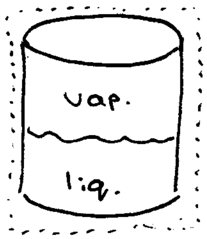
Sept. 10/18

Example: A tank of $2m^3$ volume contains Saturated ammonia ...



C.V.

$\bar{V} = 2m^2$

$T_1 = 40°c$

$m_e = ?$

$\frac{dm_{c.v.}}{dt} \neq$ constant

$\frac{dE_{c.v.}}{dt} \neq$ constant

adiabetic

(no heat passes boundary)

$$\cancel{Q_{c.v.}}^{0} + \sum \cancel{m_i}^{0}(h_i + V_i^2/2 + gZ_i) = \sum m_e(h_e + \cancel{V_e^2/2}^{0} + \cancel{gZ_e}^{0}) \ldots$$

$$\ldots + [m_2(U_2 + \cancel{V_2^2/2}^{0} + \cancel{gZ_2}^{0}) - m_1(U_1 + \cancel{V_1^2/2}^{0} + \cancel{gZ_1}^{0})] + \cancel{W_{c.v.}}^{0}$$

(no work)

Energy eq'n:

$$\Rightarrow \boxed{m_e h_e + m_2 U_2 - m_1 U_1 = 0} \quad (1)$$

Continuity eq'n:

$$\Rightarrow \boxed{m_2 - m_1 = -m_e} \quad (2)$$

From (1 and 2) $\Rightarrow -(m_2 - m_1)h_e + m_2 u_2 - m_1 u_1 = 0$

$$\boxed{m_2(h_e - u_2) = m_1 h_e - m_1 u_1}$$

From ammonia table:

$V_F = 0.001725\ m^3/kg$
$V_g = 0.08312\ m^3/kg$
$U_{F_1} = 368.74$
$U_{g_1} = 1341.0$
} @ $40°c = T_1$

$U_{F2} = 225.99$
$U_{g2} = 1325.7$
} @ $10°c = T_2$

$V = 2m^2 \Rightarrow V_F = 0.5(2) = 1m^3$

$V_g = (0.5)(2) = 1m^3$

$$m_{f_1} = \frac{V_{f_1}}{v_{f_1}} = \frac{(1)}{(0.001725)} = 579.7 \text{ kg}$$

$$m_{g_1} = \frac{V_{g_1}}{v_{g_1}} = \frac{(1)}{(0.08333)} = 12 \text{ kg}$$

$$m_1 = m_{f_1} + m_{g_1} = 579.7 + 12 = 591.7 \text{ kg}$$

$$m_1 U_1 = (m_{f_1} + U_{f_1}) + (m_{g_1} + m_{g_1} U_{g_1})$$

$$m_1 U_1 = (579.7 \times 368.74) + (12 \times 1341) = 229\,827 \text{ kJ}$$

assume $$h_e = \frac{h_g|_{40°C} + h_g|_{100°C}}{2} = 1461.1 \text{ kJ/kg}$$

$$m_1 h_e = 591.7\,(1461.1) = 864\,533 \text{ kJ}$$

$$U_2 = U_{f_2} + x_2 U_{fg_2} = U_{f_2} + x_2 (u_{g_2} - U_{f_2})$$

$$U_2 = 225.99 + x_2 (1325.7 - 225.99) \quad (4)$$

$$m_2 = V_{total} / v_2 = 2 / [0.0016 + x_2 (0.2031)] \quad (5)$$

$$v_2 = v_{f_2} + x_2 (v_{g_2} - v_{f_2})$$

Substitute (5) and (4) into (3)

$$\frac{2}{[0.0016 + x_2(0.2031)]} (1461.1 - (225.99 + x_2(1099.7))) = 864533 - 229827$$

$$x_2 = 0.011057$$

From eq'n (5) :

$$m_2 = \frac{2}{0.0016 + (0.011057)(0.2031)} = 519 \text{ kg}$$

$$m_e = m_1 - m_2 \Rightarrow m_e = 591.7 - 519 = \boxed{72.7 \text{ kg}}$$

Heat engine: we can have a system that operates in a cycle and performs net positive work and net positive heat transfer.

Heat pump: operates in a cycle, and has heat transferred to it from a low-temp. body and heat transferred from it to a high-temp. body.

Thermal efficiency: ratio of output to input

$$\eta_{th} = \frac{\text{output}}{\text{input}} = \frac{\dot{W}}{\dot{Q}_H} = \frac{Q_H - Q_L}{Q_H}$$

large power plants : 35 - 50 %

gasoline engines : 30 - 35 %

diesel engines : 30 - 40 %

$\boxed{\text{Example 5.1}}$ automobile engine 136 hp efficiency 30 %

$$\eta_{th} = \frac{\dot{W}}{\dot{Q}_H} \Rightarrow \dot{Q}_H = \dot{W}/\eta_{th}$$

$$\dot{W} = 136 \text{ hp} = 100 \text{ kW}$$

$$\Rightarrow \frac{(100\,000)}{(0.30)} = 333 \text{ kW} = \dot{Q}_H$$

$$\dot{Q}_H - \dot{Q}_L = \dot{W}$$

$$\dot{Q}_L = \dot{Q}_H - \dot{W} \Rightarrow 333 - 100 \text{ kW} = 233 \text{ kW}$$

$Q_H = \dot{m}_f q_H$ ⟶ Fuel heating value

$$m_f = \frac{\dot{Q}_H}{q_H} = \frac{333 \text{ kJ}}{35000 \text{ kJ/kg}} = 0.0095 \text{ kg/s}$$

The efficiency of a refrigerator is expressed in terms of the coefficient of performance (COP), β

$$\beta = Q_L / W \Rightarrow \frac{Q_L}{Q_H - Q_L}$$

$$\beta' = Q_H / W \Rightarrow \frac{Q_H}{Q_H - Q_L}$$

$$\beta' - \beta = 1$$

$\boxed{\text{Example } 5.2}$ From textbook

$$\dot{Q}_L = \dot{Q}_H - \dot{W} \Rightarrow 400 - 150 \Rightarrow \dot{Q}_L = 250 \text{ kW}$$

$$\beta = \frac{\dot{Q}_L}{\dot{W}} \Rightarrow \frac{(250 \text{ kW})}{(150 \text{ kW})} \cong 1.67$$

Sept. 12 /18

P1

$\dot{m}_i = \dot{m}_e$ (I)

$$\cancel{\frac{dm_{c.v.}}{dt}}^{\,0} = \sum \dot{m}_e - \sum \dot{m}_i$$

steady state

$\dot{m} = \rho V A$

$\dot{m}_i = \dot{m}_e \Rightarrow \rho_i V_i A_i = \rho_e V_e A_e$

$\rho = 1/v \rightarrow \dfrac{V_i A_i}{v_i} = \dfrac{V_e A_e}{v_e}$

$i = P_i = 5\,MPa$

$T_i = 20\,°C \underset{\text{TABLE B.1.4}}{\Rightarrow} v_i = 0.001\ m^3/kg$

$e = P_e = 4.5\,MPa$

$T_e = 450\,°C$

$\underset{\text{TABLE B.1.3}}{\Rightarrow}$ @ 4 MPa ; $v = 0.08003$
@ 5 MPa ; $v = 0.06330$

then $v_e = 0.071665\ m^3/kg$

$$\dot{m} = 5000\ kg/\cancel{hour} \times \frac{1\ \cancel{hour}}{60\ \cancel{min}} \times \frac{1\ \cancel{min}}{60\ sec} = (5000)\left(\frac{1}{3600}\right) kg/s$$

$$A_i = \frac{\dot{m} v_i}{V_i} = \frac{(5/3.6)(0.001)}{20} = 0.69\ cm^3$$

$A_i \geq 0.69\ cm^3$

$$A_e = \frac{\dot{m} v_e}{V_e} = \frac{(5/3.6)(0.071665)}{20} = 4.8 \times 10^{-3}\ m^2$$

$A_e \geq 50\ cm^2$

P3

$T_i = 25°C$ $\qquad$ $T_e = ?$

$P_i = 750 \text{ kPa}$ $\qquad$ $P_e = 165 \text{ kPa}$

$V_i = V_e$

adiabetic, $V_i = V_e$, potential negligible, $V_i = V_e$, potential negligible, no work

$$\cancel{\dot{Q}_{c.v.}} + \dot{m}_i\left(h_i + \cancel{\frac{V_i^2}{2}} + \cancel{gZ_i}\right) = \dot{m}_e\left(h_e + \cancel{\frac{V_e^2}{2}} + \cancel{gZ_e}\right) + \cancel{\dot{W}_{c.v.}}$$

same flow rate

$$\cancel{\dot{m}_i} h_i = \cancel{\dot{m}_e} h_e \Rightarrow \boxed{h_i = h_e}$$

i : $P_i = 750 \text{ kPa}$, $T_i = 25°C$ $\Big\}$ $h_i = h_f|_{25°C} = 234.59 \text{ kJ/kg}$

$\nu_i = \nu_f|_{25°C} = 0.000829 \text{ m}^3/\text{kg}$

e : $P_e = 165 \text{ kPa}$

$T_e = ?$

$h_e = 234.59 \text{ kJ/kg}$ $\Big\}$ $h_e = h_{f_e} + x_e h_{fg_e}$

$-15°C$

$234.59 = 180.19 + x_e(209)$

$x_e = 0.2603$

$\dot{m} = \rho V A$ $\qquad$ $\dot{m}_i = \dot{m}_e$

$$\frac{A_i V_i}{\nu_i} = \frac{A_e V_e}{\nu_e} \Rightarrow \left(\frac{A_e}{A_i}\right) = \frac{\nu_e}{\nu_i} \quad \text{(I)}$$

$\nu_e = \nu_f + x_e \nu_{fg}$ @ $T_e = -15°C$

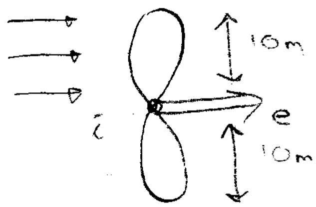
$\nu_e = 0.000746 + 0.2603(0.11932) = 0.0318 \text{ m}^3/\text{kg}$

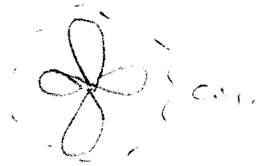
From (I):
$$\frac{A_e}{A_i} = \left(\frac{\pi/4\, D_e^2}{\pi/4\, D_i^2}\right) = \frac{\nu_e}{\nu_i}$$

$$\left(\frac{D_e}{D_i}\right)^2 = \frac{\nu_e}{\nu_i} \Rightarrow \frac{D_e}{D_i} = \left(\frac{\nu_e}{\nu_i}\right)^{0.5}$$

$$\frac{D_e}{D_i} = \left(\frac{0.0314}{0.000829}\right)^{0.5} = 6.19$$

P4





Continuity eq'n : $m_i = m_e$

Energy eq'n : $\dot{m}_i \left(h_i + V_i^2/2 + g z_i\right) = \dot{m}_e \left(h_e + V_e^2/2 + g z_e\right) + \dot{W}$

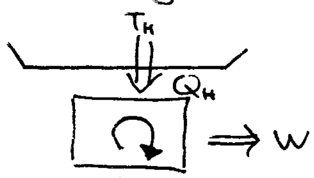
$\Rightarrow \quad \dot{W} = 0.4\,\dot{W}_e \qquad Pv = RT \Rightarrow v_i = \dfrac{RT_i}{P_i}$

Sept.13/18

All course Chapters : 4, 5, 7, 9, 10, 11, 12

Second Law of Thermodynamics

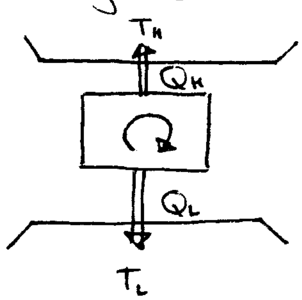
Kelvin-Planck Statement : impossible to construct a device that will operate in a cycle and produce no effect other than raising the weight and the exchange of heat with a single reservoir.



Impossible

→ impossible to build a heat engine with a thermal efficiency of 100%

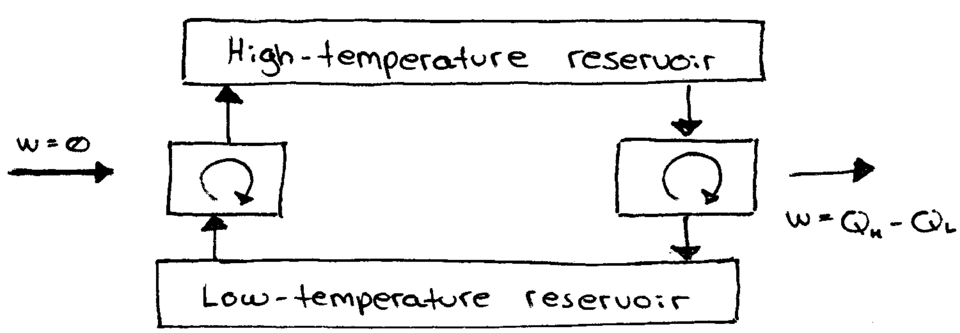
The Clausius Statement : impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a cooler body to warmer body.



Impossibe

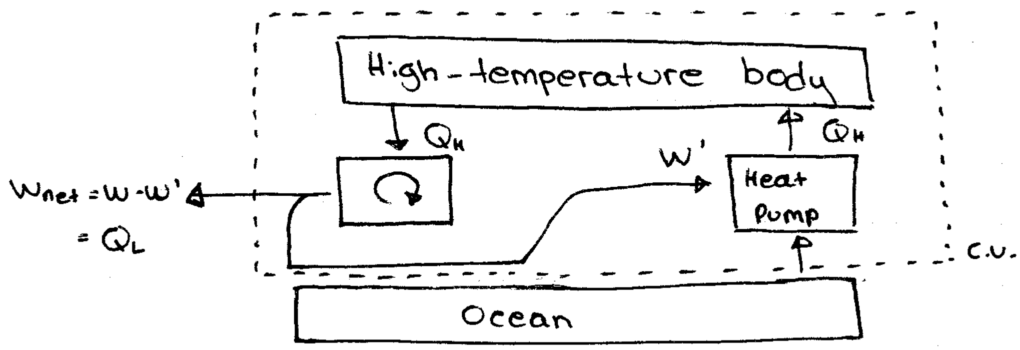
$$CoP = \beta = \frac{Q_L}{W} \not= \infty$$

→ implies COP is always less than infinity



Impossible

A perpetual motion machine (1st kind) : create work from nothing or create mass or energy, violating 1st law
(2nd kind) : extract heat from source, and convert heat into other form, violating 2nd law.
(3rd kind) : have no friction, would run infinitely but produce no work.



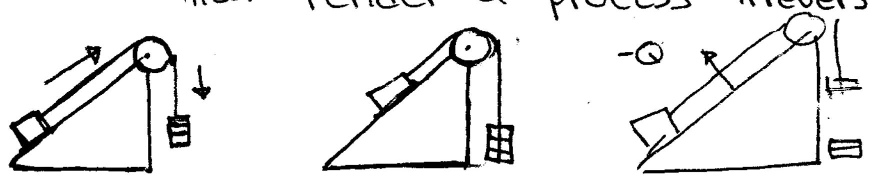
Impossible

A reversible process for a system is defined as a process that, once taken place, can be reversed. Doing so leaves no change in either system or surrounding.

Quasi-steady state - gradually add work to system

Factors that render a process irreversible

Friction (1)



(2) - unrestrained expansion
(3) - heat transfer through a finite temp. difference
(4) - mixing
(5) - Inelastic deformation
- Current through an Ohmic resistor

The Carnot Cycle

If efficiency of all heat engines is less than 100%, what is the most efficient cycle we can have?

1. A reversible isothermal process in which heat is transferred to or from the high temperature reservoir
2. A reversible adiabetic process in which the temp. of the working fluid decreases from the high temperature to the low temperature
3. A reversible isothermal process in which heat is transferred to or from low temp. reservoir
4. A reversible adiabetic process in which temp. of working fluids increase from low temp. to high temp.

Heat engine : 1 - 2 - 3 - 4 - 1 ... Q_H in, Q_L out

Refrigerator : 1 - 2 - 3 - 4 - 1 ... Q_H out, Q_L in

Two propositions regarding efficiency of Carnot

Proposition 1 : $\eta_{any} \leq \eta_{rev}$

Proposition 2 : $\eta_{rev1} = \eta_{rev2}$

Proof : Let the better machine be a heat engine and other work as a refrigerator (reversible) with same Q_L. The combination is an impossible heat engine as stated by Kelvin Plank

Efficiency of a Carnot Cycle

$\eta_{thermal} = 1 - Q_L/Q_H$

$\eta_{th} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} \Rightarrow \frac{Q_H}{Q_H} - \frac{Q_L}{Q_H}$

$\eta_{carnot} = 1 - \frac{T_L}{T_H}$

For isothermal reversible process : $Q_H/Q_L = T_H/T_L$

where T_L, T_H = absolute temp of two reservoirs

Real efficiency will be less than the ideal Carnot Cycle

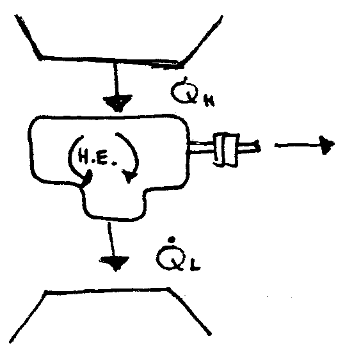
e.g. Coal Fired Power Plant / Carnot = 0.60, $\eta_{real} \cong 45\%$

Nuclear Power / Carnot = 0.40, $\eta_{real} \cong 30\%$

Gas Turbine / Carnot = 0.60, $\eta_{real} \cong 50\%$

Car Gasoline Engine / Carnot = 0.55, $\eta_{real} \cong 35\%$

Example:



$\dot{Q}_H = 1000 \text{ kW}$

$\dot{W} = 450 \text{ kW}$

$\dot{Q}_L = \dot{Q}_H - \dot{W} = 1000 - 450 = 550 \text{ kW}$

$\eta_{th} = \dot{W}/\dot{Q}_H = 450/1000 = 0.45$ or 45%

$\eta_{carnot} = 1 - T_L/T_H \Rightarrow 1 - \frac{300}{550+273} = 0.635$ or 63.5%

$\dot{W} = \eta_{carnot}\dot{Q}_H = 0.635(1000) = 635 \text{ kW}$

(carnot cycle) $\dot{Q}_L = \dot{Q}_H - \dot{W} \Rightarrow 1000 - 635 = 365 \text{ kW}$

loss $= 550 - 365 = \underline{185 \text{ kW}}$

Example: " as one mode of operation of an air cond. .. "

$$COP = \beta = \frac{\dot{Q}_L}{\dot{W}} = \frac{\dot{Q}_L}{\dot{Q}_H - \dot{Q}_L} = \frac{T_L}{T_H - T_L}$$

$$COP = \frac{24+273}{(35+273)-(24+273)} = \underline{27}$$

$$\dot{W} = \frac{\dot{Q}_L}{\beta} = \frac{4}{27} = 0.15 \text{ kW}$$