JHARSUGUDA ENGINEERING SCHOOL

DEPARTMENT OF MECHANICAL ENGINEERING

Lecturer notes on

THERMAL ENGINEERING-1

(3rd semester)

Subject code-Th-4

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Thermal Engineering - I

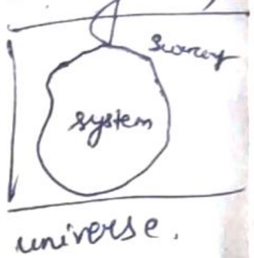
Thermodynamics system :-

A thermodynamic system is defined as any region of space or a finite quantity that occupies a volume & has a boundary.

e.g - gas cylinder of reciprocating engine.

Surroundings :- Anythings external to system

system + surrounding = universe.



Types of thermodynamic system

1) closed system → mass constant, mass can't transfer
→ Heat & work transfer.
energy

e.g - tea kettle.

2) open system → mass, energy cross the boundary of system

e.g Reciprocating compressor, boilers, turbines,

3) Isolated system :- Both mass & energy can't transfer from the system.

e.g - universe, thermoflask

4) Adiabatic system :- thermally insulated from its surrounding
work transfer but not Heat.

Theremodynamic Preoperties of system

P, V, T, entropy, enthalpy, Internal energy (U)

Pressure:-

→ it define as force per unit area.

→ unit = pascal

$1\,pa = 1\,N/m^2$

$1\,bar = 1 \times 10^5\,N/m^2 = 100\,kpa = 0.1\,MN/m^2$.

Atmospheric pressure :-

atm pressure :- ~~cot~~ Pressure due to the wt. of the column of aire above the earth surface.

std. pressure = 760 mm of Hg at 0°c ~~at~~
= 1.013 bar at sea level.

Atm pressure = $1.013 \times 10^5\,N/m^2$
$= 101.3 \times 10^3\,N/m^2 = 101.3\,kpa$.

✓ $1\,mm \text{ of } Hg = \dfrac{101.3 \times 10^3}{760} = 133.3\,N/m^2$.

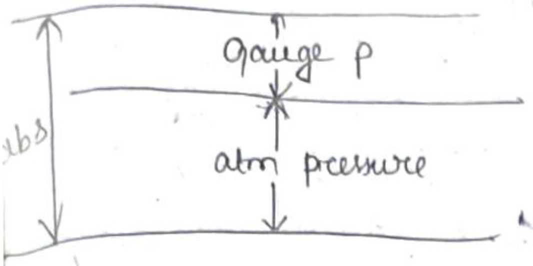
Gauge pressure :-

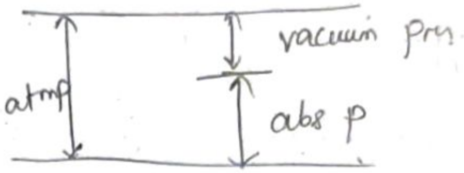
when instrument records pressure above atm pressure.

vacuume pressure:-

records pressure below atm pressure (-ve gauge pressure)

Abs pressure = Gauge p + atm p
= atm p − vacuum p





Temp (T)

→ define as degree of hotness or coldness of a body or environment.

$K = {}^\circ C + 273$

(V) **volume :-** (V) The amt of space occupied.

unit = l , m^3

(S) **entropy :-** Entropy is the loss of energy available to do work. entropy is a measure of randomness. (S) (J/Kg).

~~enthalpy~~ **internal energy :-** (U) (J/Kg or KJ)

ie of a thermodynamic system is the ~~toter~~ energy contained within it.

→ U ↑ , T ↑ , $\Delta U = q + w$

(H) **Enthalpy :-** sum of internal energy & product of P & V.

$H = U + PV$ (J/Kg)

Thermodynamic properties

Every system has some characteristic by which its physical condition describe. such as P, V, T → These are called properties of system.

~~Thermod~~ 2 types of properties

(1) Intensive property. ← independent of mass
e.g = P, V, Sp. energy, Sp. volume, ~~density~~

2) Extensive property.

↑ depend on the mass
e.g – volume, total energy.

Thermodynamic process

any properties of system changes → change of state → . ~~pro~~ thermodynamic process.

e.g → expansion of gas as it ~~pro~~ flow through turbine.

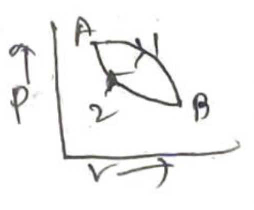
① Isochoric process – process tak place at constant volume.

2) Isobaric process → Cont Pressure.

3) Isothermal " → const. temp.

Thermodynamic cycle :-

process are performed ~~as~~ on a system in such a way that the final state is identical with initial state, ~~without change of physical properties~~



Phase

quantity of matter which is homogeneous (uniform) throughout in physical struc & chemical composition

3 phase — solid, liquid, gas.

Homogeneous & Heterogeneous system :-

Single phase → Homogeneous → e.g water, ice, water vapour.

mixture of amonia in H_2O.

more than one phase → Heterogeneous system

e.g - water + steam

ice + H_2O

water + oil.

Thermodynamic State & path.

→ State :- condition of physical existence of a system at any instant of time.

it is describe by properties such as P, T, V etc.

→ system undergo a change of state without change of phase.

→ Thermodynamic system passing through a series of states constitutes a path

Thermodynamic equilibrium

3 equilibrium satisfied.

① Mechanical ← no unbalance force

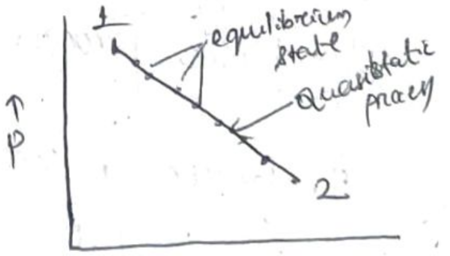
2) chemical ← no chemical reaction

3) Thermal ← no temp difference.

Quasi-static process

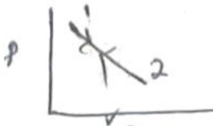
Quasi-static process is one in which the system deviates from thermodynamic equilibrium state by only of infinitesimal amount throughout the entire process.

→ This process may, practically, be considered as a series of equilibrium states & its path ~~may~~ represent graphically as continuous line on a state diagram.



Reversible process

Process which can be reversed in direction and the system follow same continuous series of equilibrium state, is said to be reversible process.



→ Quasistatic process → Reversible process

→ it exists when there is no friction.

→ no heat transfer accross finite temp difference.

In actual, reversible process cannot exist.

Irreversible process

→ will not retrace the reverse path.

Heat

→ Energy interaction between system & surrounding

(joules J) (KW)

Heat transfer 3 way

1. Conduction
2. Convection
3. Radiation

Specific Heat

amt of Heat required to raised the temp of unit mass of a substance through 1°C.

unit - Kj/kg·K.

$Q = mc(T_2 - T_1)$ in Kj

m = mass (Kg)

C = Specific Heat (Kj/Kg·K)

T_1 = initial temp

T_2 = final temp.

→ Solid, liquid → one specific heat

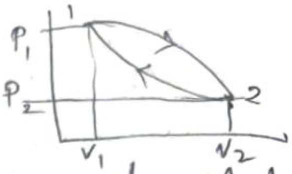
→ Gas → at const pressure → C_p

" const volume → C_v

$C_p > C_v$. $\frac{C_p}{C_v} = \gamma$.

Point function :-

when a thermodynamic property has a definite value for a given state, it is called point funct^n.



e.g = P, V, T

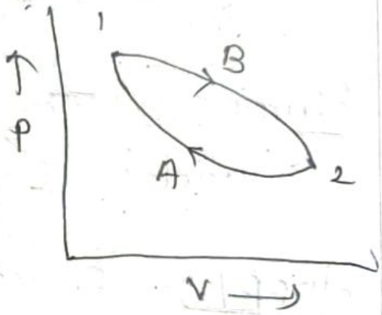
→ it depends on initial & final states of the system.

Path function

the quantities which are not thermodynamic properties, are known as path functions.

e.g = Heat, Work.

1–B–2 , 2–A–1



Comparison ~~be~~ between Heat & work

Similarities

① Heat & work both are boundary phenomena. they are observed at boundary of system.

2) Both are transient phenomena. donot possess heat & work.

3) ~~B~~ Both are represent energy crossing the boundary of system.

4) Both are path function. inexact differential thermodynamic properties.

Differencies :-

1) In stable system, no reversible work transfer. but heat transfer takes place.

2) for transfer of heat, temp difference needed.

Energy :-(E) defined as capacity to do work.
unit = N-m

→ 2 typys

- stored energy
  (energy remains within the boundary of the system)
  (KE, PE, internal energy)
- energy in transition
  (energy crosses the system boundary)
  (e.g Heat, work, electricity)

Different forms of stored energy :-

1) potential Energy :- energy possessed by a body

$P.E = mgh$ (j)

2) $K.E$ = energy possessed by a body or system by virtue of its mass & velocity of motion.

$KE = \frac{1}{2}mv^2$ (j or N-m)

3) internal Energy :- " " by a body or a system by virtue of its molecular arrangement & motion of molecules.

T↑ U↑

Work, heat & comparison bet^n two

Heat :- Heat is energy interaction bet^n the system & surrounding.

→ it defined as the energy transferred, without transfer of mass, across the boundary of a system due to temp difference bet^n the system & surrounding.

3 ways heat transfer :-

(1) Conduction :- process of heat transfer from one particle to another particle of the body, in the direction of fall of temp.

2) convection :- heat transfer from one particle to another particle of the body by convection currents

→ fluid.

3) Radiation :- heat transfer without affecting intervening medium.

→ if heat flow into a system from surroundg = +ve, +Q

" from system to surr = -ve → -Q

Work :- Energy transfered across the boundary of a system between system & surrounding.

→ work done by the system on surroundin = +W (fluid expant piston)

→ from sur to sys = −W (rotating laddle)

Comparison of Heat & work

Similarity :-

(1) heat & work are both boundary phenomena.

2) The heat & work are both transient phenomena. the systems donot posses heat or work.

3) when a system undergoes a change, heat transfer or workdone may occur at the boundary.

4) The heat & work represent the energy crossing the boundary of the system.

5) Heat & work both are path function & depend upon the process.

6) Both are inexact differential.

Difference :-

(i) For the transfer of heat, the temp difference is needed.

(ii) In stable system there can't be work transfer but there is no restriction for heat transfer.

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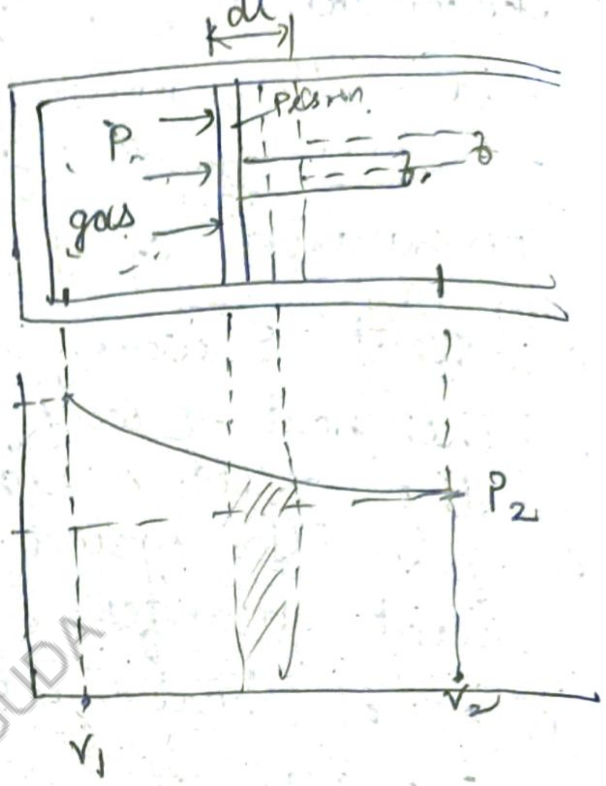
exact $\oint \phi = 0$ (cycle change of variable ϕ = 0)

inexact diff - $\oint dW \neq 0$

Work transfer : displacement work

displacement work



Let A = c/s area of piston

pressure force exerted by the ~~gas~~ gases on piston = $F_p = (P.A)$

then it give small ~~dis~~ displacement = dl

because of displacement there is small work is done.

$$dw = F_p \cdot dl$$
$$= P \cdot A \cdot dl$$

$\boxed{dw = p.dV}$ small elementary work

total workdone moving from 1 to 2 you have to integrate

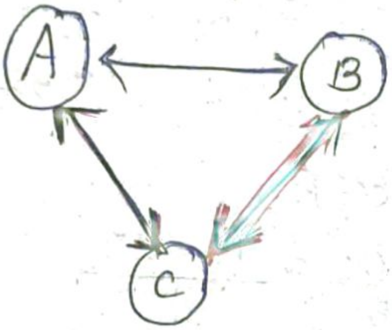
$$\int_1^2 dw = \int_1^2 p\,dV \Rightarrow \boxed{W_{12} = \int_1^2 p\,dV}$$

Laws of Thermodynamics

Zerath law of Thermodynamics

when two systems are each in thermal equilibrium with a third system, then they are also in thermal equilibrium with eachother. The statement is known as Zerath law of thermodynamics.

eg:-



temp → defined as the degree of hatness or caldness of a body or environment

→ Two body are in contact $\Rightarrow$ heat transfer from hot body at high temp to a cold body at lower temp.

→ for measuring ~~[illegible]~~ ordinary temp Thermometers use.

→ for measuring high temp – pyrometer.

→ If gas will not occupy any volume at a certain temp. This temp known as absolute zero temp.

– absolute temp = thermometric reading °C + 273

temp measuring scale

(1) celsius & Fahrenheit scale

→ it has two fixed point → censius scale

(1) Freezing point of water (0°c) ← icepoint

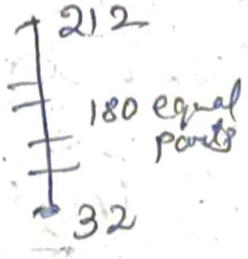
2) Boiling point of water (100°c) ← steam point

* Fahrenheit scale

→ Freezing point = 32

→ Boiling point of H_2O = 212

→ °F



Relation betn celcius & F

$$\frac{C}{100} = \frac{F-32}{180} \quad \text{or} \quad \frac{C}{5} = \frac{F-32}{9}$$

* ~~cel~~ C & F scale show same reading at −40°c ie $\boxed{-40°C = -40°F}$

First law of Thermodynamics

first law of thermodynamics for a closed or non-flow system undergoing cycle

→ According to 1st law of thermodynamics, the heat & mechanical work are mutually convertible.

→ when a closed & non flow system undergoes a thermodynamic cycle, the heat transfer is equal to net work transfer.

$$\int dQ = \int dw.$$

$$\int dQ - \int dw = 0$$

Limitation of 1st Law of thermodynamics

① we know $\oint Q = \oint W$, but this statement doesn't specify the direction in which heat & work flows.

2) Heat energy & mechanical work are mutually convertible. mechanical energy fully converted into heat energy, but a part of Heat energy converted into mechanical work.

Q·1) A closed system Consist of water. in a cylinder. Heat given to the ~~system~~ is cylinder 45 kj ~~cause~~ so that 40 ~~kw~~ kj of ~~heat~~ work done by the cylinder. determine ~~of~~ the change in internal energy during this process.

A/ $Q = 45$ kj

$W = 40$ kj

$Q = U + W$

$U = Q - W = 45 - 40 = 5$ kj

② ·A closed system Consist of water in a cylinder and being stirred by a paddle wheel, during the process 35 kj/h of work given to the system and internal energy increases to 145 kj from initial value of 120 kj during ~~xxx~~ 1hr of stirring. determine heat transfer. is the temp raising or falling.

→ $W = -35$ kj/h.

$U_2 = 145 \quad U_1 = 120$.

$dU = U_2 - U_1 = 145 - 120 = 25$ kj/h,

$Q_{1-2} = U_{12} + W_{12} = 25 \pm 35 = -10$ kj/h

$U \uparrow T \uparrow$

Classification of thermodynamic process

① closed or non-flow process :-

→ No transfer of mass across the boundaries

→ Energy into form of heat & work can transfer.

2) open or flow process :-

→ transfer of mass from the system.

→ mass enter the system & Leaves after exchanging the energy.

→ e.g turbines, compressor.

Workdone for a closed or non-flow process :-

→ Consider a system (gas) enclosed in cylinder, piston arrangement.

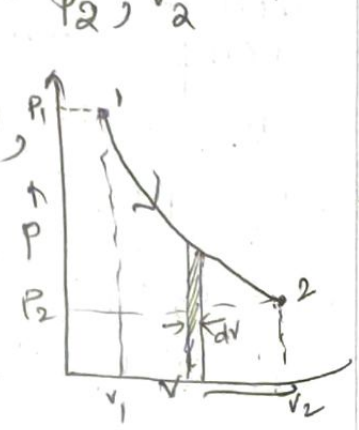
→ Let at state 1, its in equilibrium state.

P_1, V_1, T_1

→ at position 2, ~~state~~ its P_2, V_2

→ Force acting on the piston,

$F = P.A$



Force causes the piston to more through a small distance dx.

workdone = F × dx

$\delta W = P \cdot A \cdot dx = P \cdot dV$. —— (I)

dV = change in volume $= A \cdot dx$.

when gas expand from 1 to 2.

$W_{1-2} = \int_1^2 \delta W = \int_1^2 P \cdot dV$. —— (II)

$$\boxed{W = \int_1^2 P \cdot dV}$$

Q) A perfect gas expands in such a way that its pressure varies in a linear relationship with volume.

$P = aV + b$, a, b = constant.

if initial and final states of the gas are 4 bar, $0.1\,m^3$ and 2 bar, $0.2\,m^3$; determine work interaction.

→ $P_1 = 4$ bar $= 4\times10^3 = 400\,KN/m^3$, $V_1 = 0.1\,m^3$

$P_2 = 2$ bar $= 200\,KN/m^3$, $V_2 = 0.2\,m^3$.

$P_1 = aV_1 + b$ ——(I)

$400 = a \times 0.1 + b = 0.1a + b$ —— (I).

$P_2 = aV_2 + b$

$200 = 0.2a + b$ —— (II)

$0.1a + b = 400$

$0.2a + b = 200$

$a = -2000$ $b = 600$

$$\delta w = \int_{v_1}^{v_2} p\,dv$$

$$\delta w = \int_{v_1}^{v_2} (av+b)\,dv.$$

$$w_{1-2} = \left[\frac{av^2}{2} + bv\right]_{v_1}^{v_2} = \left[\frac{-2000\,v^3}{2} + 600v\right]_{v_1}^{v_2}$$

$$= \left[-1000\,v^2 + 600\,v\right]_{0.1}^{0.2}$$

$$= 30 \text{ kJ}$$

Types of Non-flow precesses.

① Rerersible non-flow precess.

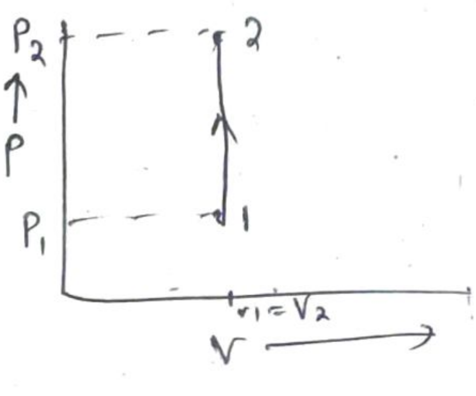
a) const. volume precess (isochoric)
b) cost. P (isobaric)
c) cost. T (isothermal)
d) adiabatic
e) ~~pro~~ polytropic proces.

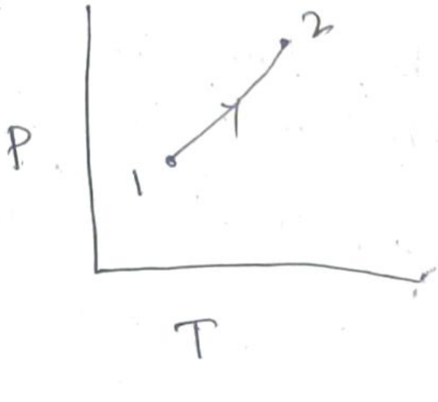
② Irrereversible non-flow precess.

const. volume precess (isochoric)

volume of gas remain constant.

Heat supply → increase P & T.





P_1, V_1, T_1 = at state 1

P_2, V_2, T_2 = " " 2.

$V_1 = V_2$

according to charles Law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}.$$

) workdone by gas $\delta w = pdv$.

$$\int dw = \int_1^2 p\,dv = P\int_1^2 dv.$$

$$W_{1-2} = P(V_2 - V_1) = 0. \quad \text{as } (V_1 = V_2)$$

$$W = 0.$$

2) change in internal energy.

$$dU = mC_v dT.$$

$$\int_1^2 dU = \int_1^2 mC_v dT = mC_v\int_1^2 dT$$

$$U_2 - U_1 = mC_v(T_2 - T_1).$$

③ Heat transfer

$$dQ = dU + dw.$$

$$Q_{1-2} = U_2 - U_1 + 0 = mC_v(T_2 - T_1)$$

③ change in enthalpy. $\begin{pmatrix} P_1V_1 = mRT_1 \\ P_2V_2 = mRT_2 \end{pmatrix}$

$$dH = dU + d(PV)$$

$$H_2 - H_1 = mC_v(T_2 - T_1) + (mRT_2 - mRT_1) \quad (C_p - C_v = R)$$

$$= mC_v(T_2 - T_1) + mR(T_2 - T_1)$$

$$= mC_p(T_2 - T_1)$$

Application of 1st law of thermodynami

(Steady flow energy equation & its application to turbine & compressor)

* flow processes :- → open system
→ transfer of mass as well as energy.
→ mass enter = mass exist

* steady flow process = flow rate in & out of the system remain constant with time.
→ no change of stored energy within the system.

unsteady flow process :-

→ working substance varies with time.

→ mass inflow ≠ mass outflow.

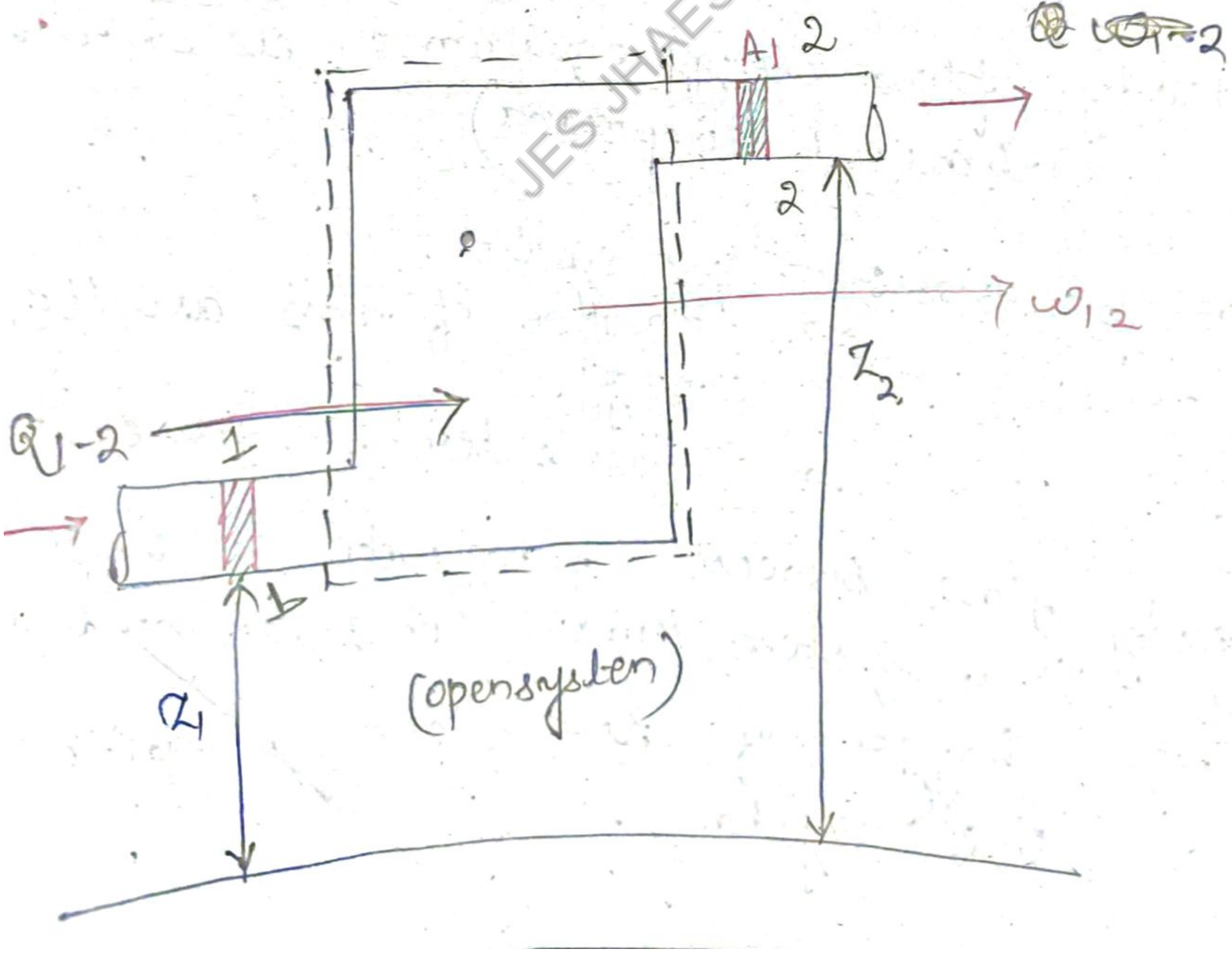
* We mostly dealing with steady flow process.

* → $m_i = m_o \Rightarrow m = C$

→ $Q = C \quad W = C$

→ working substance = uniform composition

1st law of Thermodynamic applied to steady flow process :-



working substance enter at 1-1,
with velocity V_1 & P_1
specific volume & specific internal energy
(V_{s_1}) (u_1)

2-2 velocity V_2, pressure P_2.
specific volume = V_{s_2} specific internal energy = u_2.

→ Heat transfer = Q_{12}
→ work transfer = W_{12}
⇒ (1) $m_1 = m_2$, (~~per unit~~

(~~2) Energy~~ =
therefore necessary to determine the energy flow per unit mass flowing at various position of the open system.

→ energy accompanying unit mass flow consist of following parts.

(i) PE = gZ (Z = height from datum plane)

(ii) KE = $\frac{V^2}{2}$

(iii) internal Energy 'u'

(iv) flow energy = PV_s

According to 1st law of thermodynamics law of conservation of energy.

$E_i = E_o$

$$\boxed{E_1 = E_2} \text{———} ①$$

⇒ $E = PE + KE + U +$ flow energy.

for inlet energy enter to system

$E_1 = gz_1 + \frac{V_1^2}{2} + u_1 + q_{12} + P_1V_{s_1}$ ——— ②

at exist energy leaving the system.

$E_2 = gz_2 + \frac{V_2^2}{2} + u_2 + w_{12} + P_2V_{s_2}$ ——— ③

eqⁿ (1)

$E_1 = E_2$

$$gz_1 + \frac{V_1^2}{2} + u_1 + q_{12} + P_1V_{s_1} = gz_2 + \frac{V_2^2}{2} + u_2 + w_{12} + P_2V_{s_2}$$

$$gz_1 + \frac{V_1^2}{2} + (u_1 + P_1V_{s_1}) + q_{12} = gz_2 + \frac{V_2^2}{2} + (u_2 + P_2V_{s_2}) + W_{12}$$

$$⇒ \boxed{gz_1 + \frac{V_1^2}{2} + h_1 + q_{12} = gz_2 + \frac{V_2^2}{2} + h_2 + w_{12}}$$

✓ This eq^n called steady flow energy eq^n. (SFEE)

* This can also be written as

$$q_{12} - w_{12} = \underset{(J/Kg)}{g(Z_2 - Z_1)} + \underset{(J/Kg)}{\left(\frac{V_2^2 - V_1^2}{2}\right)} + \underset{(m)}{(h_2 - h_1)}$$

$$= (PE_2 - PE_1) + (KE_2 - KE_1) + (h_2 - h_1)$$

in differential form.

$$\boxed{\delta q - \delta w = d(PE) + d(KE) + dh}$$

Q In a certain steady flow process, the properties of the fluid at inlet & outlet are follows.

→ inlet $p = 1.5$ bar, $\rho = 26\ kg/m^3$, $V = 110\ m/s$, internal energy $= 910\ kj/kg$

exist:- $p = 5.5$ bar, $\rho = 5.5\ kg/m^3$, $V = 190\ m/s$, $U = 710\ kj/kg$.

during process fluid reject 55 kj/s heat & rises through 55 m; mass flow rate of the fluid 10 kg/min.

Determine

(1) change in Enthalpy.

2) power developed during the process.

Ans P. $P_1 = 1.5\ \text{bar} = 150 \times 10^3\ N/m^2 = 150\ kN/m^2$

$(1\ \text{bar} = 10^5\ N/m^2 = 0.01\ MPa = 100\ kPa)$

$1\ \text{pascal} = 1\ N/m^2$.

$\rho_1 =$ ~~5.5 kg/m³~~ $26\ kg/m^3$

$V_{s_1} = \frac{1}{\rho_1} = \frac{1}{26} = 0.038\ m^3/kg$.

$V_1 = 110\ m/s$

$u_1 = 910\ kJ/kg$.

Outlet

$P_2 = 5.5\ \text{bar} = 550 \times 10^3\ N/m^2 = 550\ kN/m^2$

$\rho_2 = 5.5\ kg/m^3$.

$V_{s_2} = \frac{1}{\rho_2} = \frac{1}{5.5} = 0.182\ m^3/kg$

$V_2 = 190\ m/s$

$u_2 = 710\ kJ/kg$

$Q_{12} = 55\ kJ/s$

$Z_2 = 55\ m$

mass flow rate = 10 kg/min = $\frac{10}{60} = \frac{1}{6}$ kg/s.

(1) change in enthalpy :

inlet enthalpy $h_1 = u_1 + P_1 V_{s_1} = 910 + 150 \times 0.038$
$= 915.7$ kj/kg

exist " $h_2 = u_2 + P_2 V_{s_2}$

$h_2 = 710 + 550 \times 0.182 = 810.1$ kj/kg

$dh = h_2 - h_1 = 810.1 - 915.7 = -105.6$ kj/kg.

2) power developed during the process ?-

Let W_{12} = workdone or power developed during the process in kj/kg

heat rejected by the fluid

$$q_{12} = \frac{Q_{12}}{m} = \frac{-55}{1/6} = -55 \times 6 = -330 \text{ kj/kg}$$

(-ve sign due to heat rejection)

steady flow energy eq^n.

$$q_{12} - W_{12} = g(z_2 - z_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + (h_2 - h_1)$$

$$\Rightarrow -330 - W_{12} = \frac{9.81}{1000}(55 - 0) + \left(\frac{(90)^2 - (110)^2}{2 \times 1000}\right) + (-105.6)$$

$$W_{12} = -330 + 93.06 = -236.94 \text{ kj/kg}.$$

Since the mass flow rate $\frac{1}{6}$ kg/s, therefore workdone or power developed during process.

$$W_{12} = m \times W_{12} = \frac{1}{6}(236.94) = 39.5 \text{ kJ/s}$$

$$= 39.54 \text{ kW}$$

(1) A fan is to accelerate the aire to velocity of 10 m/s delivering the aire at the rate of 4 m³/s if the density of aire 1.18 kg/m³. determine the min power that must be supplied to fan.

→ $V = 10$ m/s

Volume $\vartheta = 4$ m³/s

$\rho = 1.18$ kg/m³.

mass of aire supplied by the fan

$m = \rho \times \vartheta = 4 \times 1.18 = 4.72$ kg/s

KE comparted by the fan to the aire.

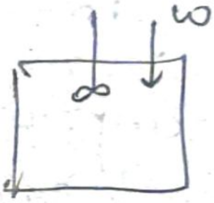
$= \frac{1}{2} m V^2 = \frac{1}{2} \times 4.72 \times (10)^2 = 236$ J/s.

So power supplied to the (1 Nm = J/s)

fan = ~~2.36~~ 236 J/s.

~~workdone fore a steady flow process~~

Q) A closed system consist of water contained in a cylinder & being stirred by a paddle wheel. during process 35 kJ/h of work has imparted to the system & the internal energy is increased to 145 kJ from an initial value of 120 kJ during one hour of stirring. Determine heat transfer & is the system temp rising or falling?



→ $W_{12} = -35$ kJ/h

$U_2 = 145$ kJ $U_1 = 120$ kJ

$du = U_2 - U_1 = 145 - 120 = 25$ kJ/h

$Q_{12} = \Delta U + W_{12}$

$\Rightarrow Q_{12} = 25 - 35 = -10$ kJ/h.

Q) The gas is compressed from an initial state of 0·35 m³ & 105 kpa to a final state of 0·14 m³ & to the same pressure. Determine change in internal energy of the gas which transfers 38 kj of heat.

→ $V_1 = 0{\cdot}35\ m^3$ $\quad P_1 = 105\ Kpa$

$V_2 = 0{\cdot}14\ m^3$ $\quad P_2 = 105\ Kpa$

$U = ?$ $\quad Q = -38\ kj$

$$W = \int P\,dV = P(V_2 - V_1) = 105 \times 10^3 (0{\cdot}14 - 0{\cdot}35)\ N\text{-}m$$

$$= -22{\cdot}05 \times 10^3\ N\text{-}m$$

$$= -22{\cdot}05\ kj$$

Now ⇒ $dQ = du + dw$

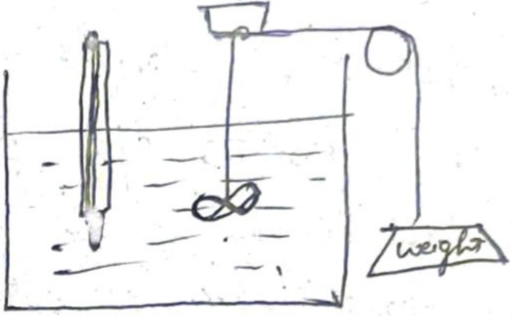
$\Rightarrow -38 = du - 22{\cdot}05$

$\Rightarrow du = -15{\cdot}95\ kj$

-ve sign indicate that there is decrease in internal energy.

Mechanical Equivalent of Heat

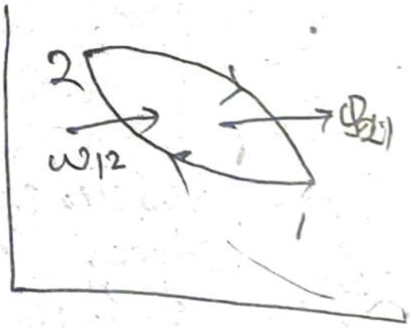
Let us consider a closed system which consist of mass of water contained in a adiabatic vessel having a thermometer & paddle wheel.



→ Let w amount of workdone on the system by paddle wheel. quantity of work can be measured by the fall of weight.

→ System initially at temp 't₁' temp rise t₂.

→ Let insulation now removed, system & surrounding interacted by heat transfer till returns to its original temp t₁ attaining condition of thermal equilibrium



→ workdone always proporsnal to heat.

$$\Sigma W \propto \Sigma Q$$

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

J = joule equivalent or mechanical equivalent of heat. $J = \frac{Nm}{J}$

→ work was transferred to the measured mass of water by means of paddle wheel driven by the falling weight.

1a — 2
b — 2
c — 1
d — 1/2

Second Law of Thermodynamics

According to 1st Law of thermodynamics Limitation: it don't specify the direction in which Heat & work flow.

→ According to 2nd Law of thermodynamics the whole of heat energy can't be converted into work & part of energy must be rejected to surrounding.

Statements of 2nd Law of Thermodynamics

(1) Kelvin - planck statement :-

"it is impossible to construct an engine which, while working in a cycle, produces no effect other than to extract heat from a single thermal reservoir & perform an equivalent work".

→ ~~effeciency~~ $\oint \dot{Q} \neq \oint W$ so $\eta \neq 100\%$

Clausius statement :-

"it is impossible to construct an engine which, while working in a cycle, produce no effect other than to transfer heat from a low temp reservoir to high temp reservoir without aid of an external agency:

→ PMM - I , PMM - II
(violet 1st Law) (violet Kelvin - planck statement)

terms used

(1) Thermal or Heat reservior :-
The thermal or heat reservior is a system or body of extremly large heat capacity, capable of absorbing or rejecting finite amount of heat without any change in temp.

e.g - river, sea, atmosphere.

2) Heat source :- it is a reservior at a high temp which heat extracted without change of its temp.

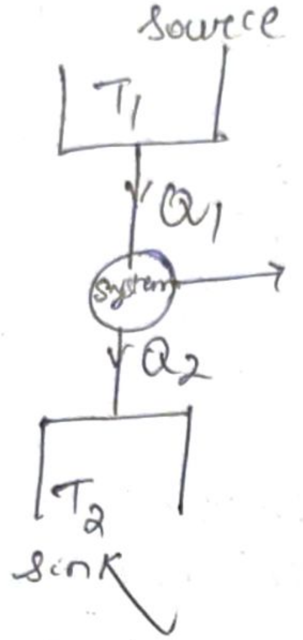
e.g Sun, boiler furnance, nuclear reactor.

3) Heat sink :- it is a reservior at a low temp. it is capable of absorbing any amount of heat without change in temp.

4) Heat Engine :- A Heat engine is a thermodynamic system used for converting heat into work while operating in a cycle between source & sink.

⑤

~~white~~ Let Q_1



$Q_1 - Q_2 = \overset{(W_E)}{\text{workdone}}$ by the system.

→ performance of heat Engine is measured by the its efficiency.

efficiency of Heat Engine = (η_E)

$$\eta_E = \frac{\text{Net workdone}}{\text{Total heat supplied}}$$

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

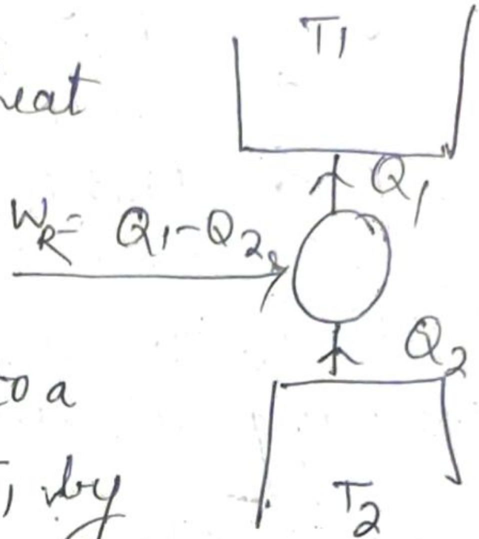
for a reversible engine = $\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$

so $\eta_R = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$

⑤ Heat pump :-

it is a thermodynamic system used for extracting Low temp body & delivered it to a high temp body.

→ ~~its~~ Let 'Q_2' amount of heat is extracted from sink having temp T_2 ~~to a higher temp~~ & supply heat Q_1 to a body at high temp T_1 by using external energy in the form of work input (w_p)



→ The performance of heatpump is measured by the co-efficent of performance.

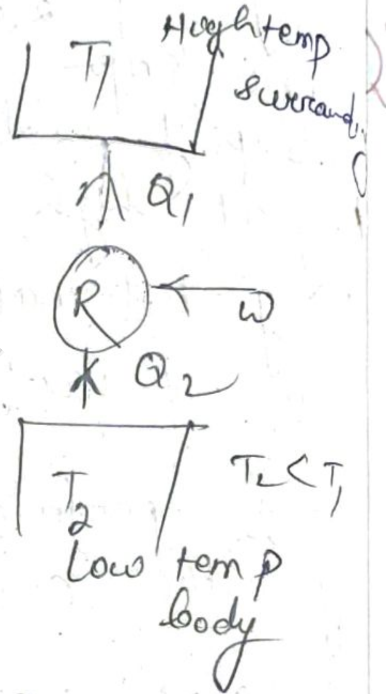
i.e $$(COP)_{HP} = \frac{\text{Heat supplied}}{\text{External work supplied}}$$

$$= \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$$

→ Heat pump is used to keep room warm in winter.

6) Refrigerator: it is a device similar to Heatpump, which extract heat from lower temp body & delivers it to a high temp body.

Let Q_2 ~~am~~ is extracted from space to be cooled at temp T_2 which is lower than temp of the surrounding. & reject Q_1 to the surrounding at temp T_1.



→ The refrigerator, while operating in a cyclic process, require an inputwork (W) to transfer heat from a low temp to a high temp.

$$(COP)_R = \frac{\text{Heat extracted}}{\text{Work input}} = \frac{Q_2}{W} = \cancel{Q_2}\frac{Q_2}{W}$$

$$= \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

Relation betn $(COP)_R$ & $(COP)_{HP}$

$$(COP)_R = \frac{T_2}{T_1 - T_2} \qquad (COP)_{HP} = \frac{T_1}{T_1 - T_2}$$

$$(COP)_R + 1 = \frac{T_2}{T_1 - T_2} + 1 = \frac{T_1}{T_1 - T_2} = (COP)_{HP}$$

$$\boxed{(COP)_P = (COP)_R + 1}$$

Chapter -3

Properties process of perfect gas

① gas → Complete vapourisation of liquid Sta

vapour → partially vapourisation " "

② ideal or perfect gas	Real gas
→ Strictly obey the gas laws under all Cond^n of temp & pressure.	→ Not obey
→ it always remain in gaseous state.	

e.g - O_2, N_2, air.

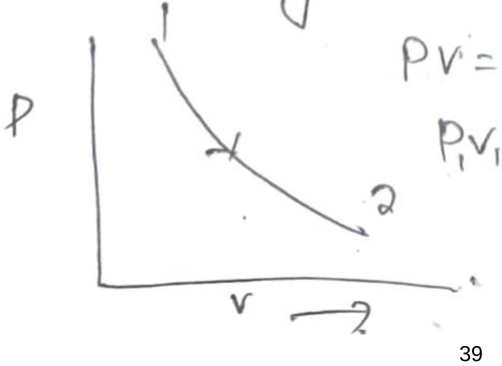
③ **Boyle's Law**

→ 1662, Robert Boyle.

→ He found that when a gas is heated at const. temp, pressure multiplied by the volume remain constant.

→ or we can say 'V' of a given mass of a perfect gas varies inversely as absolute when T const.

~~P,V~~ Boyle's Law = $P \propto \frac{1}{V}$



$PV = \text{constant}$ (T = cost)

$P_1V_1 = P_2V_2$ . . --

Charle's Law → 1787, A. C. charls.

V of a perfect gas varies directly as its absolute temp, when absolute p const.

$V \propto T$, $\frac{V}{T}$ = const (P = const)

$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3}$ = const.

→ $P \propto T$, $\frac{P}{T}$ = const.

$\frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{P_3}{T_3}$ -= const.

Gay Lussac & Regnault Law

" All perfect gases expand by the same fraction of the volume they occupy at freezing temp, when their temp is raised by 1° provided the pressure remain const.

→ fraction is found to be 1/273 at °C.

V_0 = volume of a given mass of gas at freezing temp (0°c)

V_t = " of the same gas at t°c.

$$V_t = V_0 + \frac{1}{273} V_0 t = V_0\left(\frac{273+t}{273}\right) = V_0 \frac{T}{T_0}$$

$$\boxed{\frac{V_t}{V_0} = \frac{T}{T_0}}$$

T = absolute temp at t°c.

T_0 = " " 0°c.

Combination of Boyle's & charle's Law

(General gas eqn)

$V \propto \frac{1}{P}$ $(T=C)$ (Boyle's Law)

$V \propto T$ $(P=C)$ (charle's Law)

$V \propto \frac{T}{P} \Rightarrow PV \propto T$ or $PV = K \times T$

$$\boxed{\frac{PV}{T} = K}$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3} = \text{const}$$

Joule's Law

It state that "the change in internal energy (dU) of a perfect gas is directly proportional to the change in temp (dT).

$dU \propto dT.$ m = mass of gas

$dU = mc(T_2 - T_1)$ c = const = specific heat of a gas

Characteristic eqn of a gas

we know general eqn of gas

$PV = KT.$

for 1 kg mass $PV = RT.$

m kg mass $\boxed{PV = mRT}$

R = characteristic gas const / gas const.

$$R = \frac{PV}{mT} = \frac{N \times m^3}{m^2 \times kg \times K} = \frac{N\text{-}m}{kg\text{-}K}.$$

$(1\,N\text{-}m = 1\,J)$ $R = \frac{J}{kg.K}$

R depends of types of gas.

→ for atm air = $R = 287 \frac{J}{kg \cdot K} = 0.287 \frac{kJ}{kg \cdot K}$.

universal Gas const.

~~product of~~

$$\boxed{R_u = R \cdot M}$$

R = Characteristic gas ct

M = molecular mass of gas.

$R_u = R_1 M_1 = R_2 M_2$ - - .

R_u = same for all gas $= 8314 \frac{J}{kg \cdot mole \cdot K}$

$= 8.314 \frac{kJ}{kg \cdot mole \cdot K}$.

* $PV = MRT$

$$\boxed{PV = n \cdot R_u \cdot T}$$

n = no. of kg moles.

$O_2 \rightarrow 32$ $H_2 \rightarrow 2$

$N_2 \rightarrow 28$ $CO_2 \rightarrow 44$.

Avogadro's Hypothesis

" Equal volumes of all gases at the same P & T contain equal no. of molecules".

$$\frac{\rho_1}{\rho_2} = \frac{M_1}{M_2} \quad (P, T = \text{same})$$

Specific Heat of ~~the~~ gas

it is defined as the quantity of hea required to raise the temp of 1 unit mass o substance by ~~1°C~~ one degree

→ solid, liquid → 1 specific heat

→ gas → 2 specific heat

① Specific heat const volume (C_v) (T, P ↑
. . . . (volume constant)

@ 'm' kg of mass heated in closed vessel

Q_{1-2} = ~~mC~~ mass × specific heat at v = C × Rise in temp

$$Q_{1-2} = m \times C_v \times (T_2 - T_1) = m C_v dT$$

$W = \int p\,dV$
$W = 0$
$dQ = dU +$
$\boxed{dQ = dU}$

2) Specific heat (const p) V↑ T↑.

$$Q_{1-2} = m C_p \times dT$$

$Q_{1-2} = dU + W_{1-2}$
$= mC_v(T_2 - T_1) + P(V$

Relationship between Two specific hea

① Difference bet^n specific heat.

'm' kg mass → heat at const P from temp T_1 to T_2.

Heat supplied ~~$Q = mC_p\,dT$~~

$$Q = dU + dW_{1-2} = dU + P\,dV.$$

$$\Rightarrow mC_p(T_2 - T_1) = mC_v(T_2 - T_1) + P(V_2 - V_1)$$

$$\Rightarrow m(T_2 - T_1)[C_p - C_v] = (PV_2 - PV_1)$$

$$\Rightarrow \cancel{m}[\cancel{T_2 - T_1})(C_p - C_v) = \cancel{m}R(\cancel{T_2 - T_1})$$

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

$PV = mRT$
$P_1V_1 = mRT$
$P_2V_2 = mRT$

②Ratio of specific heats :-

$$C_p - C_v = R$$

$$\frac{C_p}{C_v} - \frac{C_v}{C_v} = \frac{R}{C_v}. \qquad \left(\frac{C_p}{C_v} = \gamma \right)$$

$$\gamma - 1 = \frac{R}{C_v}$$

$$\boxed{\gamma = 1 + \frac{R}{C_v}} \qquad \boxed{\frac{C_p}{C_v} = \gamma}$$

(i) $C_p > C_v$. $\gamma > 1$

(ii) C_p, C_v different for different gases.

air $\longrightarrow$ $C_p = 1 \ kj/kg \cdot K$ $C_v = 0.72 \ kj/kg \cdot K$

$$\gamma_{air} = \frac{1}{0.72} = 1.4$$

$$\boxed{\gamma_{air} = 1.4}$$

Enthalpy of gas (H)

$$\boxed{H = U + P.V}$$

Enthalpy properties of gas.

$dU = U_2 - U_1$, $W_{1-2} = pdV = P(V_2 - V_1)$

$Q_{1-2} = dU + W_{1-2} = U_2 - U_1 + P(V_2 - V_1)$

$Q_{1-2} = (U_2 + PV_2) - (U_1 + PV_1)$

$Q_{1-2} = H_2 - H_1$

Types of Non-flow processes

① Reversible ~~non~~-flow process.

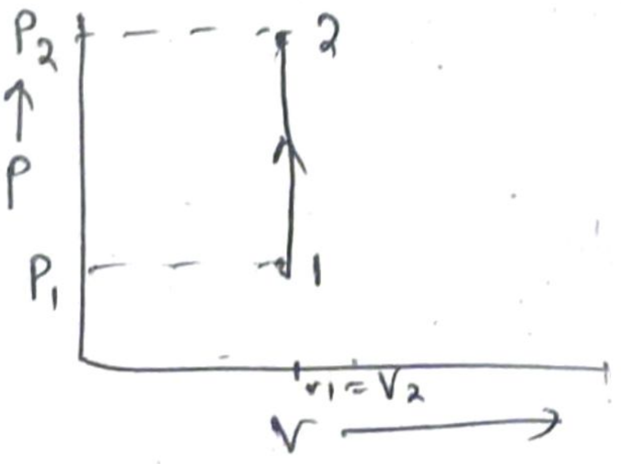
a) const. volume process (isochoric)
b) cost. P (isobaric)
c) cost. T (isothermal)
d) adiabatic
e) ~~pro~~ polytropic proces.

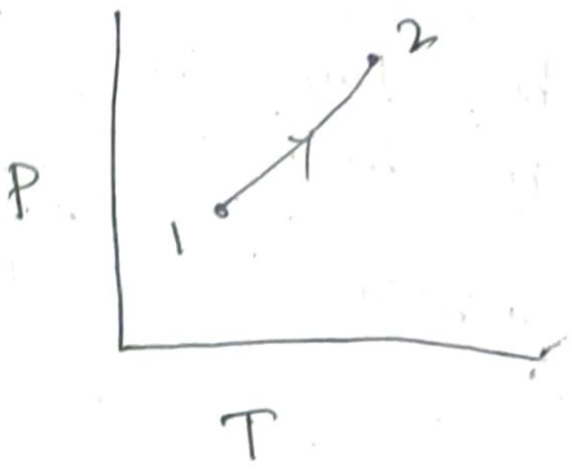
② Irreversible non-flow process.

const. volume process (isochoric)

volume of gas remain constant.

Heat supply → increase P & T.





P_1, V_1, T_1 = at state 1

P_2, V_2, T_2 = " " 2.

$V_1 = V_2$

according to <u>charles Law</u>

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}.$$

) workdone by gas $\delta w = pdv$.

$$\int dw = \int_1^2 p\,dv = P\int_1^2 dv.$$

$$W_{1-2} = P(V_2 - V_1) = 0. \quad \text{as} (V_1 = V_2)$$

$$W = 0.$$

2) change in internal energy.

$$dU = mC_v\,dT.$$

$$\int_1^2 dU = \int_1^2 mC_v\,dT = mC_v\int_1^2 dT$$

$$U_2 - U_1 = mC_v(T_2 - T_1).$$

③ Heat transfer

$$dQ = dU + dW.$$

$$Q_{1-2} = U_2 - U_1 + 0 = mC_v(T_2 - T_1)$$

③ change in enthalpy. $\left(\begin{matrix} P_1V_1 = mRT_1 \\ P_2V_2 = mRT_2 \end{matrix}\right)$

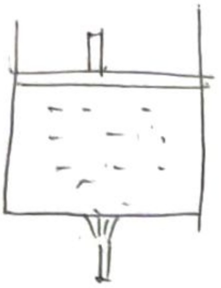
$$dH = dU + d(PV)$$

$$H_2 - H_1 = mC_v(T_2 - T_1) + (mRT_2 - mRT_1) \quad (C_p - C_v = R)$$

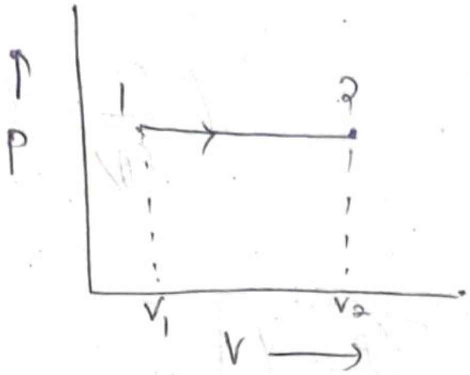
$$= mC_v(T_2 - T_1) + mR(T_2 - T_1)$$

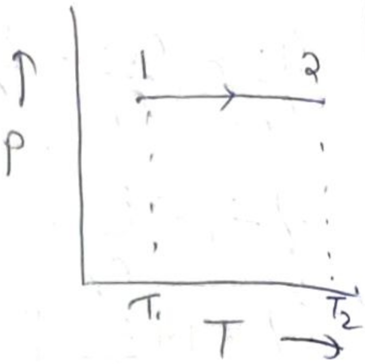
$$= mC_p(T_2 - T_1)$$

(b) Const pressure process (isobaric process)



(Heating at const P)





Let 'm' kg of gas heated at const P, from state 1 to state 2.

P_1, V_1, T_1 = state 1.

P_2, V_2, T_2 = " 2.

~~charl's Law~~ gas Law.

$\frac{\cancel{P_1}V_1}{T_1} = \frac{\cancel{P_2}V_2}{T_2}$ $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (charl's Law)

(1) Workdone by the gas.

$\delta W = P\delta V$.

$\int_1^2 \delta W = \int_1^2 P dV = P\int_1^2 dV = P(V_2 - V_1)$

$W_{1-2} = P(V_2 - V_1)$

~~P~~ $W = mR(T_2 - T_1)$ } $PV = mRT$

2) change in internal energy :-

$\int_1^2 dU = \int_1^2 mC_v dT = mC_v(T_2 - T_1)$

3) Heat transfer or heat supplied.

$$dQ = dU + dW.$$

$$\int_1^2 dQ = \int_1^2 dU + \int_1^2 dW$$

$$Q_{1-2} = (U_2 - U_1) + W_{1-2}$$

$$Q_{1-2} = (U_2 - U_1) + P(V_2 - V_1)$$

$$Q_{1-2} = mC_v(T_2 - T_1) + mR(T_2 - T_1)$$

$$Q_{1-2} = m(T_2 - T_1)(C_v + R)$$

$$Q_{1-2} = mC_p(T_2 - T_1) \qquad (C_p - C_v = R)$$

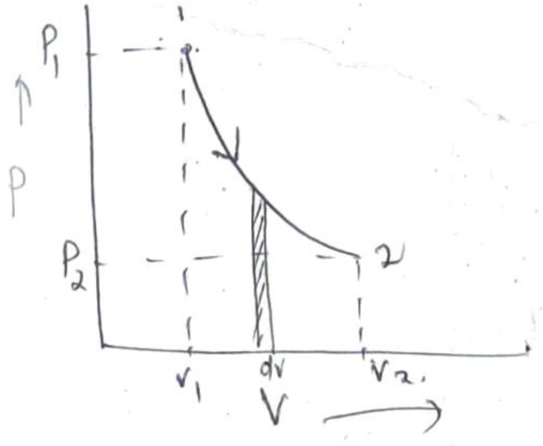
4) Change in enthalpy :-

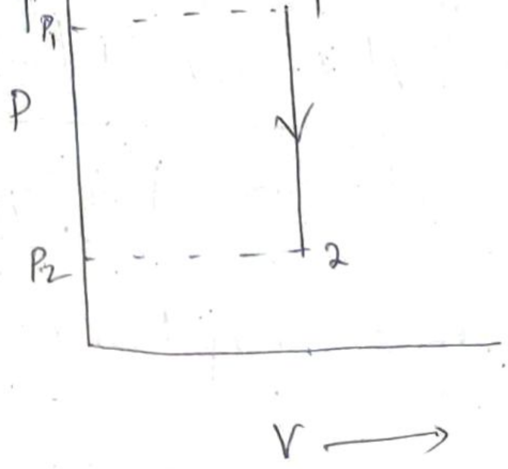
$$\int_1^2 dH = \int_1^2 dU + \int_1^2 d(PV)$$

$$H_2 - H_1 = (U_2 - U_1) + P(V_2 - V_1)$$

$$H_2 - H_1 = mC_p(T_2 - T_1)$$

③ Const temp process (isothermal process)





$P_1, V_1, T_1 \longrightarrow P_2 V_2 T_2$

Gas eq^n

$$\frac{P_1V_1}{\cancel{T_1}} = \frac{P_2V_2}{\cancel{T_2}}$$

$\Rightarrow P_1V_1 = P_2V_2 \longrightarrow$ Boyle's Law.

(i) workdone by the gas.

$$\delta w = p\,dV.$$

$PV = \text{const}$

$PV = P_1V_1 \qquad P = \frac{P_1V_1}{V}$

$$\delta w = \frac{P_1V_1}{V}\cdot dv = P_1V_1\left(\frac{dv}{v}\right)$$

workdone from state 1 to 2.

$$\int_1^2 dw = \int_1^2 P_1V_1\left(\frac{dv}{v}\right)$$

$$\Rightarrow W_{1-2} = P_1V_1\int_1^2 \frac{1}{v}\,dv$$

$$W_{1-2} = P_1V_1\Big[\ln(v)\Big]_1^2$$

$$W = P_1V_1\Big[\ln(v_2) - \ln(v_1)\Big]$$

$$\boxed{W = P_1V_1\ln\left(\frac{v_2}{v_1}\right)}$$

$$\boxed{W = 2.3\,P_1V_1\log\left(\frac{v_2}{v_1}\right)}$$

$\frac{v_2}{v_1}$ = expansion ratio.

$\frac{v_1}{v_2}$ = compression ratio.

$P_1, V_1, T_1 \longrightarrow P_2 V_2 T_2$

Gas eqⁿ

$$\frac{P_1V_1}{\cancel{T_1}} = \frac{P_2V_2}{\cancel{T_2}}$$

$\Rightarrow P_1V_1 = P_2V_2 \longrightarrow$ Boyle's Law.

(i) workdone by the gas.

$$\delta w = PdV.$$

$PV = \text{const}$

$P_1V_1 = P_1V_1 \qquad P = \frac{P_1V_1}{V}$

$$\delta w = \frac{P_1V_1}{V} \cdot dv = P_1V_1\left(\frac{dv}{v}\right)$$

workdone from state 1 to 2.

$$\int_1^2 dw = \int_1^2 P_1V_1\left(\frac{dv}{v}\right)$$

$$\Rightarrow W_{1-2} = P_1V_1\int_1^2 \frac{1}{v}\,dv$$

$$W_{1-2} = P_1V_1\left[\ln(v)\right]_1^2$$

$$W = P_1V_1\left[\ln(v_2) - \ln(v_1)\right]$$

$$\boxed{W = P_1V_1 \ln\left(\frac{v_2}{v_1}\right)}$$

$$\boxed{W = 2.3\, P_1V_1 \log\left(\frac{v_2}{v_1}\right)}$$

$\frac{v_2}{v_1}$ = expansion ratio.

$\frac{v_1}{v_2}$ = compression ratio.

2) Change in internal energy :-

$$dU = mC_v dT.$$

from 1 to 2.

$$\int_1^2 dU = \int_1^2 mC_v dT = mC_v(T_2 - T_1).$$

as $\boxed{T_1 = T_2}$

$$U_2 - U_1 = 0$$

$$\boxed{U_1 = U_2}$$

3) Heat transfered or heat supplied

$$dQ = dU + dW.$$

$$\int_1^2 dQ = \int_1^2 dU + \int_1^2 dW.$$

$$Q_{1-2} = (\cancel{U_2 - U_1})^0 + W_{1-2}.$$

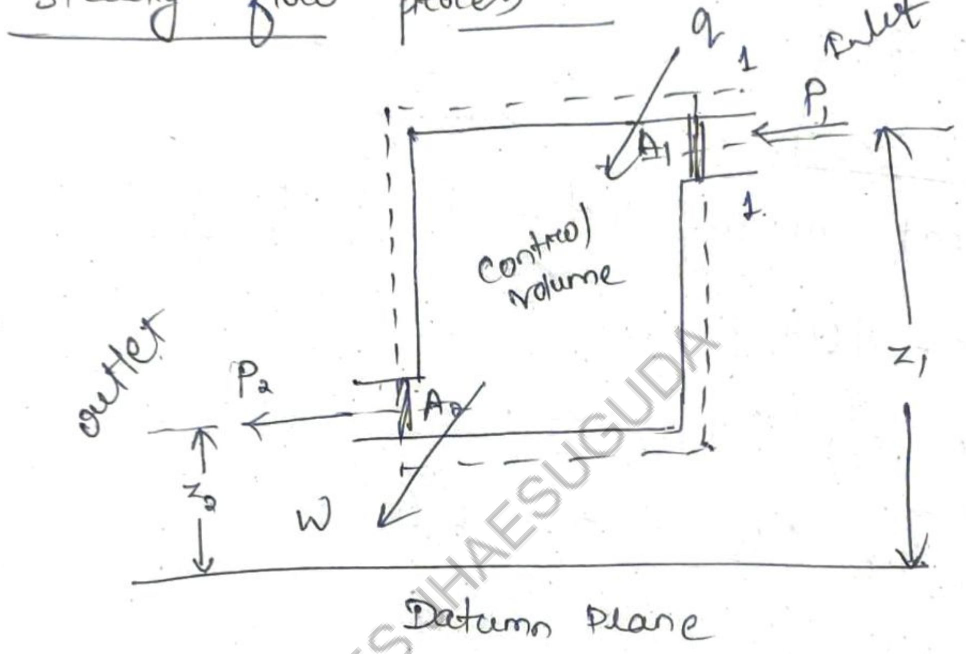
$$Q_{1-2} = W_{1-2}.$$

~~Po~~ adiabatic process	Polytropic process
(1) workdone = $\frac{P_1V_1 - P_2V_2}{\gamma - 1}$	① $W = \frac{P_1V_1 - P_2V_2}{n-1}$
2) internal energy $dU = mC_v dT$	2) $dU = mC_v dT$
3) Heat transfer $Q = 0$	3) $Q = \frac{\gamma - n}{\gamma - 1}\left(\frac{P_1V_1 - P_2V_2}{n-1}\right)$
4) Enthalpy = $mC_p dT$	4) $dH = mC_p(T_2 - T_1)$

1st Law of Thermodynamic applied to flow process.

(1) steady flow process → $m_i = m_o$, $E = const$
2) unsteady flow " → $m_i \neq m_o$ $E = change$

~~Eto~~ 1st Law of Thermodynamics applied to steady flow process



Working substance enter at 1-1 with velocity v_1, pressure P_1.
specific volume $= v_{S_1}$
Specific internal energy $= u_1$

① Heat transfer q_{1-2}
② Work transfer W_{1-2}
3)

① ~~P.E = gz~~
energy accompanying unit mass flow

(1) $PE = gz$ ($N\text{-}m/kg$ or J/kg)
2) $KE = \frac{v^2}{2}$

(3) ~~flow~~ internal energy ie u. (J/kg)

4) flow energy Pv_s (N-m/kg)

$$e_1 = gz_1 + \frac{v_1^2}{2} + u_1 + P_1 v_{s_1} + q_{1-2} \quad (J/kg)$$

$$e_2 = gz_2 + \frac{v_2^2}{2} + u_2 + P_2 v_{s_2} + W_{1-2} \quad (J/kg)$$

$$e_1 = e_2$$

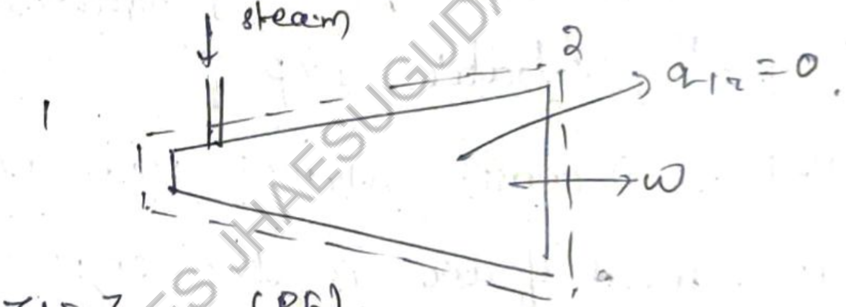
$$h_1 = u_1 + P_1 v_{s_1}$$

$$h_2 = u_2 + P_2 v_{s_2}$$

$$gz_1 + \frac{v_1^2}{2} + h_1 + q_{1-2} = \qquad + W_{1-2}.$$

SFEE

turbine



SFEE

$$z_1 = z_2 \quad (PE)$$

$$v_1 = v_2 \quad (KE)$$

$$q_{1-2} = 0$$

$$w_{1-2} = h_1 - h_2.$$

compressor

$$W_{1-2} = (h_1 - h_2) - q_{1-2}$$

q_{1-2} is negetive.

Q) A closed vessel contains 2 kg of CO_2 at a temp of 20°C & a pressure of 0.7 bar. Heat is supplied to the vessel till the gas acquires a pressure of 1.4 bar calculate the value of heat supplied. $C_v = 0.657$ kJ/kgK.

→ $m = 2\,kg$

$T = 20°C + 273 = 293K$

$P_1 = 0.7\,bar$

$P_2 = 1.4\,bar$

$C_v = 0.657\,kJ/kgK$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow T_2 = \frac{P_2 \times T_1}{P_1} = \frac{1.4 \times 293}{0.7} = 586K$$

$$Q_{12} = mC_v(T_2 - T_1)$$

$$= 2 \times 0.657 (586 - 293)$$

$$= 385\,kJ$$

Q) One kg of air is expanded at a constant pressure of 2.5 bar from a volume of $0.3 m^3$ to a volume of $0.45 m^3$.

find (1) External workdone by gas

2) Internal Energy of gas

3) Heat transfer during process.

→ m = 1kg

$p = 2.5$ bar $= 250 \times 10^3 \, N/m^2$ → $R = 287 \, J/kgK$

$V_1 = 0.3 m^3$

$V_2 = 0.45 m^3$

Specific heat at constant valume $C_v = 0.72$ kJ/kg

$C_p = 1.005$ kJ/kg K

$P_1 V_1 = mRT_1$

$$T_1 = \frac{P_1 V_1}{mR} = \frac{250 \times 10^3 \times 0.3}{1 \times 287} = 261\ K$$

$$T_2 = \frac{P_2 V_2}{mR} = \frac{250 \times 10^3 \times 0.45}{1 \times 287} = 392\ K$$

(i) external woorkdone by gas $W = P(V_2 - V_1)$

$$W = 250 \times 10^3 (0.45 - 0.3) = 37.5\ kJ$$

(ii) Internal Energy of the gas.

$$du = mC_v(T_2 - T_1) = 1 \times 0.72\ (392 - 261) = 94.32\ kJ$$

(iii) Heat transferred.

$$Q_{12} = mC_p(T_2 - T_1) = 1 \times 1.005\ (392 - 261) = 131.6\ kJ$$

Q) if a Hg barometer reads 720 mm Hg. find atm pressure in Kpa.

→ Barometric Reading = 720 mm Hg,

$1 \text{ mm of Hg} = 133.3 \text{ N/m}^2$.

$\text{atm pressure} = 720 \times 133.3 = 95976 \text{ N/m}^2$

$= \frac{95976}{1000} = 95.976 \text{ Kpa}.$

Q) Steam Leaving turbine at a pressure = 70 kpa vacuum find absolute pressure in bar. if atm pressure is 101 kpa.

→ vacuum pressure = 70 kpa

atm pressure = 101 kpa

Abs p = atm p − vacuum p

= 101 − 70 = ~~0~~ 31 Kpa (1 bar = 100 Kpa)

$= \frac{31}{100} \text{ bar} = 0.31 \text{ bar}$

Free Expansion process :-

→ Most of thermodynamics become irreversible due to presence of friction, turbulence etc. the effect of irreversibility is loss of work, i.e in compression process more work is to be supplied than the reversible work, where as in expansion process, less work is obtained from the system.

→ free-expansion occurs when a fluid is allowed to expand suddenly into a vacuum chamber through an orifice of large size.

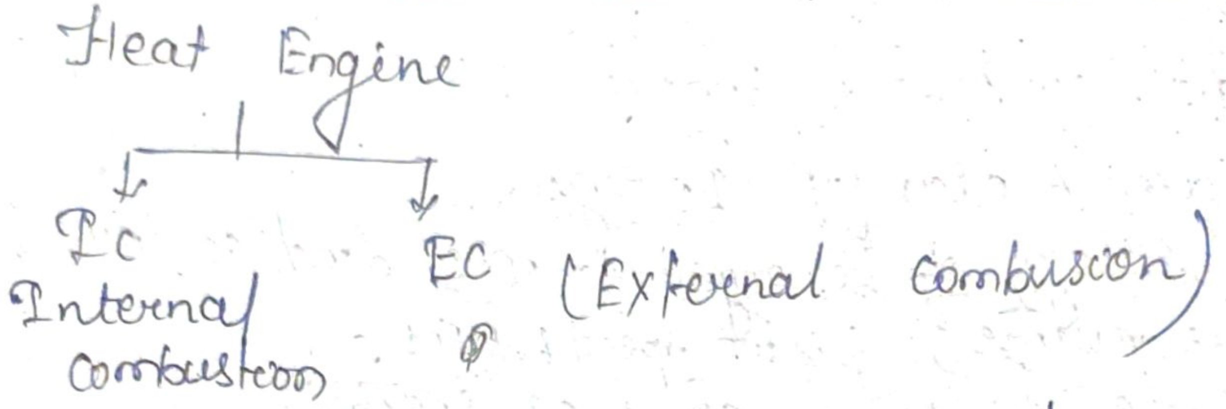
→ In this process, no heat is supplied or rejected & no external work is done.

→ enthalpy of the fluid constant.

→ this type of expansion called as Constant enthalpy process or free expansion process.

$Q_{12} = 0$, $W_{12} = 0$, $du = 0$.

IC ENGINE chapter-4

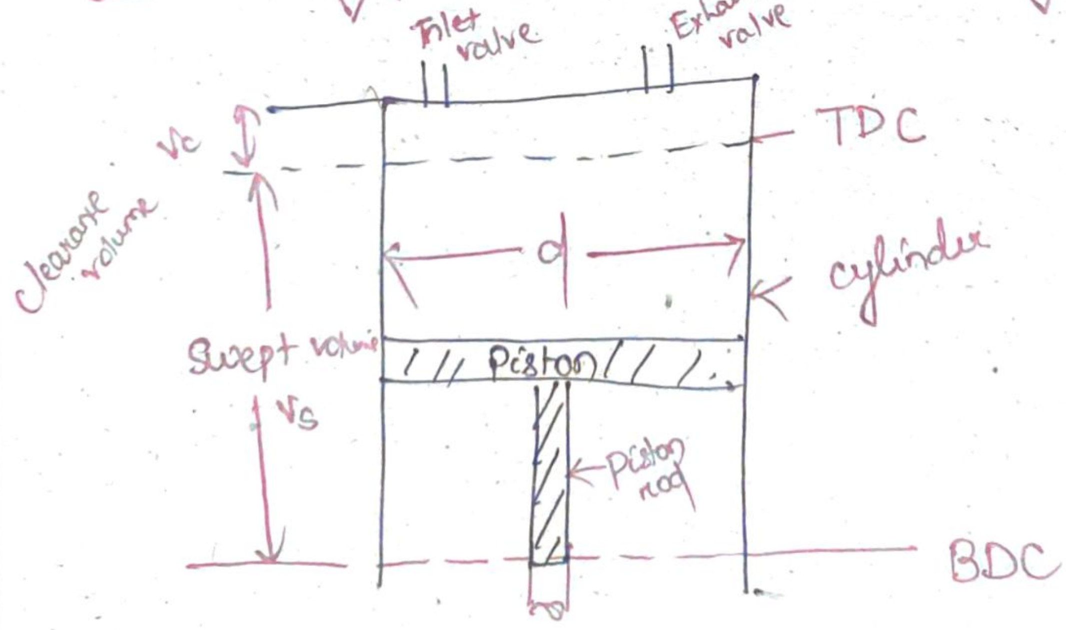


Heat Engine :- Heat Engine is a thermodynamic system used for converting heat into work, while operating in a cycle betn source & sink.

IC Engine :- It is a heat Engine in which combustion of fuel occurs inside the engine cylinder.

External combustion Engine :- It is a heat Engine where a ~~working~~ combustion takeplace outside the engine cylinder.

Terminology used in IC engine :-



Borce :- diameter of cylinder or piston

storke :- distance move by piston in ~~a~~ one direction.

TDC ⟶ BDC or BDC ⟶ TDC.

stroke = 2 x radius of crank

TDC = it is extreme position of piston near to head.

BDC - it is extreme position of piston opposite to head.

clearance volume :- it is the minimum volume of clearance betn cylinder head & the piston at TDC position.

Swept volume or stroke volume (V_s)

It is the max volume ~~of~~ swept by the piston in moving from TDC to BDC & vice-versa.

swept volume = $V_s = \frac{\pi}{4} d^2 \times l$.

Total volume or full cylinder volume :- (V)

total volume is sum of clearance volume (V_c) plus swept volume (V_s).

$$V = V_c + V_s$$

clearance ratio (c)

$$c = \frac{V_c}{V_s} = \frac{\text{clearance volume}}{\text{swept volume}}$$

compression or expansion ratio :-

$$r = \frac{\text{total volume } (V)}{\text{Clearance Volume } (V_c)}$$

$$r = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c} = 1 + \frac{1}{c}$$

10) **Mean effective pressure** (P_m)

it is the avg pressure acting on the piston during working stroke.

$$P_m = \frac{\text{workdone}}{\text{Swept volume}} = \frac{W}{V_s}$$

$$P_m = \frac{W}{\frac{\pi}{4} d^2 \times l} = \frac{4W}{\pi d^2 l}$$

11) **Air standard efficiency :-**

$$\eta = \frac{\text{workdone}}{\text{Heat supplied}} = \frac{\text{Heat supplied} - \text{Heat reject}}{\text{Heat supplied}}$$

12) **Relative efficiency :-**

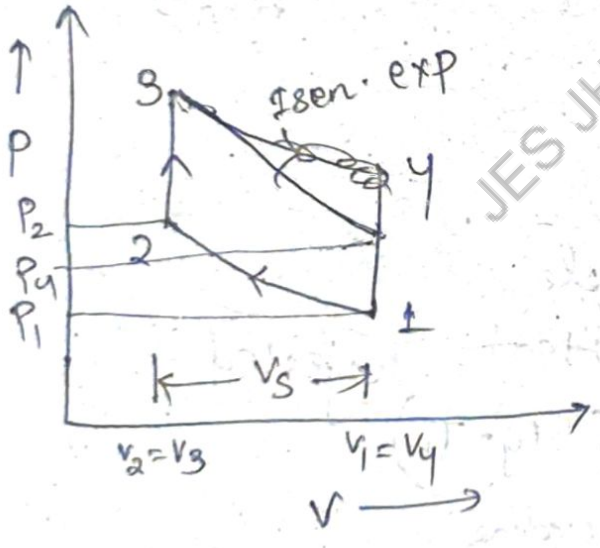
$$\eta_R = \frac{\text{Actual thermal efficiency}}{\text{Air standard efficiency}}$$

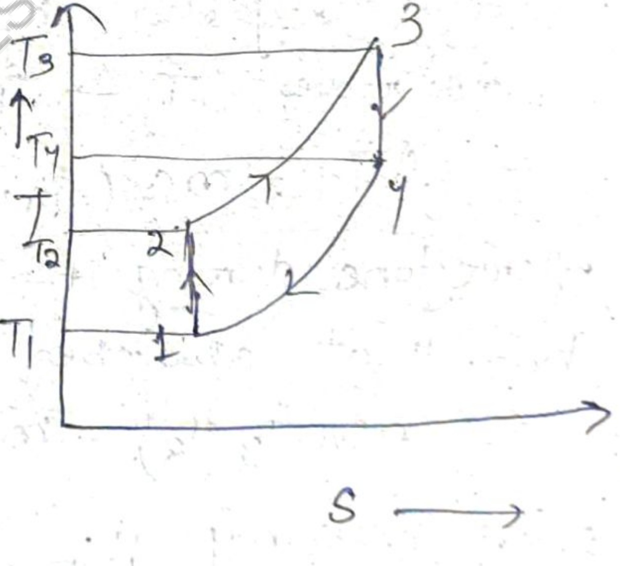
OTTO cycle (constant volume cycle)

- → This cycle is used for spark Ignition (SI) internal combustion engines.
- → Heat received & rejected at const. volume. therefore this cycle is known as const. volume cycle.
- → ottocycle consists of two const volume & two reversible adiabatic process.

m = mass of air in the engine cylinder at point 1, when piston at BDC.

P_1, V_1, T_1 = P, V, T of air at 1.





Process - 1-2

- → Reversible adiabatic compression process.
- → piston moves from BDC ⟶ TDC.
- → air compressed in reversible adiabatic manner.
- → T rises from $T_1 \longrightarrow T_2$
- → No heat rejected or absorbed by air

Process- 2-3

→ piston is rest at TDC.

→ Heat absorbed by air & Temp of air rises $T_2 \rightarrow T_3$.

Heat absorbed $Q_{23} = mc_v(T_3 - T_2)$

Process - 3-4

→ Reversible adiabates expansion process

→ TDC → BDC.

→ Temp decrease $T_3 \rightarrow T_4$

→ No heat is absorbed or rejected

process - 4-1 → const volume cooling process.

→ heat rejected by the air & temp decreases $T_4 \rightarrow T_1$.

$$Q_{4\text{-}1} = mc_v(T_4 - T_1)$$

Workdone during the cycle.

W = Heat absorbed - Heat rejected

$= mc_v(T_3 - T_2) - mc_v(T_4 - T_1)$

ideal efficiency = $\eta = \frac{\text{Workdone}}{\text{Heat absorbed}}$

$$\eta = \frac{mc_v(T_3 - T_2) - mc_v(T_4 - T_1)}{mc_v(T_3 - T_2)}$$

$$= 1 - \frac{T_4 - T_1}{T_3 - T}$$

The ratio of compression & expansion are equal. $\frac{V_1}{V_2} = \frac{V_4}{V_3} = r$

reversible adiabatic compression process 1-2

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{1}{\gamma}\right)^{\gamma-1}$$

fore reversible adiabatic expansion process 3-4

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1}$$

$$\frac{T_1}{T_2} = \frac{T_4}{T_3} \quad \text{or} \quad T_4 = \frac{T_1 T_3}{T_2}$$

$$\eta = 1 - \frac{\frac{T_1 T_3}{T_2} - T_1}{T_3 - T_2} = 1 - \frac{T_1 T_3 - T_1 T_2}{T_2(T_3 - T_2)}$$

$$\eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{1}{r}\right)^{\gamma-1}$$

Carnot cycle

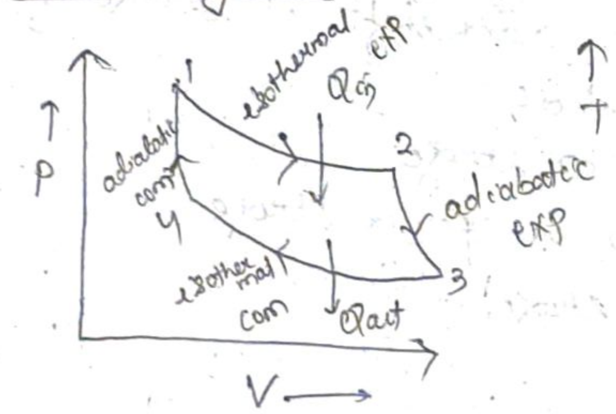
→ theoretical ideal thermodynamic cycle

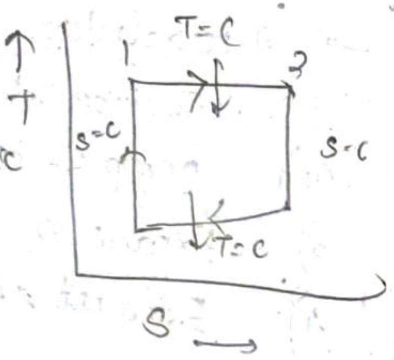
→ it provide upper limit on the efficiency that thermodynamic engine can achieve during conversion of Heat to work.

→ $\eta_{irre} < \eta_{rev}$

→ η_{all} reversible Heat Engine are same. working betⁿ same two temp.

Carnot cycle





1-2 Reversible Isothermal expansion of the gas at 'hot' temp $w = P_1V_1\ln\left(\frac{V_2}{V_1}\right)$ $(T=C)$

2-3 Isoentropic expansion of gas (insulation) $(S=C)$ $= -nC_v(T_2-T_1)$

3-4 Reversible Isothermal compression at $(T=C)$ (cold te → ↑U ↑P ↓V $w = P_1V_1\ln\left(\frac{V_4}{V_3}\right)$

4-1 Isoentropic compression of the gas $(S=C)$

— $w = nC_v(T_2-T_1)$

net work done by gas w

$w = -w_1 - w_2 + w_3 + w_4$

$= nRT_2\ln\left(\frac{V_2}{V_1}\right) - nC_v(\cancel{T_2-T_1}) + nRT_1 \ln\frac{V_4}{V_3} + \cancel{nC_v(T_2-T_1)}$

$= nRT_2\ln\left(\frac{V_2}{V_1}\right) + nRT_1\ln\left(\frac{V_4}{V_3}\right)$

$= nRT_2\ln\left(\frac{V_2}{V_1}\right) - nRT_1\ln\left(\frac{V_3}{V_4}\right)$

for adiabatic expansion of ideal gas (2-3)

$C_v\ln\left(\frac{T_2}{T_1}\right) = R\ln\left(\frac{V_3}{V_2}\right)$

$C_v\ln\left(\frac{T_2}{T_1}\right) = R\ln\left(\frac{V_4}{V_1}\right)$

$\eta = \frac{\text{workdone}}{\text{Heat supplied}} = \frac{Q_S - Q_R}{Q_S}$

=

Heat supplied (T=c) $Q_{12} = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$
<u>(1-2)</u>

$$= mRT_1 \ln\left(\frac{V_2}{V_1}\right)$$

$\frac{V_2}{V_1} = r$ = compression ratio $\quad Q_{12} = mRT_1 \ln(r)$ ①

Heat Rejection (T=c) $Q_{3-4} = P_3 V_3 \ln\left(\frac{V_3}{V_4}\right)$
(3-4)

$$= mRT_3 \ln\left(\frac{V_3}{V_4}\right)$$

$\frac{V_3}{V_4}$ = compression ratio $\quad = mRT_3 \ln(r)$ ②

Net work = HS − HR

$$= mRT_1 \ln(r) - mRT_3 \ln(r)$$

$$= mR \ln(r)(T_1 - T_3) \quad ③$$

$$\eta = \frac{NW}{HS} = \frac{\cancel{mR\ln(r)}(T_1 - T_3)}{\cancel{mR}T_1 \cancel{\ln(r)}}$$

$$\eta = \frac{T_1 - T_3}{T_1}$$

T_3 = Lower temp

T_1 = Higher temp.

$$\boxed{\eta_{\text{carnot cycle}} = 1 - \frac{T_3}{T_1} = 1 - \frac{T_{\text{lower}}}{T_{\text{Higher}}}}$$

~~η of~~

→ 'η' of ottocycle depends on compression ratio 'r' only.

η ↑ r ↑

2) Diesel cycle (const. Pressure cycle)

→ Dr Rudolph Diesel

→ 1893

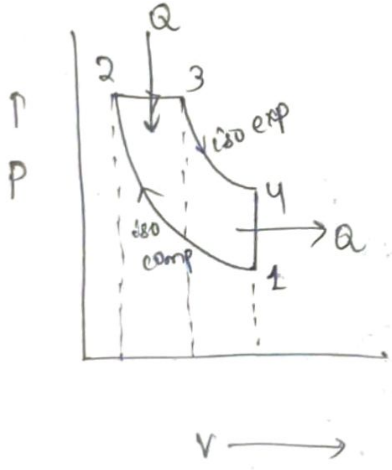
→ CI → diesel fuel

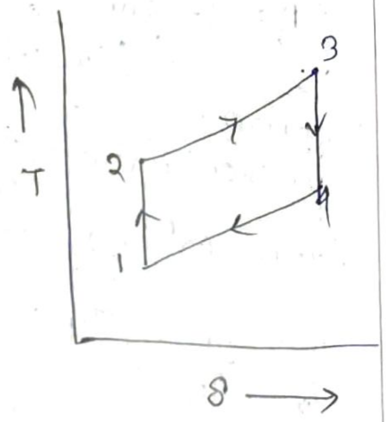
→ Heat is supplied at const 'P' so its called const Pressure cycle.

→ ④ → ② – reversible adiabatic process

— ① const. Pressure process

— ① const volume.





'm' = mass of air (kg) in engine cylinder.

P, v, T

① Process 1-2 :- (rev. adiabatic compression process.

BDC → TDC

$T_1 \to T_2 (\uparrow)$ $Q = 0$

$$\left(\frac{T_1}{T_2}\right) = \left(\frac{v_2}{v_1}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1}$$

$$T_2 = T_1 \cdot r^{\gamma-1}$$

② Process 2-3 (const. Pressure heat addition) piston move from 2-3 is cutoff at '3' supply of heat so '3' point is called cutoff point

$T_2 \to T_3$

$Q_{23} = mC_p(T_3 - T_2)$

C_p = specific heat of air at const. Pressure.

③ Process 3-4 (rev. adiabatic expansion process).

cuttoff point → BDC

$T_3 \to T_4$ (↓)

$Q_{34} = 0$.

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{1}{\rho}\right)^{\gamma-1}$$

④ (4-1) const. volume heat rejection :- 4 → 1.

$T_4 \to T_1$ (↓).

Heat rejected by air

$Q_{4-1} = mC_v(T_4 - T_1)$

W = Heat absorbed − heat rejected.

$= mC_p(T_3 - T_2) - mC_v(T_4 - T_1)$.

$$\eta = \frac{\text{Workdone}}{\text{Heat supplied}}$$

$$= \frac{mC_p(T_3 - T_2) - mC_v(T_4 - T_1)}{mC_p(T_3 - T_2)}$$

$$\eta = 1 - \frac{C_v}{C_p}\left(\frac{T_4 - T_1}{T_3 - T_2}\right)$$

$$\eta = 1 - \frac{1}{\gamma}\left(\frac{T_4 - T_1}{T_3 - T_2}\right) \text{ ——— (I)}$$

r = compression ratio $= \frac{V_1}{V_2}$

ρ = cut-off ratio $= \frac{V_3}{V_2}$

r_1 = expansion ratio $= \frac{V_4}{V_3} = \frac{V_1}{V_3} = \frac{V_1}{V_2} \times \frac{V_2}{V_3}$

$r_1 = \frac{r}{\rho}$

1-2

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1}$$

$$T_2 = T_1 r^{\gamma-1} \text{ ——— (II)}$$

2-3 $\frac{V_2}{T_2} = \frac{V_3}{T_3}$

$$T_3 = \frac{V_3 T_2}{V_2} = \rho \cdot T_2 = \rho \cdot T_1 \cdot r^{\gamma-1} \text{ ——— (III)}$$

6.3 Application of different ...
... Heating values of fuel. ...number. Cetane number.

3-4

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{1}{r_1}\right)^{\gamma-1} = \left(\frac{\rho}{r}\right)^{\gamma-1}$$

$$T_4 = T_3\left(\frac{\rho}{r}\right)^{\gamma-1} = \rho \cdot T_1 \cdot r^{\gamma-1}\left(\frac{\rho}{r}\right)^{\gamma-1} = T_1 \cdot \rho^{\gamma} \text{ ——— (IV)}$$

Substituting T_2, T_3, T_4 from eqⁿ (II), (III), (IV) in eqⁿ (I)

$$\eta = 1 - \frac{1}{\gamma}\left(\frac{T_4 - T_1}{T_3 - T_2}\right)$$

$$= 1 - \frac{1}{\gamma}\left(\frac{T_1\rho^{\gamma} - T_1}{\rho T_1 \cdot r^{\gamma-1} - T_1 \cdot r^{\gamma-1}}\right)$$

$$= 1 - \frac{\cancel{T_1}(\rho^{\gamma} - 1)}{\gamma \cancel{T_1} r^{\gamma-1}(\rho - 1)}$$

$$\boxed{\eta = 1 - \frac{(\rho^{\gamma} - 1)}{\gamma r^{\gamma-1}(\rho - 1)}}$$

* * *

→ $\rho > 1$, so $\eta \uparrow \rho \uparrow$.

· $\eta_{\text{(compression ratio)}} = \eta_{\text{otto cycle}} > \eta_{\text{diesel cycle}}$

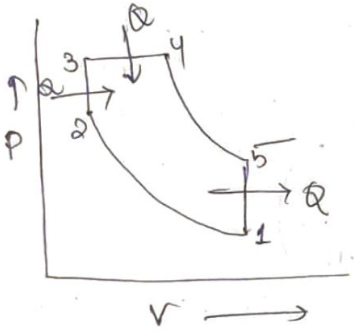
→ ~~$\rho = 1$, $\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right]$~~

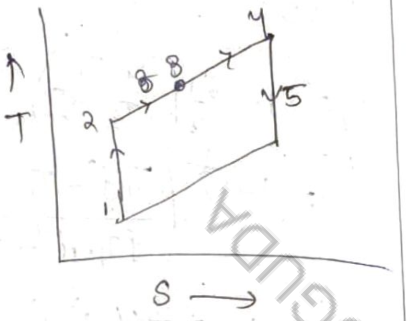
compression ratio for diesel cycle $14 < r < 18$.

Dual cycle

→ Combination of otto cycle & Diesel cycle.

→ 2 rev. adiabatic process
  2 const. volume process.
  1 const. pressure process.





1-2 (rev. adiabatic compression process)

$BDC \rightarrow TDC$

$T_1 \rightarrow T_2 \ (\uparrow)$

$Q_{12} = 0$

2-3 const. volume heat addition,

$T_2 \rightarrow T_3 \ (\uparrow)$

$Q_{23} = mC_v(T_3 - T_2)$

3-4 Const. pressure heat addition.

$T_3 \rightarrow T_4 \ (\uparrow)$

$Q_{34} = mC_p(T_4 - T_3)$

4-5 rev. adiabatic expansion process

$T_4 \rightarrow T_5 \ (\downarrow)$ $Q_{45} = 0$

Process 5-1 const volume heat rejection.

$Q_{5-1} = mC_v(T_5 - T_1)$

W = Heat absorbed − heat rejected.

$W = (Q_{23} + Q_{34}) - Q_{51}$

$$\eta = \frac{W}{Q_{supplied}}$$

$$\boxed{\eta = 1 - \frac{(\alpha_p \cdot \rho^{\gamma} - 1)}{r^{\gamma-1}\left[(\alpha_p - 1) + \gamma \alpha_p(\rho - 1)\right]}}$$

r = compression ratio = $\frac{V_1}{V_2}$

α_p = pressure ratio = $\frac{P_3}{P_2}$

$\rho = \frac{V_4}{V_3} = \frac{V_4}{V_2}$ = cut-off ratio

$\eta_{otto} > \eta_{dual} > \eta_{diesel}$ (Same compression Ratio)

$\eta_{diesel} > \eta_{dual} > \eta_{otto}$ (Same max P & T)

Fuel & combustion

(1) Define fuel

→ Fuel is ~~supply~~ a combustible substance it burns in the presence of oxygen & release heat energy.

→ various types of fuel are solid, liquid & gas.

→ Most of fuel contain carbon & hydrogen as main constituent they are called hydrocarbon fuels. C_nH_m

→ Each fuel consists of certain amt of bonded energy → Chemical energy & it is in the form of internal energy. In combustion the interactive bonds of the molecules of the fuel & O_2 are broken & rearrangement of atoms in new molecular combination takes place. during this process energy release in the form of heat → total no. of atom remain unchanged → Law of conservation of mass.

Types of fuel

Characteristic of an Ideal fuel

(i). It should have a high heating value.
ii) free from moisture & non-combustible matter.
iii) not harmful & pollutant
iv) moderate ignition temp.
v) easy to transport & store in minimum space
vi) High combustion efficiency.
vi). Low cost.

classification of fuel

(a) solid fuel - Coal.

Peat - wood + vegetable matter.
- 30 % moisture.
- calorific value - 14,500 kJ/kg

Lignite :- volatile matter + moisture + Low carbon %
- brown colour
- high ash & low heating value.
- calorific value - 21,000 kJ/kg.
- heavy smoke

Fuel & combustion

→ Fuel is a substance which release heat Energy when burn at sufficient high temp.

→ use of fuel

(i) ~~p~~ use in power plant
ii) Industrial purpose.
iii) Blastfurnance.

Fuel constituent

All fuel contain Hydrogen & carbon.

fuel usally contain

(i) Hydrogen
ii) carbon
iii) Sulphur
iv) oxygen
v) Nitrogen
vi) Ash

Characteristic of fuel

(i) Easy ignition.
ii) High heating value (calorific value)
iii) ~~E~~ Low smoke emission.
iv) Easily contrallable combustion properties.

Types of fuels

(1) According to physical state
a) Solid b) Liquid c) Gas

2) According to the nature of origine.

Solid fuels

→ fuels which are found in their solid stat at room temp.

e.g- wood, charcoal, Straw, wood ...

Advantages:
→ Easier trasportation & storage.
→ Low production cost.
→ Moderate ignition temp.

Disadvantages:-
→ Large energy is wasted.
→ handling & controlling cost high.
→ Ash content is high.

Liquid fuels

→ Most liquid fuels are derived from the remains of dead plants & animals by exposure to heat & pressure in Earth's crust.

e.g – petrol, gasoline, kerosine, diesel oil, ~~petrol~~

Advantages:-
(i) High calorific value.
(ii) Burn without ash.
(iii) easy transpotation.
(iv) Required less space.

disadvantages:-
(i) high cost as compain to solid fuel.
ii) Storage methods are costlier.
(iii) risk of fire.

Gaseous fuel

→ Gaseous fuel are occur in nature, most gaseous fuels are composed of hydrocarbons, carbon monoxide, hydrogen & mixture of them all.

e.g – Natural gas, coal gas, coke oven as.

advantage
(i) Transpotation through pipe is easy.
(ii) high heat content.
(iii) clean after use.

Disadvantages:-
(i) Large storage tanks required.
2) high & strickt safty measured need to followed.

Heating value of fuel

→ ~~Or~~ Heating value / calorific value of a fuel is defined as the total quantity of heat liberated by the complete combustion of unit quantity of fuel.

→ for solid or liquid = kj/kg

→ For gaseous fuel = kj/m³.

→ Cv maybe expressed by two values.

a) Higher calorific value (HCV)

b) Lower calorific value (LCV)

Higher calorific value

→ it is defined as the total amt of heat liberated when unit quantity of fuel is completely burnt & the product of combustion are cooled to room temperature.

Lower calorific value :-

→ it defined as the amt of heat liberated by complete combustion of unit quantity of fuel & the product of combustion are not cooled at room temp but allowed to escape in atmosphere.

$$LCV = HCV - m_s L \quad kj/kg$$

m_s = mass of water vapour formed per kg of fuel burnt

L = latent heat of water ~~value~~ vapour at 15°C.

= 2466 kj/kg.

→ ~~ECP~~ -

$$HCV = LCV + \left(\frac{9 \times h \times \text{Latent heat of water}}{100} \right)$$

h = % of Hydrogen in fuel.

To define the Quality of fuel.

Octane no.

→ octane no. indicates the tendency of (petrol) fuels to knock. higher is the octane no., the more difficult the auto ignition

→ standard fuel combination
  a) iso-ocate
  b) n-heptane

petrol engine

#

→ if during compression stroke the P, T of fuel is more the then its ~~auto~~ autoignition temp. it will burnt before heat supply due to spark plug.

→ Due to this knocking tendany takes place in Engine.

→ so fuel Quality should be such that during compression stroke it will not reach it autoignition temp. (self ignition)

→ The Quality of petrol which reduce its ~~knocking~~ autoignition tendancy & knocking properties is known as octane no.

~~more~~ ↑ octane no. ↑ good quality of fuel.

→ iso-octane (↑ anitknock) ; n-heptane (↓ antiknock)

→ % of iso-octane → its octane no.

→ octane no. 90 mean → 90% iso-octane
→ 10% n-heptane

Cetane no.

→ Quality of diesel fuel.

→ normal-hexadecane called cetane.

→ 50% cetane + methyle-napthalene

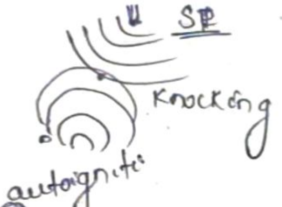
%-cetane in fuel called Cetane no..

→ after fuel spray to before fuel Combustion called ignition delay.

→ cetane no. of diesel means its ignition delay should be less. so that it will burnt early.

octane no.

→ ~~petc~~formace/ Quality of petrol.



Ⓚ damage piston, cylinder, connecting rod

→ India = ~~87~~ speed 93 speed 99

→ ~~of~~ during compression stroke charge temp is high (reached its autoignition temp)

→ ~~it~~ ~~char~~ fuel burn before using sparkplug.

→ to reduce knocking in engine, we must ~~consider~~ ~~[illegible]~~ see there should not be autoignition temp, in the fuel.

→ ~~on~~ petral antiknock properties ~~is~~ called octane no.

cetane no.

performance of diesel fuel

→ India 47 - 5]

[→ n-hexadecan ($C_{16}H_{34}$) → cetane
← methyle napthalene

– ~~85~~ 55% cetane no.

it has 55% cetane & rest methyle napthalene.

→ ignition delay (↓)

–

→ octane no. ↑
antiknock ↑

→ ~~[illegible]~~

petral

① iso-octane (anti knock properties ↑) C_8H_{18} (% of this show octane no. of fuel)

② n-heptane (↓)

let 93% ~~p~~ octane no.

93% — isooctane

7% - n-heptan

e.g = 105%

100% isoctane

5% more pure ~~octa~~ isooctane.