* I.C. Engines *

Book - Automotive Mechanics
by Joseph Heitner. (Theory)

- IC Engines by V. Ganeshan. (Questions)
- IC Engines by Mathur & sharma

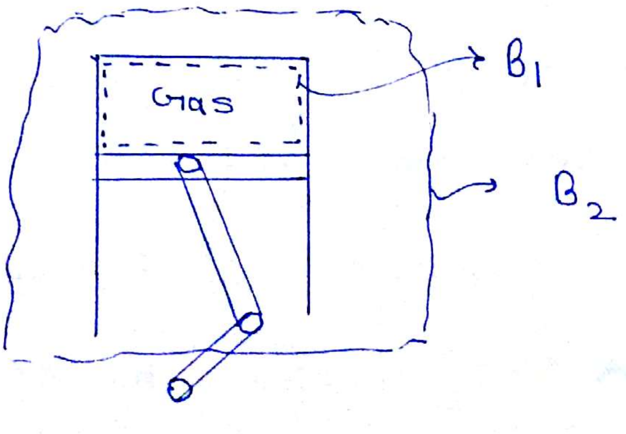
Thermodynamics - It is the field of science which deal with energy causes by gasses and pressure. It conversion in term of Heat and work and it's relationship with be various properties of system.

Properties: - Property of a system is that quantity which belong to the system and without which system can not exists. Thus P, V, T are the fundamental properties of System.

Heat & work are not the property of System.

System:- Referance to any space a matter or a group of matter within a definite boundary whether real or ~~img~~ imagenory is define a system.
In the fig. shown, The gas inside the piston cylinder arrangment is a system for both the boundaries B_1 & B_2. In the case of the Cylinder. It is a sourending for Boundary B_1 and a System for boundary B_2.

Sourending:- Any matter that is outside the boundary and affect the behavious of system is define as sourending.
In the fig. The cylinder is a sourending for boundary B_1 for the region if the cylinder will not exist The gas flow in all direction



Piston cylinder arrangment

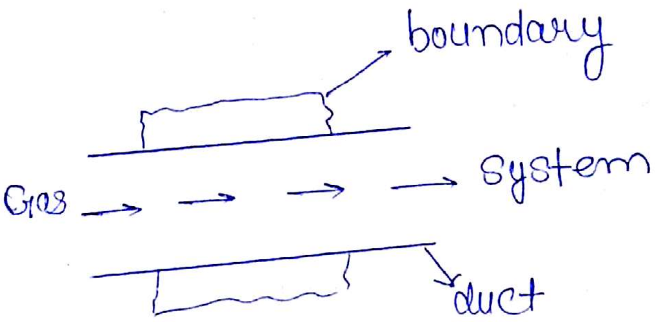
Types of system:-

Close system:- when no mass transfer by only energy transfor taking place across the boundaery then the system is know as close system.

Eg:- A Gas inside a piston cylinder arrangment.

Open/Flow System:- when there is both mass and energy ~~taking~~ transfer taking place across the boundary the system is know as open or flow system.

Eg. Flow of a fluid trough a duck.

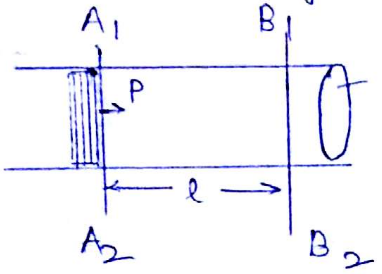


Isolated system:- It is the system which is compilately seprated or isolated from the sourrending. In this case, neither mass nor energy transfer taking place across the boundary.

Eg. Gas inside a thermes flask.

work done for a Flow System:

let us Consider fluid Flowing through a duct as shown in fig.
Taking into account, a perticular layer of Fluid. flowing from section $A_1 A_2$ to section $B_1 B_2$ for which the displacement is l and if it is imagnied that the flow takes place due to the pressure exerted by an imagionary piston formed by the different layer of fluid and if this pressure is equal to P, than the work done for the flow will be given by



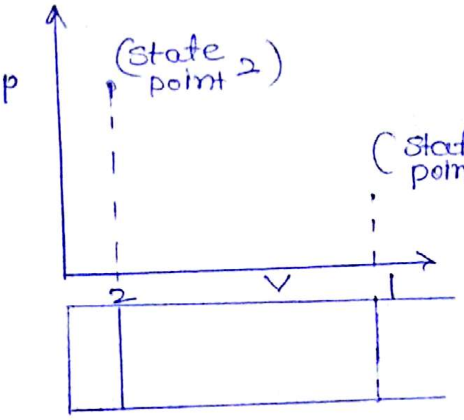
$$W = \text{Force } (F) \times \text{displacement } (l)$$

$$= \text{pressure } (P) \times (A) \times l$$

$$= P \times (A \times l)$$

$$\boxed{W = \underbrace{P \times Vol.}_{\text{Const.}}} \Rightarrow \boxed{W = \underbrace{PV}_{\text{Const.}}}$$

P-V diagram:- The P-V or pressure-Volume diagram is the diagram the pressure is given by the height of diagram and volume is given by length of diagram. The P-V diagram is know as indication diagram. The state of the gas (inside the cylinder) is given by a point in P-V Diag. Thus this point is known as state point of the gas



Process:- when a system udergoes changes from one condition to another condition it is then said to have completed a process (one state point to another state point.)

Cycle.:- when a system after undergoing a number of processes is able to attain it's origional condition (origion P, V, T) It is then said to have completed a cycle.

If the cycle is not Completed, Then Continuous work will not be obtain.

The different operation require for Complete cycle.

Heat addition - Heat rejection - Expansion (work done) - compression

The order in which different operation carried out is as follows.

Heat Addition
↓
Expansion (useful work done)
↓
Heat Rejection
↓
Compression.

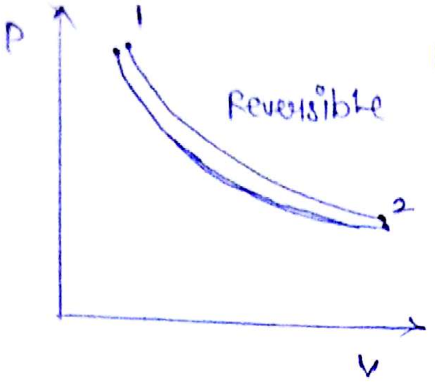
Ideal Cycle :- for an ideal cycle, the expansion and the compression processes should be reversible and adiabatic (isentropic processes)

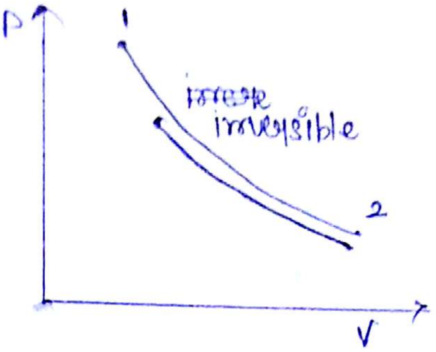
Reversible/irreversible process.

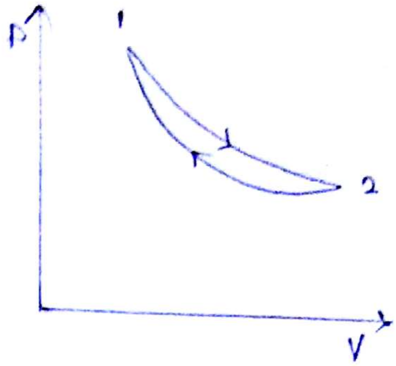
When a system undergoes a process in such a manner that it is able to retain it's origional Condition by following some path in reverse direction, the process is than know as reversible process.
On the other hand if the systen unable to return to it's origional condition by following the reverse path the process is than know as an irreversible process.

Also, if the system is able retain it's origional

Condition by following a different path the processes is still ~~irreve~~ irreversable process.





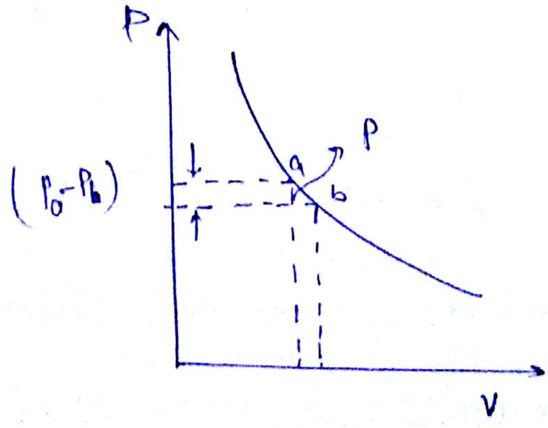


Quasi- static process :- when a system undergoes a processes in such a manner that the final $cond^n$ is nearest to origional and equilibrium condition the process is then know as quasi-static Process.

A quasi static process is same a differentially same change in calculas.

It is used under condition when any value that is remain constant remain constant.

A quasi- static process can be use only for a irreversible process



$$W = P \times V$$
$$\underset{\text{const.}}{\downarrow}$$

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

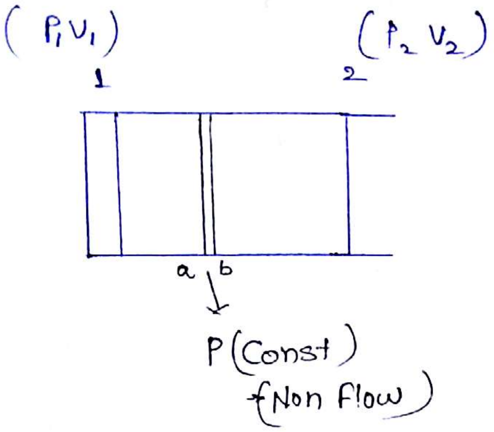
$$W = \int_1^2 P\,dv$$

* To calculate work done always ~~constant~~ Consider quasi-static process.

Work done for close system (Non pt Flow system)

⇒ A quasi-static process taken in Consideration

let us considering a gas expanding from state point 1 to 2 in such a manner then the pressure and volume change from P_1, V_1 to P_2, V_2.



* whenever P = Constant take quasi-static process.

For the non flow system there is no energy available outside. then the energy taken from the system it self due to this pressure of gas decreasing (P not Const.). We thus Consider a quasi-static process for which change in pressure is negligible and the change in volume dv. If the imaginory constant pressure for the quasi-static process 'P' the work done for quasi static process will be

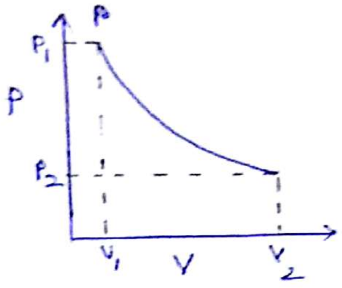
$$dw = P \times dv$$

the work done for entire process will be

$$w = \int_1^2 P dv.$$

Types of process :-

1) Constant-Volume Process (or isochoric or isometric process)
2) Constant-Pressure Process (or isobaric process)
3) Constant-temp. process (or isothermal or hyperbolic Process)



$$V \propto \frac{1}{P} \Rightarrow V = C/P$$

$$\Rightarrow PV = \text{Constant}$$

Use only for Gas not for vapour,

4) Adiabatic Process (No heat transfer)
5) Polytropic process (P, v & T changes, Heat transfer also takes place)

Question Determine work done for different process undergoes by a close system as per above condition.

① Constant Volume Process :-

when V = Const.

then dV = 0

$$\therefore p \times dv = p \times 0 = 0$$

$$W = \int_1^2 P\,dv = \int_1^2 0 = [C]_1^2 = C - C = 0$$

$$\therefore \boxed{W = 0}$$

② constant - pressure ~~Vol~~ ~~Pressure~~ Process :-

$$P = \text{Const.}$$

$$W = \int_1^2 P\,dV = P\int_1^2 dV = P[V]_1^2$$

$$\therefore \boxed{W = P(V_2 - V_1)}$$

③ constant temp. ~~Pressure~~ Process. :-

$$T = \text{constant}$$

$$P \times V = C \quad \text{or} \quad P = \frac{C}{V}$$

$$W = \int_1^2 P\,dV = \int_1^2 \frac{C}{V}\,dV = C\int_1^2 \frac{dV}{V}$$

$$W = C(\ln V)_1^2$$

$$W = P_1V_1\left(\ln\frac{V_2}{V_1}\right)$$

$$\boxed{W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)}$$

④ Adiabatic process :-

$$PV^{\gamma} = C, \text{ or } P = \frac{C}{V^{\gamma}} = C \times V^{-\gamma}$$

$$W = \int_1^2 P\,dV = \int_1^2 C \cancel{\times} V^{-\gamma}\,dV = C\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_1^2$$

$$W = \left(\frac{PV^{\gamma}.V^{-\gamma+1}}{-\gamma+1}\right]_1^2 = \left(\frac{PV}{-\gamma+1}\right)_1^2$$

or $$W = \frac{P_2V_2 - P_1V_1}{-\gamma + 1}$$

$$\therefore \boxed{W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}}$$

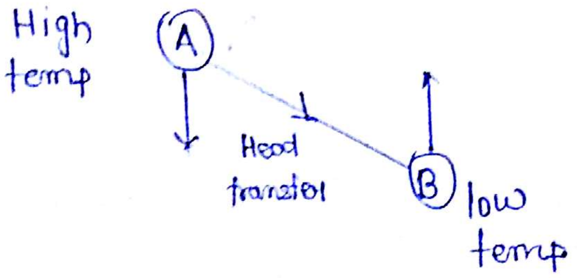
⑤ Polytropic process:-

$$\therefore \boxed{W = \frac{P_1V_1 - P_2V_2}{n - 1}} \qquad PV^n = C$$

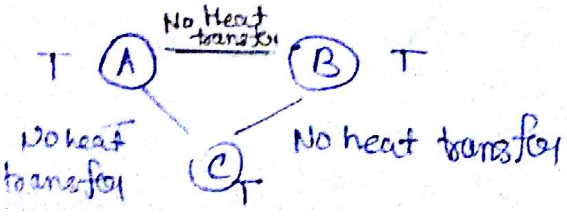
Thermal equilibrium :-

When there is no heat transfer between two bodies, then they are them said to a thermal equilibrium with one another

under ideal condition. the temp of two bodies will be same when they are in thermal equilibrium with one another



Zero th law when two bodies are seprately are in thermal equilibrium with a third body then first two bodies will also be in thermal equilibrium.



Gas:- The state atain after complate evaporation of liquid is defined as gas.

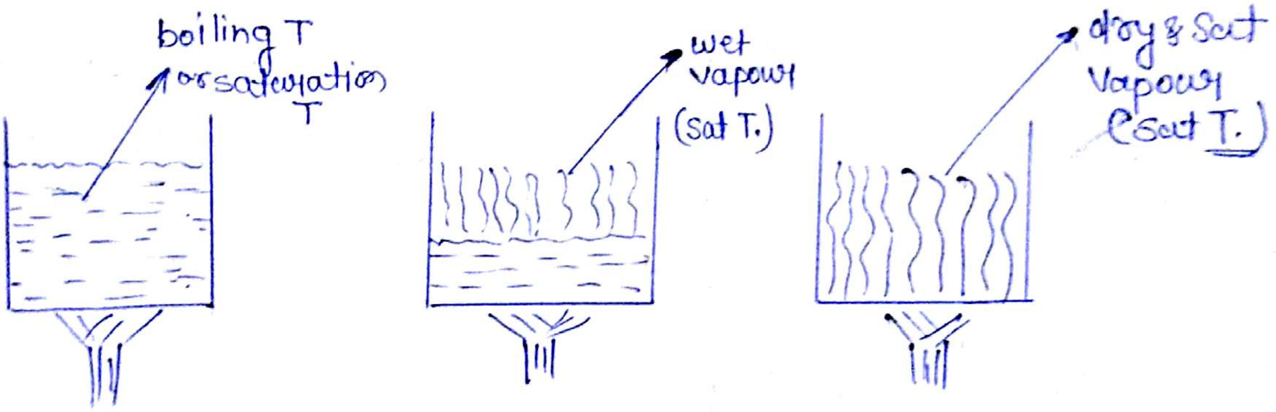
Ideal Gas: An ideal gas is the one which obey all the Gas law.

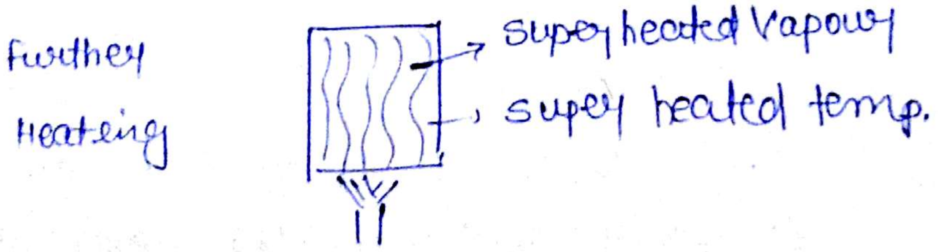
Real Gas:- No real gas is perfect as non obey the gas law. Under certain condition of temp & pressure some gasses behaive like a perfect gas.

Ex- ~~Ar~~, O_2, N_2, H_2 etc.

Real gases are the gases that are available in practice.

Vapour:





Vapour:- The state existing due to incomplate evopratio of liquid is define as vapour liquid will be present in the vapour given in the above definition such a vapour is know as wet vapour. The temp of wet vapour will be the boiling temp. that is also know as the saturation temp.

Heating the wet vapour, at one stage, will result in all the liquid being transfered in vapour. such a vapour is know as dry and saturated vapour. The temp of this vapour will be the saturation temp. When the dry and saturated vapour is heated, ~~than~~ the vapour than available is known as superheated vapour. The temp. of super heated vapour is known as super heated temp.

Diff. Gas law

Boils law:- Temp. remaining Constant. The Volume of the Given mass of a gas is inversaly perportional to its absolute pressure.

when $T =$ Constant.

then $V \propto \frac{1}{P}$ or $V = C/P$ or $P \times V = C$

$$\therefore P_1V_1 = P_2V_2 = \cdots = P_nV_n = C \quad -①$$

Charl's law (1st statement)

when $P =$ Constant the volume of Given mass of a gas is directly perportional to it's absolute temp.

when P = Const, then $V \propto T$

or $V = CT \therefore \frac{V}{T} = C$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \text{ or } \boxed{\frac{V_2}{V_1} = \frac{T_2}{T_1}} \quad -②$$

when V = Const, than $P \propto T$

or $P = CT \therefore \frac{P}{T} = C$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \text{ or } \boxed{\frac{P_2}{P_1} = \frac{T_2}{T_1}} \quad -③$$

Charl's law (2nd statement) :- Pressure remaining Constant, The volume of the given mass of a gas, increase or decrease by 1/273 of its origional volume for every degree increase or decrease °C scale of Temp.

when P = a Constant

$$V = V_0 + \frac{t°C}{273} V_0$$

$$\text{or } V = V_0 \left(1 + \frac{t°C}{273}\right)$$

$$\therefore V = V_0 \left[\frac{273 + t°C}{273}\right]$$

when the temp of gas is $-273\,^\circ c$, then the Volume of the Gas equal to zero

To have zero temp. when Volume of Gas is zero. A new scale of temp is introduce know as the absoulate or the kelvin a scale of temp Such that zero temp in kelving Scale corrospond to -273 in the the $^\circ c$ so scale of temp.

The change in temp is same in both the scale. Thus the relationship between the kelvin scale and $^\circ c$ sacl scale will be as under $T_k = 273 + t\,^\circ c$

$$T.K = 273 + t\,^\circ c \qquad - ⓓ$$

We have from equation ⓐ & ⓓ

$$\therefore\ V = V_0 + \left[\frac{Tk}{273}\right]$$

Thus, we have for the volumes V_1 & V_2

$$V_1 = V_0\left[\frac{T_1\,k}{273}\right] \qquad - ⓑ$$

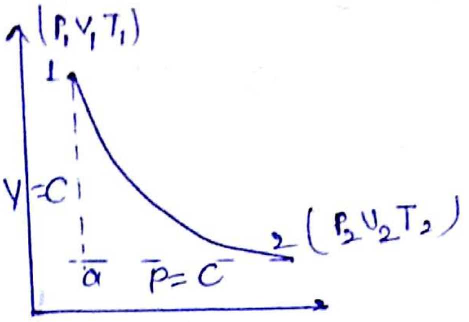
$$V_2 = V_0\left[\frac{T_2\,k}{273}\right] \qquad - ⓒ$$

equation ⓑ devide by equation ⓒ Gives

$$\frac{V_2}{V_1} = \frac{T_2\,k}{T_1\,k}$$

Which is in accordance with the first statement of charlls law. It is thus clear that the temp. applied for thermodynamic must be in the kelvin scale of Temp. only.

Universal Gas law:-



let us consider a system undergoing change from state point ① to state point ② in such a manner that P,V,T changes from P_1, V_1, T_1 to P_2, V_2, T_2 if the final condition is obtain by first taking a constant volume path 1-a and then by a constant pressure path, we that have for the constant volume process.

$$V_1 = V_a$$

$$\& \quad \frac{T_a}{T_1} = \frac{P_a}{P_1} \quad \text{or} \quad T_a = T_1 \times \frac{P_a}{P_1} \quad - ①$$

And for the constant Pressure process (a·2) we get

$$P_2 = P_a$$

$$\& \quad \frac{V_a}{V_2} = \frac{T_a}{T_2} \quad \therefore \quad T_a = T_2 \times \frac{V_a}{V_2} \qquad — ②$$

From ① & ②

$$T_1 \times \frac{P_a}{P_1} = T_2 \times \frac{V_a}{V_2}$$

$$\text{or} \quad T_1 \times \frac{P_2}{P_1} = T_2 \times \frac{V_1}{V_2}$$

$$\therefore \quad \boxed{\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}}$$

$$\therefore \quad \frac{PV}{T} = \text{a Constant } R$$

$$\therefore \quad \boxed{PV = RT}$$ Gas equation

R - Gas Constant.

If the mass '**m**' is introduce in equation (Gas mass

$$\boxed{PV = m R_c T}$$ (Characteristic gas equation)

R_c - characteristic Gas constant.

Heat

Unit of heat :- one unit of Heat is the amount of heat require to raise the temp. of 1 gram of air through 1°C.

- One unit of heat in the SI unit is ~~Not~~ know as 1 Joule.

- **Specific heat** : Specific Heat of a substance is the amount of heat required to raise the temp. of 1 gram of that substant through 1°C

$$C = \frac{Q}{mt}$$

$$Q = m \times c \times t$$

let us consider a mass m of substant will heated until the raise in temp. t if the heat transfer for this purpose is Q. ~~wh~~ we have from above definition the specific heat is given by

$$\boxed{C = \frac{Q}{mt}}$$

$$t \rightarrow Q/m$$

$$1 \rightarrow \frac{Q}{mt}$$

or $$\boxed{Q = m \times C \times t}$$

∴ Heat transfered = (mass × specific heat × change in temp.)

Specific Heat of Gases:- Gas have many specfic heat. Two of the important specific heat are

1) The specific heat at constant pressure (C_p)
2) The specific heat at constant volume (C_v)

The specific heat at constant pressure is always greater than the specific heat at constant volum ($C_p > C_v$). for the reason - ~~There is a region~~ reason there is increase in ~~numbers of~~. volume of also during constant heat

Thus, $C_p > C_v$ (Always)

or $\frac{C_p}{C_v} > 1$

Also $\frac{C_p}{C_v} = $ a const γ (> 1)

First law of thermodynamic

For a cycle:- For ~~era~~ a complete cycle heat and work transfer are mutually conversed into one another.

~~wh~~ we have from the above statement.

$$\text{cyclic } dQ = \text{cyclic } dw$$

The following points are to be noted

① Heat added to the gas is taken positive

② Heat rejected from the system is taken negative

③ Work done by the gas (expansion work) is taken positive.

④ Work done on the gas (compression work) is taken negative.

If the cycle comprises of 4 processes

$$dQ_1 + dQ_2 + dQ_3 + dQ_4 = \text{Cycle work}$$

let $HA = (dQ_1 + dQ_3)$

$$HR = -(dQ_2 + dQ_4)$$

Also $(dQ_1 + dQ_3) - [-(dQ_2 + dQ_4)] = \text{work of cycle}$

$\therefore$ ~~HA =~~ $\boxed{HA - HR = W}$ ★ only for cycle

* won't take it for process

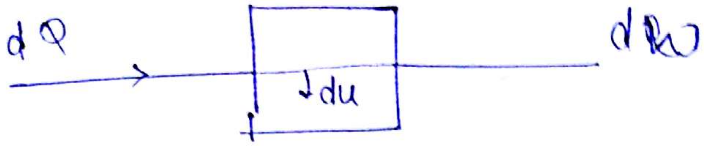
& $\boxed{\eta_{th} = \frac{W}{HA}}$

For a process :-

Kelvin plank's statement:- It is impossible for a self acting machine to convert all the heat supplied into useful work

It is clear from the above statement that during a process, the work output will be always less than the heat supplied The reason is that to convert the heat input into work, the system must get activated for this purpose, the system must consume some energy for itself & chance the work output will be reduced.

The energy taken by system internaly is called change in ~~ind~~ infomal energy (du). Hence the relation b/w the heat transfer (dQ) and work output (dw) will be as follows



$$dQ = du + dw$$

The energy taken by the system internaly, thus no external work. Hence then in internal energy can not bring out ~~in~~ any change in Volume. Hence the change in internal energy for the the system will bring out change in temp. only.

~~The~~ Thus internal energy define of a system in following maner.

Internal energy is the energy ~~on~~ present in system due to its Temp. Thermodynamically it is given by

$$\boxed{du = mc_v dt}$$

for any ~~cycle~~ process

Hence, the change in internal energy express in term.

~~$dQ = du + dw$~~ $\boxed{du = mC_v dT}$ for any process

It is should ~~not~~ ~~be~~ be noted that change in internal energy for complate cycle and for constant temp. process is equl to zero

Heat transfer for diff process

① Constant vol. process.

$$dQ = du + dw = du + 0$$

$$\therefore dQ = du$$

or $\boxed{dQ = mC_v dt}$ —(1)

② Constant pressure process.

$$dQ = mc\,dt$$

p is a const, thus $c = C_p$

∴ ~~po~~ for a const. pressure process

$$\boxed{dQ = mC_p dT} \quad \text{—(2)}$$

$$dQ = du + dw$$

when p = a constant

$$mC_p dT = mC_v dT + pdV \quad \text{—(a)}$$

& $d(PV) = d(mRt)$

$$d(PV) = mR\,dt \quad \text{—(b)}$$

From ⓐ & ⓑ

$$mC_p\,dT = mC_v\,dT + mR\,dT$$

$$\therefore \boxed{C_p - C_v = R}$$

For other process we can also use this

③ Constant Temp. process :-

$$dQ = du + dw = 0 + dw = dw$$

$$\boxed{dQ = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)} \quad -③$$

④ Adiabatic process :-

$$dQ = 0$$

(ideal condition)

or $$du + dw = 0$$

or $$mc_v\,dt + pdv = 0 \quad - ⓐ$$

and $$d(pv) = d(mRt)$$

or $$pdv + vdp = mRdt$$

$$dt = \frac{pdv + vdp}{m(C_p - C_v)} \quad -ⓑ$$

From ⓐ & ⓑ

Now $$c_v\left[\frac{pdv + vdp}{C_p - C_v}\right] + pdv = 0$$

$$(pdv + vdp) + \frac{C_p - C_v}{C_v} \times pdv = 0$$

$$pdv + vdp + (\gamma - 1)\, pdv = 0$$

$$vdp + \gamma\, pdv = 0 \qquad -ⓒ$$

divide eq ⓒ by PV

$$\frac{vdp}{PV} + \gamma \frac{Pdv}{PV} = \frac{0}{PV} = 0$$

$$\therefore \frac{dP}{P} + \gamma \frac{dv}{V} = 0$$

Integrating $\ln p + \ln v^{\gamma} = \ln C$

so $\ln(PV^{\gamma}) = \ln(C)$

$$\therefore \boxed{PV^{\gamma} = C}$$

⑤ Polytropic process:-

$$dQ = du + dw$$

$$dQ = mc_v(t_2 - t_1) + \frac{P_1V_1 - P_2V_2}{n-1} \qquad -ⓐ$$

$$dQ = c_v\left[\frac{P_2V_2 - P_1V_1}{C_p - C_v}\right] + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$dQ = \frac{P_1V_1 - P_2V_2}{n-1}\left[\frac{-(n-1)}{\frac{C_p - C_v}{C_v}} + 1\right]$$

$$\therefore \boxed{dQ = \frac{\gamma - n}{\gamma - 1} \times \frac{P_1V_1 - P_2V_2}{n-1}} \quad - (b)$$

From (a)

$$dQ = mc_v(t_2 - t_1) + \frac{m(C_p - C_v)[t_1 - t_2]}{n-1}$$

$$= m(t_2 - t_1)\left[C_v + \frac{C_v - C_p}{n-1}\right]$$

$$= m(t_2 - t_1)\left[\frac{nC_v - C_v + C_v - C_p}{n-1}\right]$$

$$\boxed{dQ = m(t_2 - t_1)\left(\frac{nC_v - C_p}{n-1}\right)}$$

✱ when mass & temp Given.

$$dQ = m \times C_n \times dt.$$

$$\therefore \boxed{C_n = \frac{nC_v - C_p}{n-1}}$$

specific heat की किसी value को C_p & C_v से ज्ञात किया जा सकता है।

Entropy of Gases

Measurement ↗ variation ↗

Entropy is define as the degree of randomness of the body.

The change in entropy can also be define as under the execs energy present in body can not be removed for a given particular temp. The is define as the entroy of system.

In thermodynamic change in entropy equal to

$$\boxed{ds = \frac{dQ}{T}}$$

Change in entropy for different process Going on.

① Const. Vol. process :-

$$\int_1^2 ds = \int_1^2 \frac{dQ}{T}$$

$$S_2 - S_1 = \int_1^2 \frac{m c_v dT}{T}$$

$$\therefore \boxed{S_2 - S_1 = m c_v \ln\left(\frac{T_2}{T_1}\right)}$$

② Constant pressure process :-

$$\boxed{S_2 - S_1 = m c_p \ln\left(\frac{T_2}{T_1}\right)}$$

③ Constant temp process:-

$$dS = \frac{dQ}{T} \qquad T = \underline{Const}$$

or
$$S_2 - S_1 = \frac{P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)}{T}$$

or
$$S_2 - S_1 = \frac{mRT \ln\left(\frac{V_2}{V_1}\right)}{T}$$

$$\boxed{S_2 - S_1 = mR \ln\left(\frac{V_2}{V_1}\right)}$$

④ Adiabatic process:-

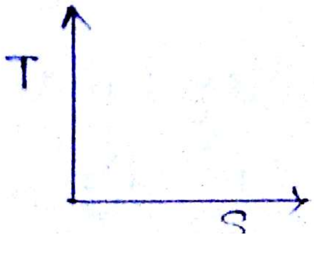
$$\int_1^2 ds = \int_1^2 \frac{dQ}{T}$$

$$S_2 - S_1 = \int_1^2 \frac{0}{T} = \int_1^2 0 = [C]_1^2 = C - C = 0$$

$$\therefore \boxed{S_2 - S_1 = 0} \quad \text{or} \quad \boxed{S_1 = S_2}$$

Thus the change in entropy for a reverssible adiabatic process is zero or entropy remain Constant throught process.

- The contant v, & contant P. process in T-S diagram.



* Constant Volume and Constant pressure are in Temprature pr Entropy diagram

$$dS_p = mC_p \ln T_2/T_1$$

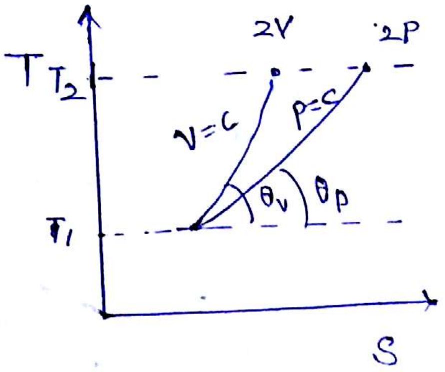
$$dS_v = mC_v \ln T_2/T_1$$

* The two process are shown in T-S diagram then.

* The change in entropy for constant pressure process will be more (more change in length).

as $C_p > C_v$

* From T-S diagram it is clear that the slope of Constant Volume process is greater the slope of Constant pressure process.



$$\boxed{\theta_v > \theta_p}$$

~~Rever~~ Externaly Reversible cycle:-

A cycle is said to be externaly reversible when there is energy balance between system and sourounding. For this purpose the following energy equation must be Complately satisfy.

$$\boxed{HA - HR = W}$$

Internal Reversible Cycle:-

For a cycle, If heat addition and heat rejection takes place at constant temp. the cycle is than know as an internaly reversible cycle.

* When a cycle both internaly & externaly reversible then it know as a complately reversible cycle. only carnot cycle is both internaly and externaly reversible. Thus only carnot cycle fully reversible cycle All other ideal cycle are irreversible cycle.

$$dQ = du + dw$$

$$dQ = 0 + dw$$

$$du = 0$$

$$mc_v(t_2 - t_1) = 0 \Rightarrow \boxed{t_1 = t_2}$$