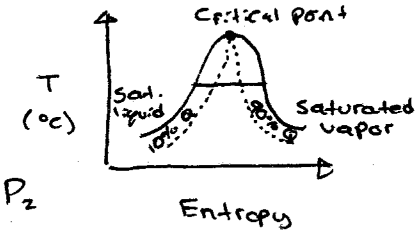
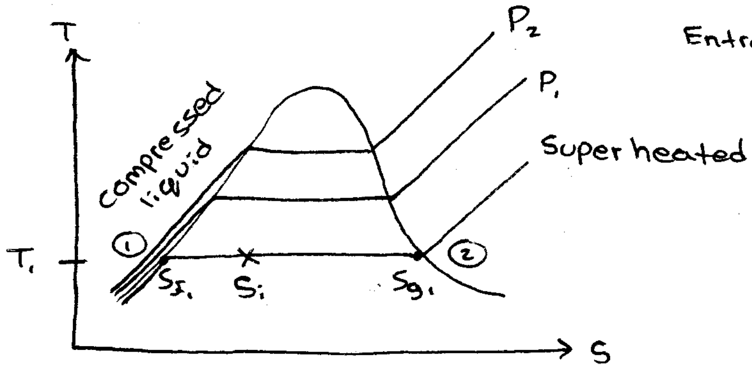
The Entropy of a Pure Substance (extensive prop.)

$s = (1-x)s_f + x s_g$

$s = s_f + x s_{fg}$





$$s_1 = s_{f_1} + x_1 \underbrace{(s_{g_1} - s_{f_1})}_{s_{fg_1}}$$

$x_1 = 0$ @ 1

$x_1 = 1$ @ 2

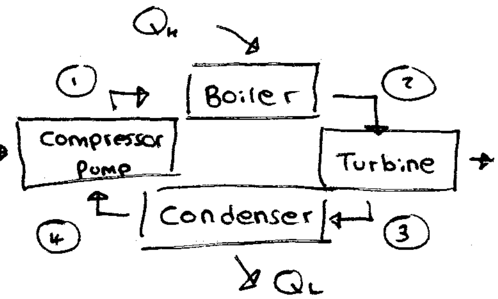
The Carnot Cycle

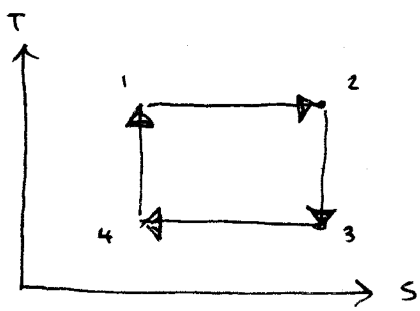
1-2 : A reversible isothermal process

2-3 : A reversible adiabetic process

3-4 : A reversible isothermal process

4-1 : A reversible adiabetic process

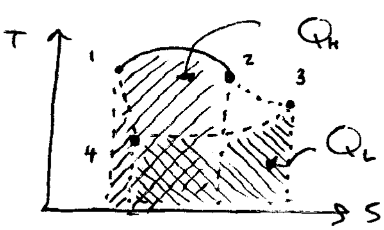




Entropy change in reversible process :

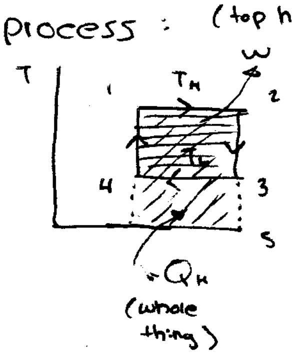
$$s_2 - s_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_{rev}$$

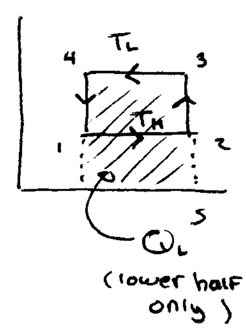
$$s_4 - s_3 = \int_3^4 \left(\frac{\delta Q}{T}\right)_{rev} = \frac{{}_3Q_4}{T_L}$$



(For example)

(top half)





(a constant entropy process is called isentropic process)

Entropy Change of a Control Mass during irreversible process

$$ds = \left(\frac{\delta Q}{T}\right)_{rev} \qquad ds > \left(\frac{\delta Q}{T}\right)_{irr}$$

Balance of Entropy:

rate of change = +in − out + generation

$$\frac{dS_{c.v.}}{dt} = \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \sum \frac{\dot{Q}_{c.v.}}{T} + \dot{S}_{gen}$$

$$S_{c.v.} = \int \rho s \, dV = m_{c.v.} s = m_A s_A + m_B s_B + \cdots$$

$$\dot{S}_{gen} = \int \rho \dot{s}_{gen} \, dV = \dot{S}_{gen,A} + \dot{S}_{gen,B} + \cdots$$

$$\sum \frac{\dot{Q}_{c.v.}}{T} = \int \frac{d\dot{Q}}{T} = \int_{surface} (\dot{Q}/A_{local})/T \, dA$$

The Steady State process

$$\frac{dS_{c.v.}}{dt} = 0$$

$$\sum \dot{m}_e s_e - \sum \dot{m}_i s_i = \sum_{c.s.} \frac{\dot{Q}_{c.v.}}{T} + \dot{S}_{gen}$$

$$\dot{m}(s_e - s_i) = \sum_{c.s.} \frac{\dot{Q}_{c.v.}}{T} + \dot{S}_{gen}$$

dividing the mass flow rate

$$s_e = s_i + \sum q/T + s_{gen}$$

(7.1)

$\boxed{\text{Example}}$ Steam enters a steam turbine at a pressure of 1 MPa...

The continuity:

$$\cancel{\frac{dm_{c.v.}}{dt}}^{\,0\,(\text{steady state})} = \dot{m}_i - \dot{m}_e \longrightarrow \dot{m}_{in} = \dot{m}_{out} = \dot{m}$$

The energy equation:

$$h_i + \underbrace{V_i^2/2}_{\times 1000} = h_e + \underbrace{V_e^2/2}_{\times 1000} + w$$

(no q − adiabetic; no z − negligible)

The second law:

$$s_e = s_i$$

$P_i = 1\text{ MPa}$, $T_i = 300\,^\circ\text{C}$ $\xrightarrow{\text{TABLE}}$ $h_i = 3051.15$ KJ/kg, $s_i = 7.1228$ KJ/kg·K

$P_e = 150$ kPa, $s_e = s_i = 7.1228$ KJ/kg·K $\Big\}$ @ 150 kPa, $s_g = 7.2232$

$s_g > s_e$, must be in saturated region

$$h_e = h_{f_e} + x_e h_{fg_e}$$

$$S_e = S_{f_e} + x_e S_{fg_e} \Rightarrow x_e = \frac{S_e - S_{f_e}}{S_{g_e}} = \frac{7.122 - 1.4335}{5.7897}$$

$$x_e = 0.9827$$

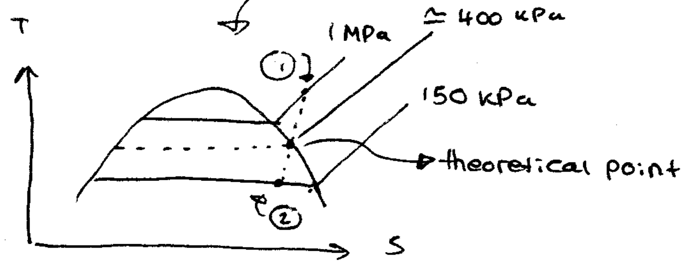
$$h_e = (467.08) + (0.9827)(2226.46)$$

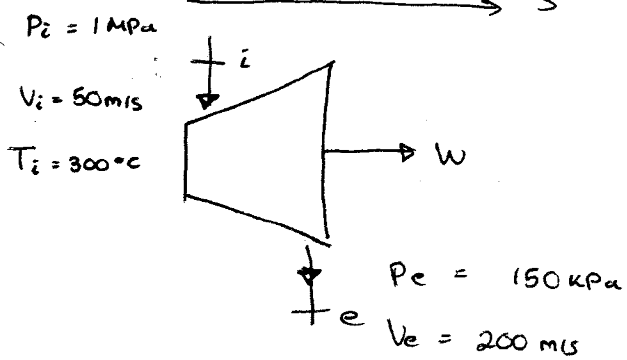
$$h_e = 2655 \text{ kJ/kg}$$

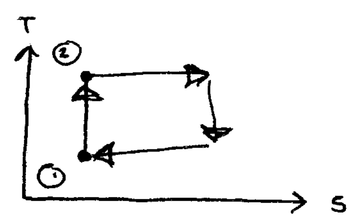
From energy Eq'n: $(3051.2) + \left(\frac{50^2}{2000}\right) = 2655 + \left(\frac{200^2}{2000}\right) + w$

$$w = 377.5 \text{ kJ/kg}$$

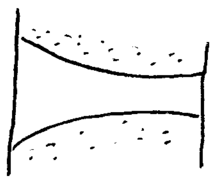
(For this example)







$\boxed{\text{Example}}$ - 7.2



$P_i = 1\ \text{MPa}$

$T_i = 300\ °c$

$V_i = 30\ m/s$

$P_e = 0.3\ \text{MPa}$

$S_e = S_i$

$$\left.\begin{array}{l} P_i = 1\ \text{MPa} \\ T_i = 300\ °c \end{array}\right\} \begin{array}{l} h_i = 3051.15\ \text{kJ/kg.k} \\ S_i = 7.1228\ \text{kJ/kg.k} \end{array}$$

$$\left.\begin{array}{l} P_e = 0.3\ \text{MPa} \\ S_e = 7.1228\ \text{kJ/kg.k} \end{array}\right\} S_g = 6.9918\ \text{kJ/kg.k}$$

$S_e > S_g \quad \therefore$ superheated

(use superheated table)

By interpolation, $h_e = 2780.2\ \text{kJ/kg}$

$$h_i + V_i^2/2 = h_e + V_e^2/2$$

$$(3051.15) + \left(\frac{30^2}{2(1000)}\right) = 2780.2 + \frac{V_e^2}{(1000 \times 2)}$$

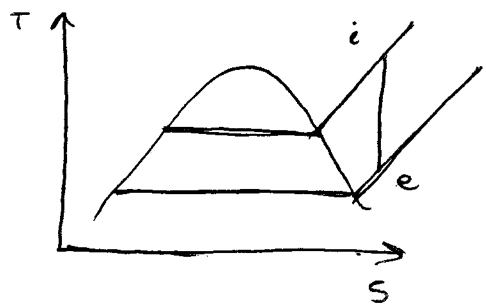
$$\boxed{V_e = 737\ m/s}$$

$q = 0$

$w = 0$

$m_i = m_e$

$PE_1 \simeq PE_2$



Tutorial 1, P2 :

Continuity eq'n:

$\dot{m}_i = A_i V_i \rho_i = \dot{m}_e = A_e V_e \rho_e \qquad v = 1/\rho$

Energy eq'n :

$\cancel{q}^0 + h_i + V_i^2/2 + \cancel{gz_i}^0 = h_e + V_e^2/2 + \cancel{gz_e}^0 + \cancel{w}^0$

- assume adiabatic process $\Rightarrow q = 0$
- assume $gz_i \doteq gz_e$
- air is an ideal gas $\longrightarrow h = c_p T$

$h_i + V_i^2/2 = h_e + V_e^2/2$

$h_e - h_i = V_i^2/2 - V_e^2/2 = \left(\frac{200^2}{2} - \frac{20^2}{2}\right)/1000 = 19.8 \text{ kJ/kg}$

$h_e - h_i = C_p(T_e - T_i) = 19.8 \text{ kJ/kg}$

$\hookrightarrow T_e = T_i + \frac{(h_e - h_i)}{C_p} = 300 + \frac{(19.8)}{1.004} = 319.72 \text{ K}$

(absolute value)

From continuity :

$v_e = v_i \left(\frac{A_e V_e}{A_i V_i}\right) \longrightarrow v_e = \frac{RT_i}{P_i}\left(\frac{A_e V_e}{A_i V_i}\right) = RT_e/P_e$

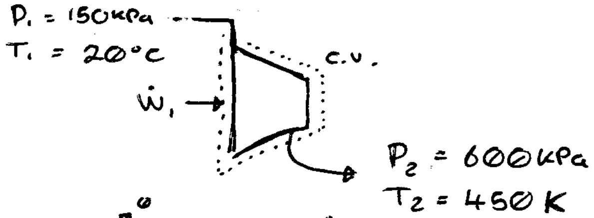
$Pv = RT \Rightarrow v_i = \frac{RT_i}{P_i}$

$v_e = \frac{RT_e}{P_e}$

$\Rightarrow P_e = P_i\,(T_e/T_i)(A_i V_i/A_e V_e) = 100\left(\frac{319.72}{300}\right)\left(\frac{100 \times 200}{860 \times 20}\right)$

$P_e = 123.92 \text{ kPa}$

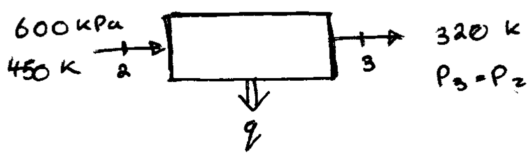
Tutorial 1, P7:



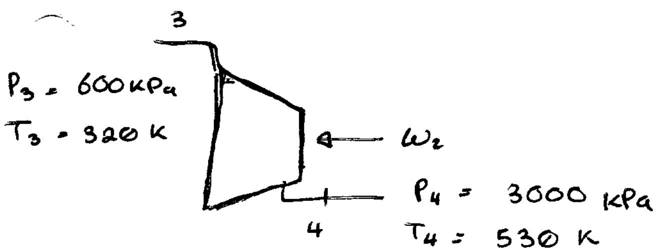
Assume: $\Delta PE = 0$
$\Delta KE = 0$
$w_1 = \dfrac{\dot{W}_1}{\dot{m}}$

$$\cancel{q}^{0} + h_1 + \cancel{V_1^2}^{0}/2 + \cancel{gz_1}^{0} = h_2 + \cancel{V_2^2}^{0}/2 + \cancel{gz_2}^{0} + w$$

$$w_1 = h_1 - h_2 = C_p(T_1 - T_2) = 1.042\,(293-450)$$
$$= -163.6\ kJ/kg$$



$$q_{2\text{-}3} + h_2 = h_3 \Rightarrow q_{2\text{-}3} = h_3 - h_2 = C_p(T_3 - T_2)$$
$$= 1.042\,(320-450)$$
$$q_{2\text{-}3} = -135.5\ kJ/kg$$



$$w_2 = h_3 - h_4 = C_p(T_3 - T_4) = 1.042\,(320-530)$$
$$= -218.8\ kJ/kg$$

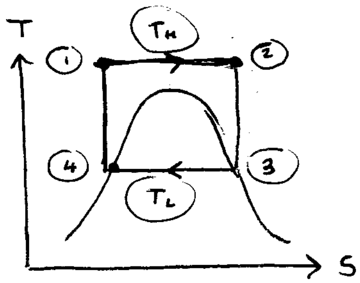
Sept. 20/18

For Carnot Cycle:

(3) Sat. liquid

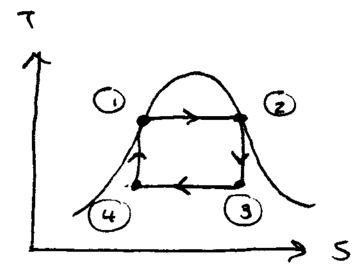
(4) Sat. vapor

Boiler is in superheat

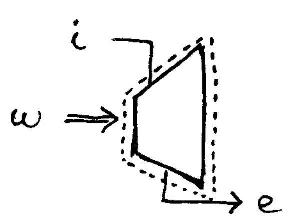


(1) inlet of Boiler is saturated liquid

(2) outlet of Boiler is saturated vapour



Example (7.3 from textbook)



$$S_e = S_i + \left(\cancel{q/T}\right)^{0} + S_{gen}$$

$$S_e = S_i + S_{gen} \quad (1)$$

$\rightarrow$ Sat. Vap. $T_s = -20°C$ $\xrightarrow{\text{TABLE}}$ $S_i = 1.7395\ kJ/kg.K$

$\rightarrow$ $P_e = 1\ MPa$, $T_e = 40°C$ $\xrightarrow{\text{TABLE}}$ $S_e = 1.7148$

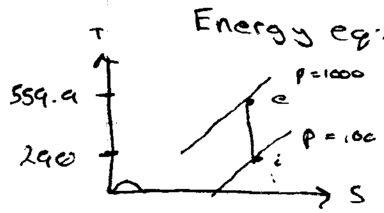
From (1): $S_{gen} < 0$ impossible

Example (7.4 from textbook)

↳ can assume air is an ideal gas

$S_e = S_i$ $\qquad \dfrac{T_e}{T_i} = \left(\dfrac{P_e}{P_i}\right)^{\frac{k-1}{k}}$ isentropic, ideal gas $\quad k = c_p/c_v$

$C_p = 1.004\ kJ/kg.K$, $k = 1.4$ $\quad T_e = 290\left(\frac{1000}{100}\right)^{\frac{1.4-1}{1.4}} = 559.9\ K$



Energy eqn: $\omega = h_i - h_e = C_p(T_i - T_e)$

$= 1.004(290 - 559.9) = -271\ kJ/kg$

Example (7.5 From textbook)?

sat. vap. $P_3 = 300$ kPa

$\dot{m}_1 = 2$ kg/s

$T_1 = 200°C$

$P_1 = 300$ kPa

$T_2 = 20°C$

$P_2 = 300$ kPa (assumed)

liquid

(I) continuity eq'n $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

(II) energy eq'n $\cancel{\dot{Q}_{cv}} + \sum m_i(h_i + \cancel{KE} + \cancel{PE}) = \sum m_e(h_e + \cancel{KE} + \cancel{PE}) + \cancel{W_{cv}}$

$\Rightarrow \boxed{m_1h_1 + m_2h_2 = m_3h_3}$

(III) Second law eq'n:

$$\dot{m}_1s_1 + \dot{m}_2s_2 + \dot{S}_{gen} = \dot{m}_3s_3$$

From (I) and (II) $\dot{m}_1h_1 + \dot{m}_2h_2 = (\dot{m}_1 + \dot{m}_3)h_3$

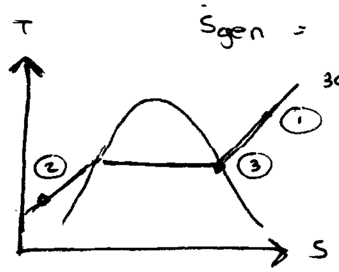
$$\dot{m}_2 = \dot{m}_1\left(\frac{h_1 - h_3}{h_3 - h_2}\right) = \frac{2865 - 2725.3}{2725.3 - 83.94}(2) = 0.106 \text{ kg/s}$$

From (I) $\Rightarrow \dot{m}_3 = \dot{m}_2 + \dot{m}_1 = 0.106 + 2 = 2.106$ kg/s

From (III) $\dot{S}_{gen} = \dot{m}_3s_3 - (\dot{m}_1s_1 + \dot{m}_2s_2)$

$\dot{S}_{gen} = 2.106(6.9918) - (2(7.3115) + 0.106(0.2966))$

$\dot{S}_{gen} = 0.072$ kW/K



The transient process

$$d/dt\,(ms)_{c.v.} = \sum \dot{m}_is_i - \sum \dot{m}_es_e + \sum \frac{\dot{Q}_{c.v.}}{T} + \dot{S}_{gen}$$

integrated over the time interval t

$$\int_0^t d/dt\,(ms)_{c.v.}\,dt = (m_2s_2 - m_1s_1)_{c.v.}$$

$$\int_0^t \left(\sum \dot{m}_is_i\right)dt = \sum m_is_i \qquad \int_0^t \left(\sum \dot{m}_es_e\right)dt = \sum m_es_e$$

$$\boxed{(m_2s_2 - m_1s_1)_{c.v.} = \sum m_is_i - \sum m_es_e + \int_0^t \sum_{c.s} \frac{\dot{Q}_{c.v.}}{T}\,dt + {}_1S_{2\,gen}}$$

$\boxed{\text{Example}}$ (7.6 from textbook)