Laws of thermodynamics

(1) Zeroth law of Thermo.

When a body A is in thermal equilibrium with body B and also separately B with body C, then body B and C will be in thermal equilibrium.

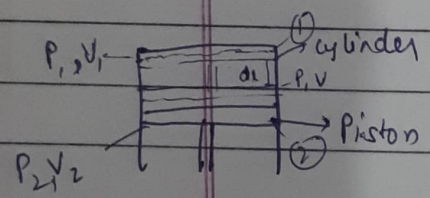
⊙ Work transfer

In thermodynamics, work transfer is considered as occuring b/w the system and surrounding

Work transfer by system is taken as (+)ive work

" " " ~~by surr.~~

Work " " on system is taken as (-)ive work



let the area of piston = a

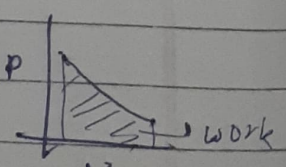
pdv work or displacement work.

$$F = p \cdot a$$

$$dW = F \cdot dl = P \cdot a \cdot dl = P \cdot dv$$

$$\int dw = \int_1^2 P \cdot dv$$

Area under p-v curve gives work



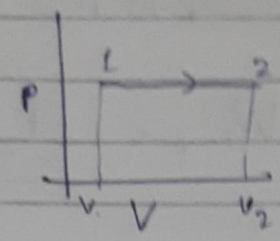
In the quasi-static work, we can calculate work by graph

we can apply $\int dw = \int p\,dv$

(i) Constant Pressure

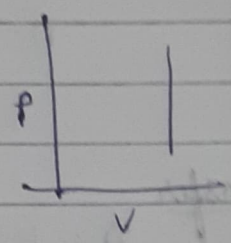
$$W_{1-2} = \int_{V_1}^{V_2} p\,dv$$

$$P(V_2 - V_1)$$



(ii) Constant Volume

Zero work in this process

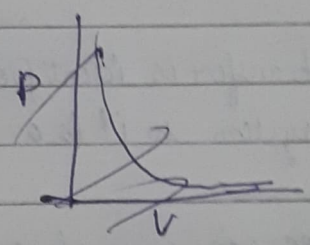


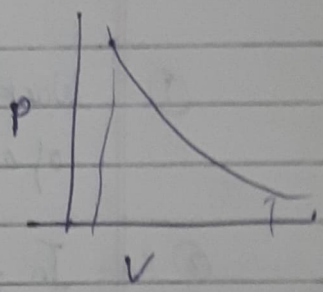
(iii) Constant temp.

$$PV = K$$

$$W_{1-2} = \int_1^2 p\,dv$$

$$PV \ln\left(\frac{V_2}{V_1}\right)$$





$PV^n = C$ Polytropic process

$$\int_1^2 p\,dv = \int_1^2 \frac{C}{V^n}\,dv$$

$$= C\left[\frac{V^{-n+1}}{-n+1}\right]_1^2$$

$$= P_1 V_1^n \left[\frac{V^{-n+1}}{-n+1}\right]_{V_1}^{V_2}$$

$$P_1V_1^n = P_2V_2^n = C$$

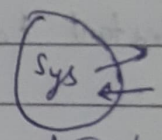
$$\frac{P_1V_1^n}{-n+1}\left[V_2^{1-n} - V_1^{1-n}\right]$$

$$W_{1-2} = \frac{P_2V_2 - P_1V_1}{1-n}$$

$$= \frac{P_1V_1}{n-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]$$

Work transfer

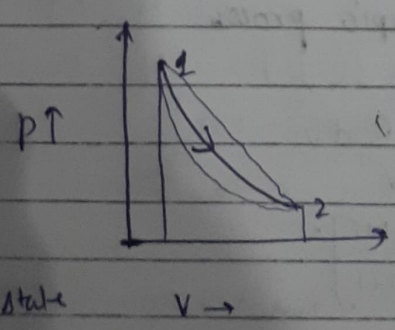
It is boundary phenomenon



① Work transfer is identified ~~by~~ only at the ~~boundary of~~ boundary of a system so it is a boundary phenomena.

② In free expansion of gas there is no resistance to the fluid at the system boundary as the volume of the gas increases to fill up the vacuum space. Since, vaccum doesnot offer any resistance, there is no work transfer involved in free expansion

③



Work tr

1 state

③ Point function is properties of system.

path function ~~is exa~~ inexact differential

(4) Work is a path function so, it is denoted by $đw$ (inexact differential)

only possible in quasi static

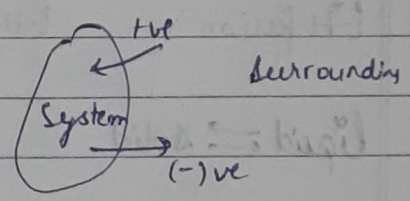
$$\int_1^2 đw = \int_1^2 p\,dv$$

$$\left\{ dv = \left(\frac{1}{p}\right) đw \right\}$$

exact differential but it is state function

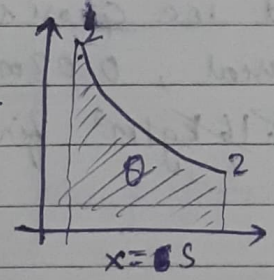
Here $\left(\frac{1}{p}\right)$ is termed as integrating factor

Heat transfer



diathermic boundary - heat transfer take place / possible

adiabatic boundary = heat transfer not possible



Only possible in quasi state

$\boxed{\text{Heat transfer is path function}}$

it is denoted by $đθ$ (inexact differential)

$$\int_1^2 đθ = \int_1^2 T\,dx$$

$$\boxed{dx = \frac{1}{T}\,đθ}$$

~~Integration~~ Integrating factor

entropy is state function (Pbins)

always use kelvin temp scale

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Specific heat (per unit mass)

$$c = \frac{Q}{M \cdot \Delta t}$$

c → small letter; Q → heat; M → mass; Δt → temp; $J/kg\,K$

at constant pressure → C_p

at constant volume → C_v

(II) latent heat

- L.H. fusion: liquid ⇄ solid
- L.H. vapourization: liquid ⇄ gas
- L.H. sublimation: solid ⇄ gas

Q) A mass of gas is compressed in a quasi static process from 80 kPa, 0.1 m^3 to 0.4 mega Pascal, 0.03 m^3 for this pv^n = constant initial air density is 1.16 kg/m^3 find the work done by piston

$$\frac{1}{r} = \left(\frac{3}{10}\right)^n$$

$$\log_2\left(\frac{1}{3}\right) = n\left(\log_2\left(\frac{3}{10}\right)\right) \qquad P_1V_1^n = P_2V_2^n \qquad \boxed{n = 1.3}$$

$$-2.32 = n(1.58 - 3.32) \qquad W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$-2.32 = -1.74n$$

$$n = 1.3 \qquad \boxed{W = -1.3 \times 10^4}$$

Q.) A mass of 1.5 kg of air is compressed in quasi static process from 0.1 mega Pascal to 0.7 mega Pascal for which PV = Constant. The intial density of air is 1.16 kg/m³. Find the work done by the piston to compress the gas air.

Intial Volume = $\frac{1.50}{1.16}$ = 1.29

$$\text{Work} = PV \ln\left(\frac{V_2}{V_1}\right) = PV \ln\left(\frac{P_1}{P_2}\right)$$

$$= 129 \times 10^3 \ln\left(\frac{0.1}{0.7}\right) = 129 \times 10^3 \ln\left(\frac{1}{7}\right)$$

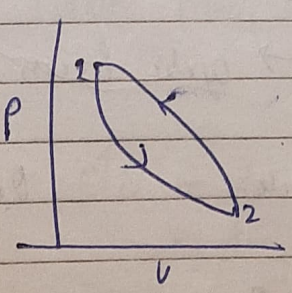
$$= -129 \times 10^3 \times 1.97$$

$$W = -250960$$

$$= -2.5 \times 10^5$$

1st law of thermodymacis

(i) Transfer of heat and performance of work may both cause the same effect in a system.



$$Q = m c_p (t_2 - t_1)$$

$$W_{1-2} \propto Q_{1-2}$$

$$\Sigma W_{cycle} \propto \Sigma(Q)_{cycle}$$

$$\boxed{(\Sigma W)_{cycle} = J\,\Sigma(Q)_{cycle}}$$ → first law's thermodynamics

J → Joule's equivalent

$$J = 1\,Nm$$

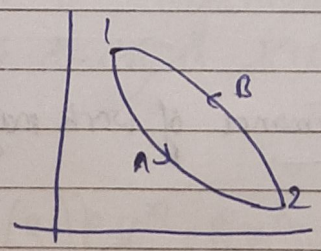
$$\boxed{\oint dW = \oint dQ}$$ → Work transfer and heat transfer is equal in cyclic process.

first law of thermodynamics for cyclic process

$$\boxed{Q = \Delta E + W}$$

$\Delta E \rightarrow \boxed{\Delta U}$

$\Delta E \Rightarrow$ Energy is the property of a system.



$Q_A = \Delta E_A + W_A$

$Q_B = \Delta E_B + W_B$

$A \to B \rightarrow$ cyclic process

$$(\Sigma W)_{cycle} = (\Sigma Q)_{cycle}$$

$$Q_A + Q_B = \underbrace{(\Delta E_A + \Delta E_B)}_{0} + W_A + W_B$$

$$W_A + W_B = Q_A + Q_B$$

$$\Delta E_A + \Delta E_B = 0$$

$$\boxed{\Delta E_A = -\Delta E_B}$$

$dE \rightarrow$ exact differential

so energy is ~~point~~ path independent

$$E = E_k + E_p + U$$

$$\boxed{đQ = dE + đW}$$

$$\Rightarrow đQ = du + đW = \boxed{đQ = du + pdv}$$

first law of thermodynamics for a process.

$$\boxed{Q = \Delta U + \int p\,dv}$$

Specific heat capacity at constant volume. (C_v)

The specific heat of a substance at constant volume (C_v) is defined as the rate of change of specific internal energy with respect to temp. when volume is held constant.

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

$$(\Delta u)_v = \int_{T_1}^{T_2} C_v\,dT$$

$$đQ = du + đW$$
$$= du + p\,dv$$

at constant volume

$$(Q)_v = (\Delta u)_v$$

$$(Q)_v = (\Delta u)_v = \int C_v dT$$

Enthalapy (H) = $\boxed{H = m \cdot h}$

Specific enthalapy

$$[h = u + pv]$$

If only pdv work is present

$$dQ = du + pdv$$
$$(dQ)_p = du + d(pv)$$

$$(dQ)_p = d(u + pv)$$

at constant Pressure $(dQ)_p = d(H)$

1. The enthalapy of a substance that is 'h' is defined as $h = u + pv$
2. $h = u + pv$ is the specific enthalapy and it is property of system.
3. Heat transfer at Constant pressure increases the enthalapy of the system.
4. For ideal gas, specific enthalapy $h = u + RT$

Total enthalapy is denoted by (H)

$$H = mh$$

mass

PPM → 1

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$C_p \Rightarrow$ The specific heat at a constant pressure (C_p) is defined as the rate of change of enthalapy w.r.t temperature when pressure is constant

$$C_p = \left(\frac{\partial h}{\partial T}\right)_P \qquad (h, T, P)$$

$$\boxed{(\Delta h)_p = \int_{T_1}^{T_2} C_p \, dT}$$ → question मिलेगा

1st law :

$$\boxed{đQ = du + p\,dv}$$

$$h = u + pv$$

$$dh = du + p\,dv + v\,dp$$

$$\boxed{dh = đQ + v\,dp}$$

$$đQ = dh - \cancel{v\,dp}^{\,0}$$

$$(đQ)_p = dh$$

$$\boxed{\cancel{Q_p = C_p}} \qquad \boxed{Q_p = \int_1^2 C_p \, dT}$$

~~Output~~

PMM (1) = Perpetual motion machine

There can be no machine which could continuously

supply mechanical work without some form energy disappearing simultaneously.

Such a ~~fictitous~~ fictitious machine is called perpetual motion machine of 1 kind (PMM 1)

Q) A ideal stationary mass of gas is compressed without friction from an initial state of $0.3 m^3$ and $0.105 MPa$ to an final state of $0.15 m^3$ and $0.105 MPa$. There is a transfer of 36.7 kJ of heat from the gas during the process. How much does the internal energy of the gas

Ans) $W = p(V_2 - V_1)$

$15.7 kJ = W$

$Q_{1-2} = \Delta U + W_{1-2}$

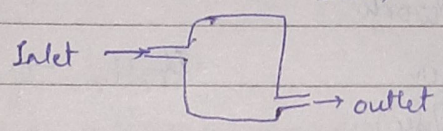
$\Delta U = 21.85 kJ$

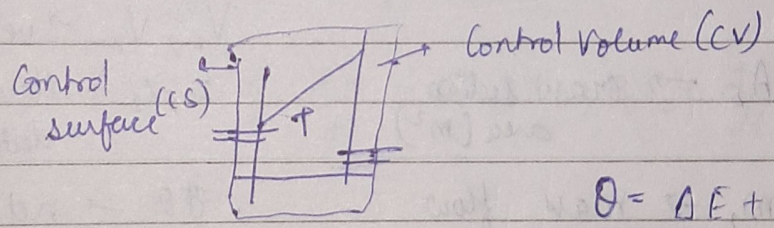
Q) A piston and cylinder machine contains a fluid system which passes through a complete cycle of four processes. During a cycle the sum of ~~internal~~ all heat transfer is $-170 kJ$ (per cycle). The system completes 100 cycles per minute

Process	Q (kJ/min)	W (kJ/min	ΔE (kJ/min)
a-b	0	2170	-2170
b-c	21,000	0	21,000
c-d	-21,00	24,300	-36,600
d-a	-35900	-53,670	—
			0

First law for open system

~~Steady~~ Steady / flow Process





$$Q = \Delta E + W$$

$$\downarrow$$

$$E_k + E_p + U$$

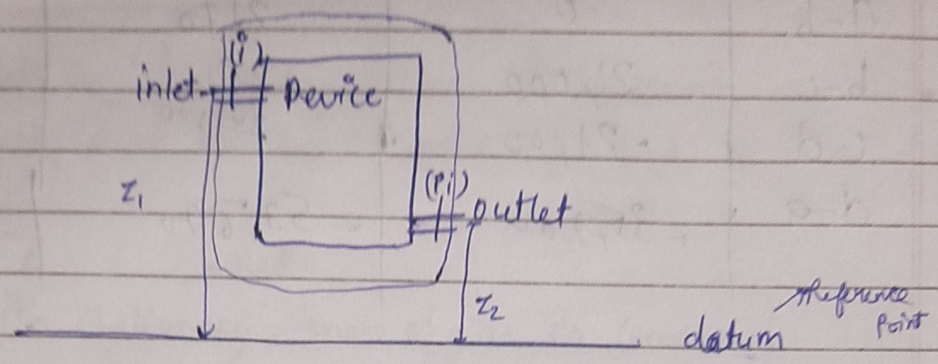
Steady flow Process

Steady flow means that the rates of flow of mass and energy across the control surface are constant.

At steady state of a system / control volume any thermodynamic property will have a fixed value at a particular location. and will not alter with time

The thing which is rotating is called shaft

- Thermodynamic properties may vary along space coordinates but do not vary with time.



Related Quantities

$\frac{dW_x}{dt}$ → net rate of shaft work transfer (J/sec)

v_1, v_2 → Specific Volume (m^3/kg)

u_1, u_2 → Specific Internal energy (J/kg)

V_1, V_2 → velocity (m/sec)

A_1, A_2 → cross section area (m^2)

z_1, z_2 → Elevation from datum (m)

m_1, m_2 → mass flow rate (kg/sec)

$\frac{dQ}{dt}$ → net rate of heat transfer (J/sec)

MASS BALANCE Equation

$$\omega_1 = \omega_2$$

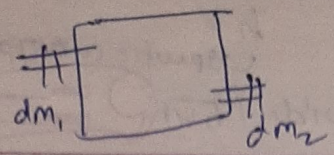
$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$$

Energy balance

Work done

(i) Shaft work (W_f)

(ii) Displacement work



Control volume
↳ Volume is fixed

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$$- P_1 v_1 \, dm_1 + P_2 V_2 \, dm_2$$

Net work in rate form

$$\frac{dW}{dt} = \frac{dW_x}{dt} - P_1 V_1 \frac{dm_1}{dt} + P_2 V_2 \frac{dm_2}{dt}$$

$$= \frac{dW_x}{dt} - P_1 V_1 w_1 + w_2 P_2 V_2$$

Mass balance

$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$$

Energy balance

$$w_1 e_1 + \frac{dQ}{dt} = w_2 e_2 + \frac{dW}{dt}$$

$$w_1 e_1 + w_1 P_1 V_1 + \frac{dQ}{dt} = w_2 e_2 + w_2 P_2 V_2 + \frac{dW}{dt}$$

$$e = e_k + e_p + u$$

$$e_1 = \frac{V_1^2}{2} + g z_1 + u_1$$

w

$$w_1 \left[\frac{V_1^2}{2} + g z_1 + u_1 + P_1 V_1\right] + \frac{dQ}{dt} = w_2 \left[\frac{V_2^2}{2} + g z_2 + u_2 + P_2 V_2\right] + \frac{dW}{dt}$$

from mass balance

$w_1 = w_2 = w = \frac{dm}{dt}$ so equation is written like this

$$w \left[\frac{V_1^2}{2} + g z_1 + u_1 + P_1 V_1\right] + \frac{dQ}{dt} = w \left[\frac{V_2^2}{2} + g z_2 + u_2 + P_2 V_2\right] + \frac{dW}{dt}$$

$$\frac{dm}{dt} \left[\frac{V_1^2}{2} + g z_1 + \underbrace{u_1 + P_1 V_1}_{h_1}\right] + \frac{dQ}{dt} = \frac{dm}{dt} \left[\frac{V_2^2}{2} + g z_2 + \overset{h_2}{u_2 + P_2 V_2}\right] + \frac{dW}{dt}$$

$\frac{dm}{dt}$ $\quad$ $\frac{dm}{dt}$ $\quad$ $\frac{dm}{dt}$ $\quad$ $\frac{dm}{dt}$

h = specific enthalpy

dm/dt से divide किया

$$\boxed{h_1 + \frac{V_1^2}{2} + gz_1 + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2} + gz_2 + \frac{dW_x}{dm}}$$

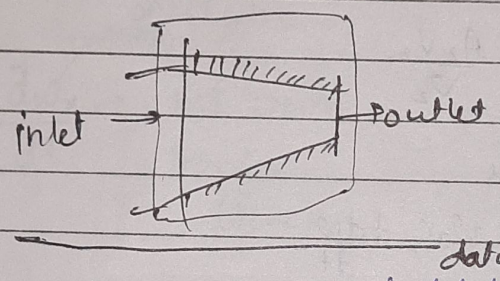
that is general equation

Steady flow Energy equation

parameters not or remain constant with time

$$\rightarrow Q - W_x = (h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

$$\rightarrow dQ - dW_x = dh + v\,dv + g\,dz$$



insulated heat transfer neglect

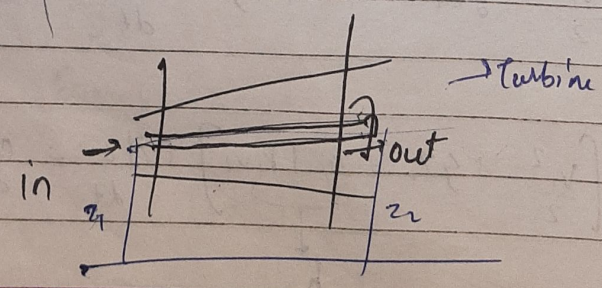
$$h_1 + \frac{V_1^2}{2} + \cancel{gz_1} + \cancel{\frac{dQ}{dm}} = h_2 + \frac{V_2^2}{2} + \cancel{gz_2} + \cancel{\frac{dW_x}{dm}}$$

$$\boxed{h_1 + \frac{V_1^2}{2} + \cancel{gz_1} = h_2 + \frac{V_2^2}{2}}$$

$V_1 \leq < V_2$

$$h_1 = h_2 + \frac{V_2^2}{2}$$

$$\boxed{V_2 = \sqrt{2(h_1 - h_2)}}$$



In case $\frac{dQ}{dm} = 0$ → Insulated $\qquad z_1 = z_2 = z$

V_1, V_2 → neglected

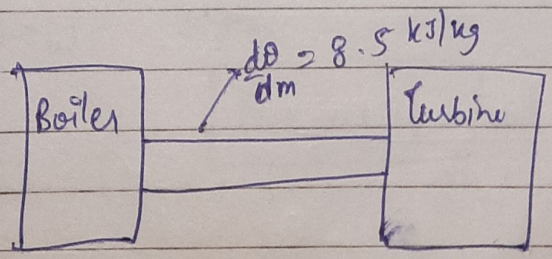
$$h_1 = h_2 + \frac{dW}{dm}$$

$$\boxed{h_1 - h_2 = \frac{dW}{dm}}$$

Q.) In steam power plant steam flows steadily through a 0.2 m diameter pipe of pipeline from the boiler to the turbine at the boiler end the steam conditions are found to be $P_1 = 4\,MPa$, $T_1 = 400°C$, $h_1 = 3213.6\ kJ/kg$, $v_1 = 0.073\ m^3/kg$ (specific volume).

at turbine in conditions are found to be $P_1 = 3.5\,MPa$, $T = 392°C$, $h = 3202.6\ kJ/kg$, $v = 0.084\ m^3/kg$. There is a heat loss of 8.5 kJ/kg from the pipeline. Calculate the steam flow rate.

Ans



$$\frac{dW_x}{dm} = 0$$

$$\boxed{V_1 = 0.87 V_2}$$

$$h_1 + \frac{V_1^2}{2} + \frac{dQ}{dm} = h_2 + V_2^2$$

$V_1 = 125.1 \, m/sec$

$W = 53.8 \, kg/s$

Q.) A certain water heater operates under steady flow conditions receiving 4.2 kg/sec of water at 75°c temperature, enthalapy 313.93 kJ/kg. The water is heated with mixing with steam which is supplied to the heater at temp. 100.2°c and enthalapy 2676 kJ/kg. The mixture leaves the heater as liquid water at temp 100°c and enthalapy 419 kJ/kg. How much steam must be supplied to the heater per hour.

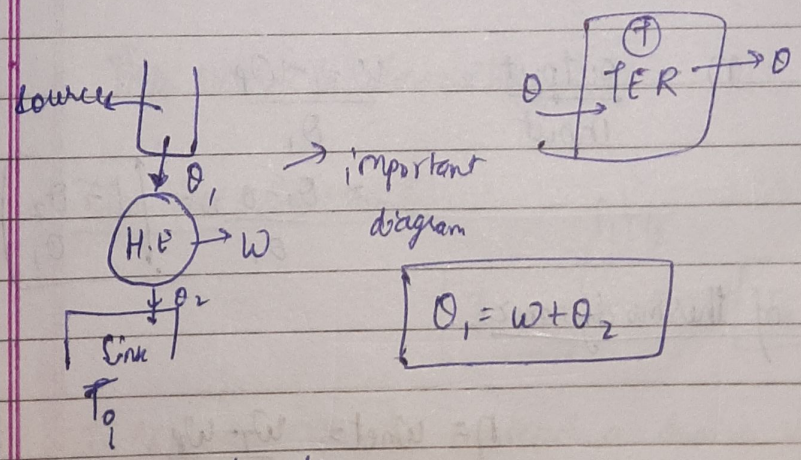
2nd law of thermodynamics

(1) Spontaneous (→ natural) Process = Unidirectional (→ Reversible)

Heat flow, fluid flow, material diffusion, time

Work transfer → internal energy increases → heat transfer

(i) Energy Reservoir : The thermal Energy reservoir is defined as a large body of infinite heat capacity, which is capable of ~~of~~ absorbing and rejecting an unlimited ~~quan~~ quantity of heat without ~~differing~~ ~~approach~~ appreciable changes in its coordinates.



→ important diagram

$$Q_1 = W + Q_2$$

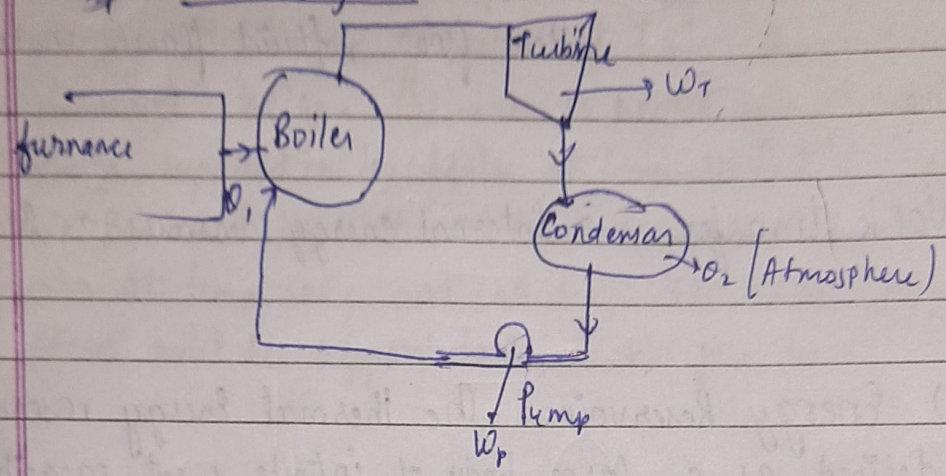
0 = Environment condition

Heat engine

A heat engine may be defined as a device which ~~work~~ operates in a thermodynamic cycle converts part of energy/heat received from high temp reservoir to useful work

and rejects the remaining heat to lower temp reservoir.

Heat Engine



$$\boxed{Q_1 - Q_2 = W_T - W_P}$$

$$\text{Efficiency} = \eta = \frac{\text{output}}{\text{input}} = \frac{W_T - W_P}{Q_1}$$

$$= \frac{Q_1 - Q_2}{Q_1} = \boxed{1 - \frac{Q_2}{Q_1}}$$

2nd law of thermodynamics

$$\eta = W_{net} = \frac{W_T - W_P}{Q_1}$$

Thermal efficiency of a heat engine always less than unity. It means that heat engine cannot be 100% efficient.

Petrol (Spark) S.I engine = ~~30-35~~ 30-35%

CI engine = 35-40%

PMM1 → there has no input.

Power plants = 35 - 50 %
Gas Power plants = 60 - 65 %

Kelvin Planck statement

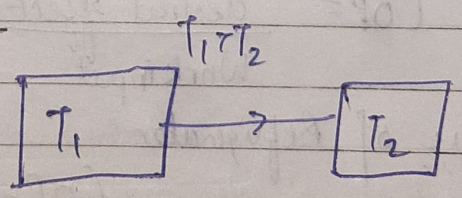
It is impossible for a heat engine to produce net work in a complete cycle if it exchanges heat only with bodies at a single fixed temperature.

If $Q_2 = 0$ then $\eta = 1$
and efficiency is 100

If Q_2 becomes 0, it means that the heat engine will produce net work in a complete cycle by exchanging heat with one reservoir. Thus, ~~we~~ ~~we~~ ~~we~~ violated the kelvin planck statement such heat engine is called PMM2.

This PMM 2 is impossible

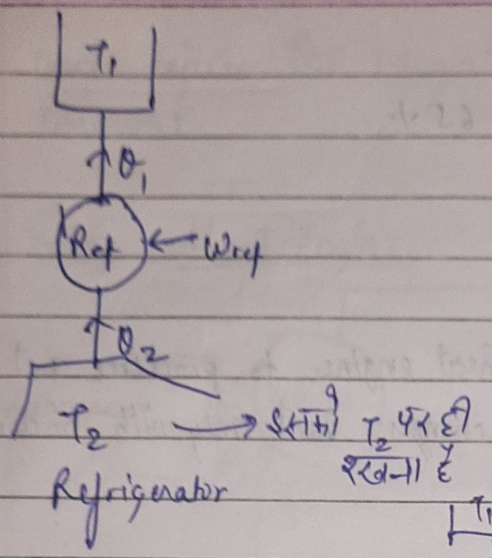
Clausius Statement

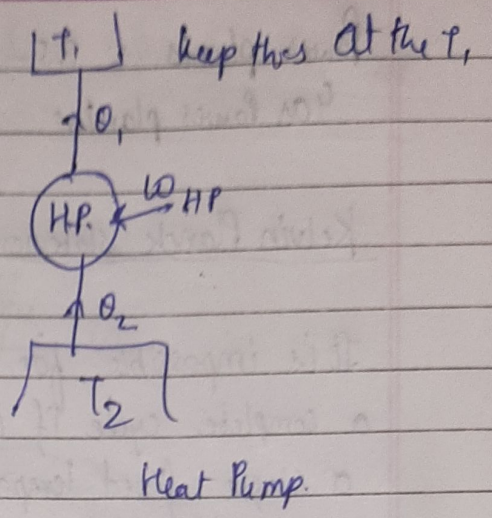


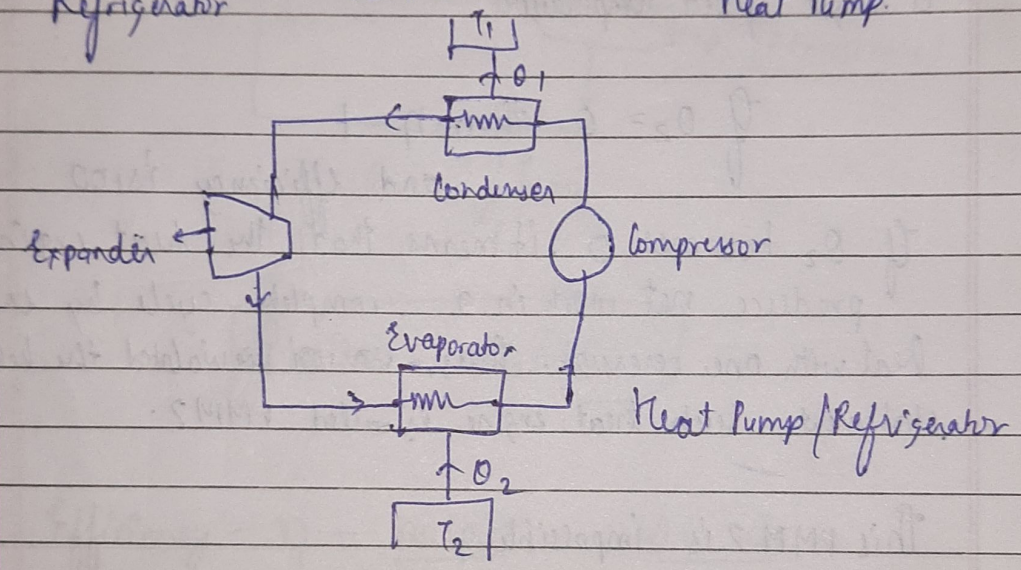
(1) It is impossible to construct a device which operating in a cycle will produce not effect other than the transfer of heat from ~~cold~~ cooler to ~~ka~~ hotter body.

Refrigerator | Heat Pump

(746 watt = 1HP)







$$COP = \frac{\text{desired effect}}{\text{Work input}}$$

In case of Refrigerator

$$COP = \frac{Q_2}{Q_1 - Q_2} = \frac{Q_2}{W_{net}}$$

Heat Pump

$$COP = \frac{Q_1}{Q_1 - Q_2}$$

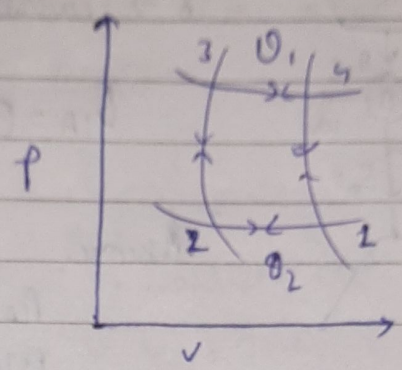
$$(COP)_{ref} + 1 = \frac{Q_2}{Q_1 - Q_2} + 1 = \frac{Q_1}{Q_1 - Q_2}$$

$$(COP)_{ref} + 1 = (COP)_{heat\ pump}$$

Reversible [illegible] slope [illegible] adiabatic

$Q_1 - Q_2$ must be greater than 0

Carnot cycle



Carnot cycle

- Carnot cycle is reversible cycle, it consist of four process, two of them are reversible isothermal and other two are adiabatic reversible.

- (i) A/c to diagram 1-2 → rev. isothermal

$$-Q_2 = U_1 - U_2 + W_{1-2}$$

(ii) 2-3 → rev. adiabatic

$$0 = U_3 - U_2 + W_{2-3}$$

(iii) (3-4)

$$Q_1 = U_4 - U_3 + W_{3-4}$$

(iv) 4-1

rev adiabatic

$$0 = U_1 - U_4 + W_{4-1}$$

add all 4

$$Q_1 - Q_2 = 0 + \Sigma W$$

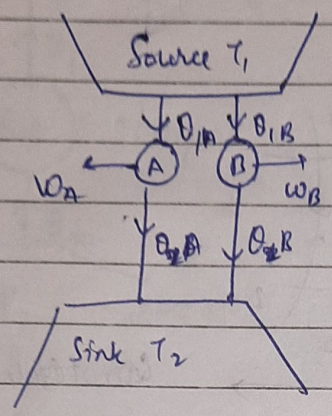
$$\Sigma Q = \Sigma W$$

$$\boxed{\oint Q = \oint W}$$

Exam में आयेगा

Carnot theorem

Prove $\eta_B > \eta_A$



B → reversible engine

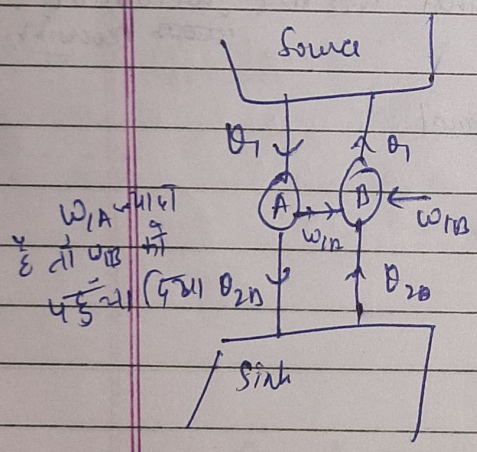
$Q_{1A} = Q_{1B} = Q_1$

Assume

$\eta_A > \eta_B$

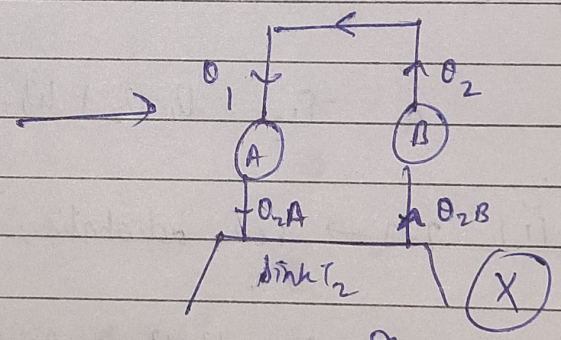
$\frac{W_A}{Q_1} > \frac{W_B}{Q_2}$

$W_A > W_B$



W_{1A} मानो ये है तो W_{1B} भी पड़ेगा। तथा

B is reversible so we reverse it



2nd Kelvin Planck का violated हो रहा। एक source नहीं हो सकता।

"It states that of all heat engines operating between a given constant temperature source and a given constant temperature sink, non rev has a higher efficiency than a reversible engine.

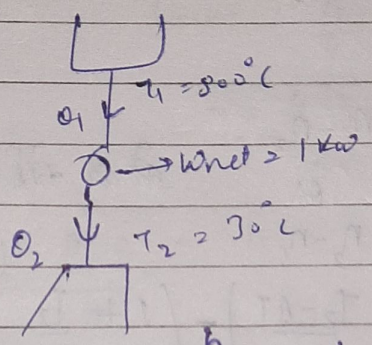
$$\eta = 1 - \frac{Q_2}{Q_1} \qquad Q = f(T)$$

$$Q_1 - Q_2 = 0$$

$$\boxed{\eta_{rev} = 1 - \frac{T_2}{T_1}}$$

→ rev के लिए use होगा।

Q.) A cyclic heat engine operates b/w a source Temp of 800°c and a sink Temp 30°c. What is the least rate of heat rejection per kW net out put of the engine



$T_1 = 1073$

$$\eta_{rev} = 1 - \frac{303}{1073} = 0.718$$

$$0.718 = \frac{W_{net}}{Q_1}$$

$$Q_1 = \frac{1}{0.718} = 1.392 kW$$

$$Q_2 = Q_1 - W_{net}$$
$$= 0.392 kW$$

Q.) Which is the more effective way to increase the efficience of a carnot engine

(i) To increase T_1 keeping T_2 Constant

(ii) To ~~increase~~ decrease T_2 keeping T_1 Constant

Example से समझो

$$\eta = 1 - \frac{T_2}{T_1}$$

(1) $T_1 \rightarrow$ Constant and $T_2 \downarrow \Delta T$

$$\eta_1 = 1 - \frac{T_2 - \Delta T}{T_1}$$

(ii) $T_2 \rightarrow$ Constant , $T_1 \uparrow \Delta T$

$$\eta_2 = 1 - \frac{T_2}{T_1 + \Delta T}$$

$$\eta_2 = \eta_1 - \eta_2$$

or

$$\eta_2 - \eta_1$$

कोई भी solve करे

$$\eta_1 - \eta_2 = \left(1 - \frac{T_2 - \Delta T}{T_1}\right) - \left(1 + \frac{T_2}{T_1 + \Delta T}\right)$$

$$\frac{-(T_2 - \Delta T)(T_1 + \Delta T) + T_2 \cdot T_1}{T_1(T_1 + \Delta T)}$$

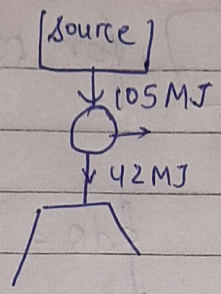
$$\frac{-T_2 T_1 - T_2 \Delta T + \Delta T T_2 + \Delta T^2 + T_2 T_1}{(+)_{ive}}$$

$$\frac{\Delta T(T_1 - T_2) + (+ve)}{+ve} > 0$$

$\boxed{\eta_1 > T_2}$ Because it is positive to in $T_1 \rightarrow$ increase can efficiency is more increase.

Q) ~~In~~ An inventor claims to have develop an engine that takes in 105 MJ at a temp of 400 kelvin, rejects 42 MJ at a temp of 200 kelvin. and delivers 15 kWH of Mechanical work. Could you advice investing money to put this engine in the market.

Ans)



$Q_1 = 105\,MJ$ $\quad T_1 = 400K$

$Q_2 = 42\,MJ$ $\quad T_2 = 200K$

$$\eta_{rev} = 1 - \frac{T_2}{T_1}$$

$$= \left(1 - \frac{200}{400}\right) = 50\%$$

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

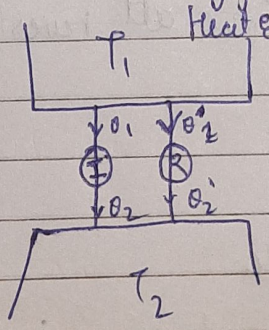
$$= 60\%$$

Entropy

The entropy is the measure of randomness of disorder of any system.

E → Energy, Equilibrium, Entropy.

Heat Engine



$HE_{irrev} = Q_1 - Q_2 > 0$

$H_{rev} = Q_1 - Q_2' > 0$

$$\oint_{rev} \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2'}{T_2} = 0$$ → Reversible हैं कि

$\eta_I < \eta_R$

$\frac{W_I}{Q_1} < \frac{W_R}{Q_1}$

$W_I < W_R$

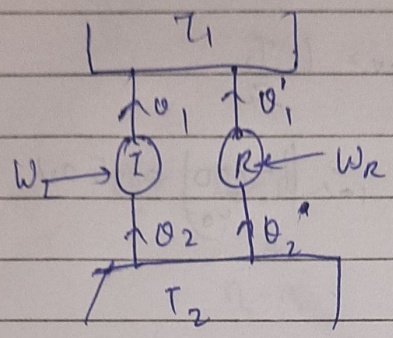
$Q_1 - Q_2 < Q_1 - Q_2'$

$Q_2 > Q_2'$

$$\oint \frac{dQ}{T} = \left(\frac{Q_1}{T_1}\right) - \left(\frac{Q_2}{T_2}\right) < 0$$

$$\boxed{S \leq 0}$$ for reversible and irreversible

Refrigerator



$$\oint dQ = \left.\begin{matrix} Q_2 - Q_1 \\ Q_2 - Q_1' \end{matrix}\right\} < 0$$

Irreversible

reversible

$$\oint_{rev} \frac{dQ}{T} = \frac{Q_2}{T_2} - \frac{Q_1'}{T_1} = 0$$

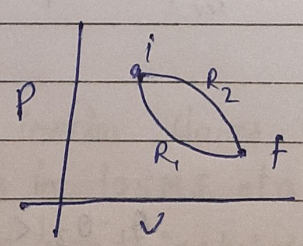
$$W_I > W_R$$
$$W_I + Q_2 > W_R + Q_2$$
$$Q_1 > Q_1'$$

Irr

$$\oint \frac{dQ}{T} = \frac{Q_2}{T_2} - \frac{Q_1}{T_1} < 0$$

$$\boxed{\oint \frac{dQ}{T} \leq 0}$$ for all reversible and irreversible

$$\oint \frac{dQ}{T} > 0$$ → impossible



$$\left| \oint_{R_1, R_2} \frac{dQ}{T} = 0 \right|$$

$$\int_{i\,R_1}^{f} \frac{dQ}{T} + \int_{f}^{i} \frac{dQ}{T} = 0$$

$$\int_i^f \frac{dQ}{T} = -\int_f^i \frac{dQ}{T}$$

$$\int_i^f \frac{dQ}{T} = \int_i^f \frac{dQ}{T}$$

first law by clausius

Entropy is property

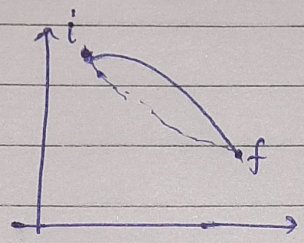
$\rightarrow S_f - S_i$

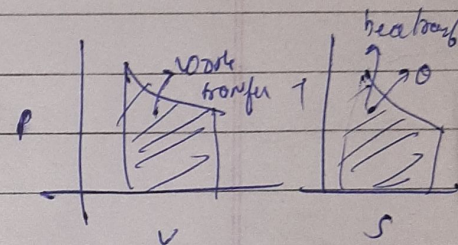
$S =$ Entropy.

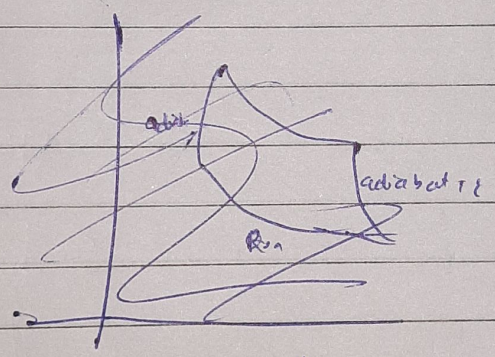
$s \rightarrow$ specific entropy

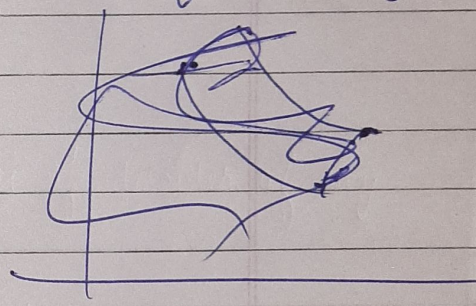
specific entropy $J/kg\,K$

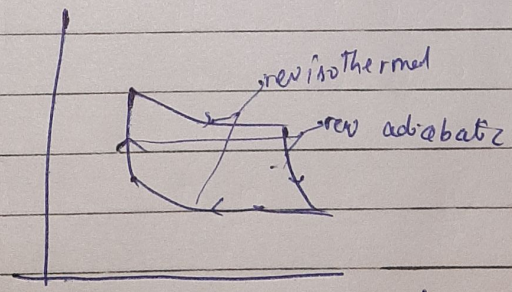
tropee → transformation

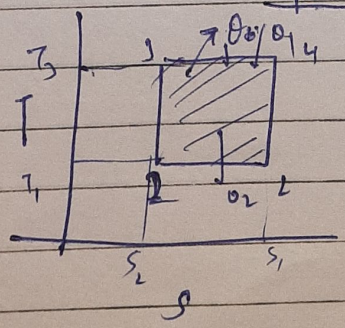












rev. adiabatic → isentropic

S = constant

$Q_1 = (S_1 - S_2)\,T_3$

$Q_2 = (S_1 - S_2)\,T_1$