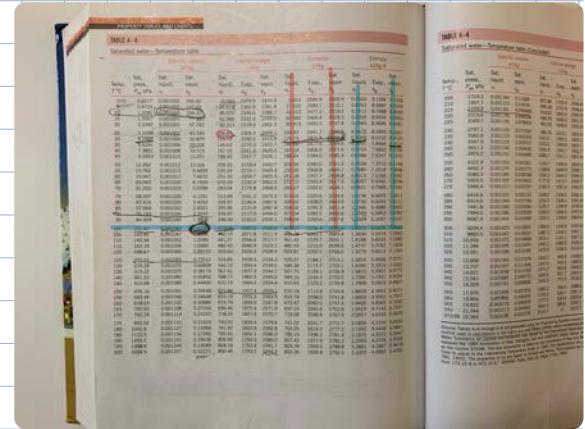
$$\begin{aligned}\Delta S_{\text{water}} &= S_2 - S_1 \\ &= (1.3072) - (7.3542) \\ &= \underline{-6.047 \text{ kJ/kg·K}}\end{aligned}$$

Heat

$$\Delta S_{\text{sur}} = \frac{Q_b}{T_b}$$

$$\begin{aligned}\Delta E &= Q_b = \Delta H = m(h_1 - h_2) = (1\text{kg}) \cdot (2675.6 - 419.17 \text{ kJ/kg}) \\ &= \underline{\underline{2256.4 \text{ kJ}}}\end{aligned}$$

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



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

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



Assume steady-state

Water (20°C , 100 kPa): $C_v = 4.18 \text{ kJ/kg}\cdot\text{K}$
 $\gamma = 0.001 \text{ m}^3/\text{kg}$
 $h = 2675 \text{ kJ/kg}$
 $\rho = 997 \text{ kg/m}^3$

$$\dot{W}_{\text{rev}} = - \int_1^2 \dot{m} dp \quad \leftarrow \text{systemal } \frac{\partial h}{\partial p} \text{ eq}$$

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

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

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

$$= \dot{m} \cdot (p_2 - p_1)$$

$U_1 = U_2 = \text{const}$ (specific volume)

$$* Q = AV \quad \dot{m} = \rho A V = \rho Q$$

[m^3/s] [m^2]. [m/s]

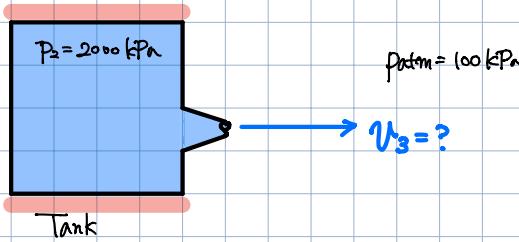
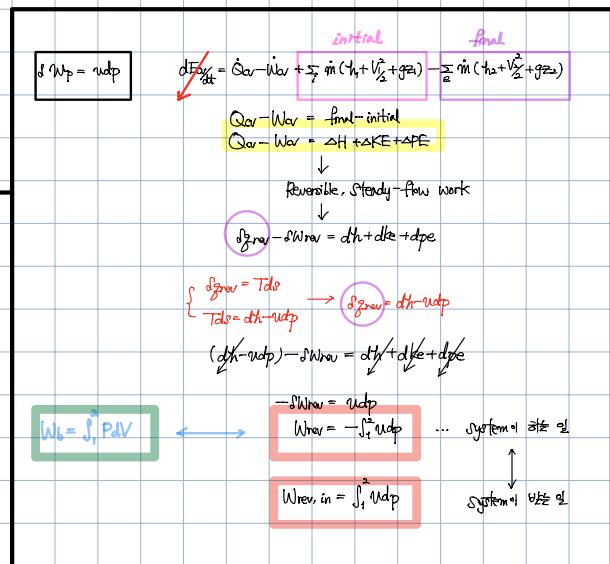
$$\dot{W}_{\text{rev,in}} / \rho Q = \dot{m} \cdot (p_2 - p_1)$$

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

= 1900 kJ/m^3 **Ans.(a)**

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

b) V_{waterjet}



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

$$? \quad p_2 = 2000\text{ kPa} \rightarrow h_2 = ?$$

$$? \quad p_3 = 100\text{ kPa} \rightarrow h_3 = ?$$

< Energy Balance >

$$\frac{dE}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m} (h_i + k_e + p_e) - \sum \dot{m} (h_f + k_e + p_e)$$

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

\because adiabatic $\dot{W}_{cv} = \Delta H + \Delta KE + \Delta PE$

$U_2 \approx 0$ (stationary) $U_3 \gg 0$ (very fast) } velocity

$$\gamma \rightarrow 2 \quad \text{---} W = \Delta H + \Delta KE + \Delta PE$$

$$\dot{W}_{\text{in}} = \int_1^2 \dot{m} dp = h_2 - h_1$$

$$\therefore O = (h_3 - h_2) + \frac{1}{2} U_3^2$$

$$\therefore U_3 = \sqrt{2(h_2 - h_3)} \quad \leftarrow h_1 \approx h_3$$

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

$$= \sqrt{2(h_2 - h_3)}$$

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

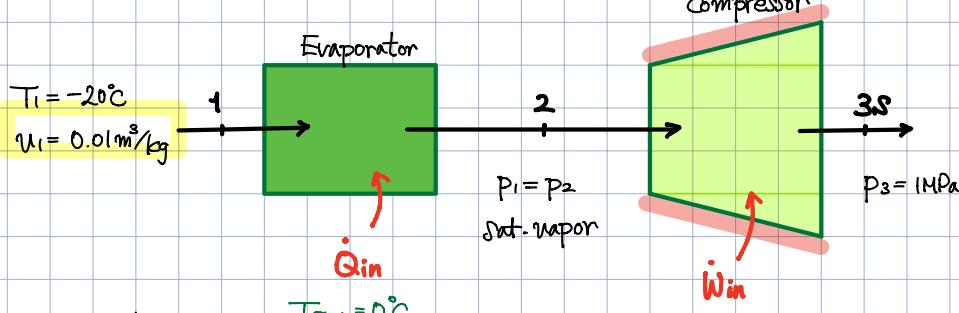
$$= \sqrt{2 \cdot (0.001 \text{ m}^3/\text{kg}) \cdot (2000 - 100 \text{ kPa}) \cdot \frac{1000 \text{ Pa}}{1 \text{ kPa}}} \quad [\text{m/s}^2]$$

$$= 61.6 \text{ m/s} \quad \text{Ans.(b)}$$

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

Ref-134a

$m = 1 \text{ kg/s}$



a) \dot{Q}_{in}

b) \dot{W}_{in}

c) S_{gen}

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

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

$$\underline{\text{State 1:}} \quad T_1 = -20^\circ\text{C} \rightarrow h_f = 0.0007362 \quad h_f = 25.49$$

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

$$v_1 = v_f + x_1(v_g - v_f) \rightarrow x_1 = \frac{v_1 - v_f}{v_g - v_f} \quad 0.0092(3)$$

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

$$= 0.0632 \quad \Rightarrow 0.1465538$$

$$\therefore h_1 = h_f + x_1(h_{fg})$$

$$= (25.49) + (0.06) \cdot (212.91)$$

$$= 38.26 \text{ kJ/kg}$$

$$\underline{\text{State 2:}} \quad \text{saturated vapor}, \quad p_1 = p_2$$

$$h_2 = h_g = 238.41 \text{ kJ/kg}$$

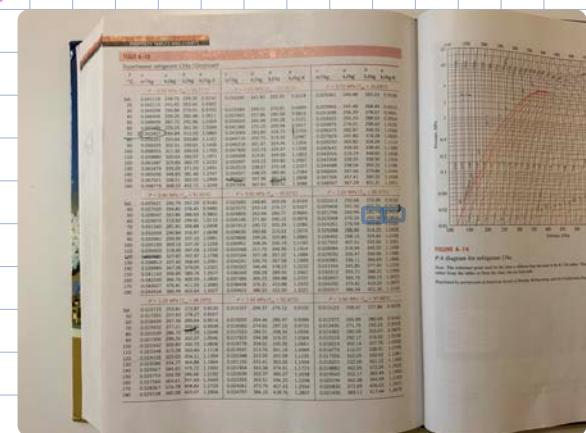
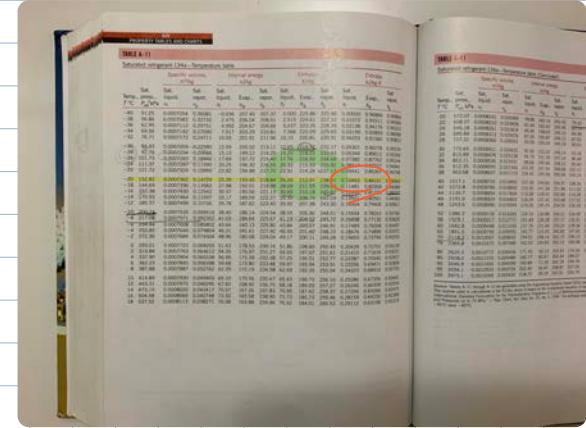
$$\dot{Q}_{in} = \dot{S}_g = 0.94564$$

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

$$= (1 \text{ kg/s}) \cdot (238.41 - 38.26 \text{ kJ/kg})$$

$$= 200.15 \text{ kW}$$

Ans.(a)



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

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

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

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

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

$$= 42.16 \text{ kW}$$

State 3.8: $p_3 = 1 \text{ MPa}$, ideal \rightarrow isentropic

$$\dot{S}_2 = \dot{S}_3 = 0.94564$$

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

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

$$\leftarrow -11.03$$

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

$$\therefore h_{3s} = (271.73) + ((1.03) \cdot (0.80173)) = 280.57 \text{ kJ/kg}$$

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

(c) < entropy generation >

$$\frac{dS_{gen}}{dt} = \sum \frac{\dot{Q}_b}{T_b} + \sum \dot{m}_i S_i - \sum \dot{m}_e S_e + \dot{S}_{gen} \quad \leftarrow \dot{m} = \dot{m}_i = \dot{m}_e$$

$$\begin{aligned} \dot{S}_{gen} &= \dot{m} (\sum S_e - \sum S_i) - \sum \frac{\dot{Q}_b}{T_b} \\ &= \dot{m} (S_3 + S_f - S_1 - S_g) - \frac{\dot{Q}_b}{T_b} \end{aligned}$$

$$(1 \text{ kg/s}) \cdot (0.9786 - 0.1556 \text{ kJ/kg.K}) - \frac{200.15}{273 \text{ K}}$$

$$= 0.8236 - 0.73315$$

State 1: $T_1 = -20^\circ\text{C} \rightarrow u_f = 0.0007362 \quad h_f = 25.49$
 $v_1 = 0.01 \text{ m}^3/\text{kg} \quad v_g = 0.14729 \quad h_g = 212.91$

$$\begin{aligned} x_1 &= 0.06 \quad s_f = 0.10463 \rightarrow s_r = s_f + x_1 \cdot s_{fg} \\ s_{fg} &= 0.84101 \quad = (0.10463) + (0.06) \cdot (0.84101) \\ &= 0.1550 \end{aligned}$$

State 30: $p_3 = 1 \text{ MPa}$, ideal \rightarrow isentropic

$$s_2 = s_3 = 0.94564 \star \star$$

h	s
271.71	0.9179
h_{30}	0.94564
282.74	0.9525

42.16

$$\eta_c = \frac{\dot{W}_{in,ideal}}{\dot{W}_{in,real}} = \frac{\dot{m}(h_{30} - h_2)}{\dot{m}(h_3 - h_2)} = \frac{(280.57) - (238.41)}{h_3 - (238.4)} = 0.8$$

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

$$\therefore h_3 = 238.4 + \frac{42.16}{0.8} = 291.1$$

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

$$\frac{0.9525 - s_3}{0.9525 - 0.9858} = \frac{292.74 - 291.1}{282.74 - 293.38} = 0.7857$$

$$-0.0333$$

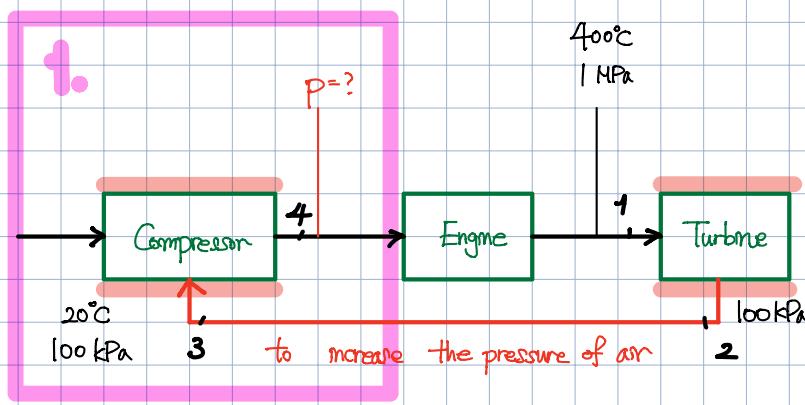
$$0.9525 - s_3 = -0.02616$$

$$-0.36$$

$$-10.64$$

$$\therefore s_3 = 0.9786$$

Diesel Turbocharger: Turbine → Compressor



$$\Delta ke = \Delta pe = 0$$

Adiabatic, ideal (reversible)

$$C_p = 0.28 \text{ kJ/kg·K}, k = 1.4$$

Calculate the air pressure at the compressor exit
(engine intake)
to increase the pressure of air

$$T_1 = 400^\circ\text{C}, p_1 = 1 \text{ MPa}$$

$$Q - W = \Delta H$$

$$q - w = \Delta h$$

$$\begin{aligned} q - w &= \Delta h \\ \text{adiabatic} &\quad \leftarrow \Delta h = C_p \Delta T \\ W_T &= \int_1^2 \Delta h = \int_{T_1}^{T_2} C_p dT \\ &= C_p (T_2 - T_1) \end{aligned}$$

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

$$\begin{aligned} &= (0.28 \text{ kJ/kg·K}) \cdot (673 - 348.58 \text{ K}) \\ &= 90.84 \text{ kJ/kg} \end{aligned}$$

$$-W = \Delta H$$

$$-W_C$$

$$\begin{aligned} W_C &= \Delta H = C_p (T_4 - T_3) \longrightarrow W_T = C_p T_4 - C_p T_3 \\ \frac{1}{W_T} & \end{aligned}$$

$$\therefore T_4 = T_3 + \frac{W_T}{C_p}$$

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

$$= 348.58 \text{ K}$$

< Adiabatic >

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = \left(\frac{P_2}{P_1}\right)^{\frac{1.4}{1.4}}$$

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

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

$$= 348.58 \text{ K}$$

6.

< Adiabatic >

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}} = \left(\frac{P_4}{P_3}\right)^{\frac{1.4}{1.4}}$$

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

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

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

$$= 1358.4 \text{ kPa}$$

Ans.

3.

2.

4.