

(18)

BASIC MECHANICAL ENGINEERING

Thermodynamics → Energy & Entropy
heat movement

System - A space or region for a matter.
An area where you are focussed and pay attention
for the sake of study, analysis of a problem.

Surroundings - External to system exceeding
the boundary walls

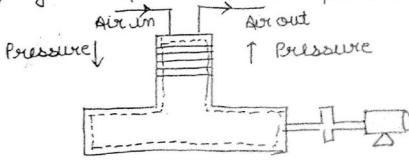
Types of System.

1) Control Mass (closed system)
→ Heat and work cross boundary

2) Control volume (open system)
→ Heat, Work and Matter → cross

3) Isolated system (No Exchange)
no interaction b/w system and surroundings

2) Eg: compression in petrol pump



Heat has to
be removed
by water
cylinder

Macroscopic And Microscopic study of system:

Microscopic (statistical) → Individual effect of 1 atom.

Macroscopic measurable / observable quantity.
combined effect of all molecules

Properties And State

Ice → at 0°C and atmospheric pressure with change in pressure freezing temperature changes.

Increasing pressure increases the boiling pt.

State: It is identified or described by some measurable and observable quantity (macroscopic quantity) of a system. change of property.

Properties: are defined as any quantity that depends on the state of the system and is independent of the path it has arrived / reached from. characteristics by which the physical condition of a system may be described

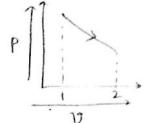
INTENSIVE

Mass independent
pressure, Temperature

EXTENSIVE

Mass dependent
volume, energy

PROCESS:- It can be defined as the succession of state through which a system passes.



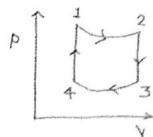
QUASI STATIC PROCESS / EQUILIBRIUM PROCESS

It is the one in which the deviation from thermodynamic eqⁿ is infinitely small and all the states of the system pass through during a quasi static process may be considered as equilibrium state.

In thermo we always talk about quasi static process
→ It is infinitely slow process.

CYCLE: A system undergoes a no. of processes (change in state, energy transfer) and returns to its original state.

Eg:



PHASE: A quantity of matter homogeneous throughout in chemical composition and physical properties.

ZEROTH LAW OF THERMODYNAMICS

- Temperature scale comes from this law.
- If 2 bodies are in thermal equilibrium with the 3rd body then they are also in thermal eq' with each other.
- Properties that is same in all 3 bodies \rightarrow Temp

THERMOMETRIC PROPERTIES

PROPERTY	THERMOMETER	SYMBOL
Length	Alcohol / Mercury	L
Electric Resistance		R
Thermo couple	EMF	E
control Vol	Pressure	P
control pressure	Volume	V
Radiation	Intensity of Radiation	I or J

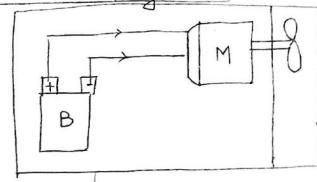
→ Water and Hydrogen are treated as base

THERMODYNAMIC EQUILIBRIUM: no change in macroscopic properties

- 1) Thermal (separated by diathermic wall and no change in property)
- 2) Mechanical (dynamic condition does not change absence of unbalanced force between system and surroundings)
- 3) Chemical (No composition change) no chemical reaction or transfer of matter

THERMODYNAMIC WORK: Work is done up nett effect external to system could be a raising of a weight work done by the system (+ve) to system (-ve)

Consider a system:

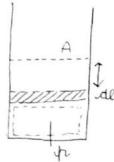


Here the mechanical energy i.e. the fan working is delivered out of the system boundary
As heat is entering from chemical \rightarrow electrical \rightarrow mech. work inside the system

11th August, 2016

Unit of Work :- $1 \text{ N} \cdot \text{m} = 1 \text{ J}$
 $1 \text{ KN} \cdot \text{m} = 1 \text{ KJ}$

WORK DONE :- work done in a control mass with a movable boundary.

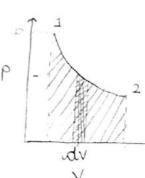


$$\text{work done} = \rho \times A \times dh$$

$$dW = \rho dV$$

$$\int dW = \int \rho dV$$

WORK AS A PATH FUNCTION:



It depends on the path travelled
Point function: Thermodynamic properties are independent of the path traversed.
Depends on initial and final state.

(Transient)

HEAT: Heat is a form of energy which flows across the boundary of system due to temperature difference. Heat also a path function

UNIT: J

J/T



Free expansion: The expansion of gas against vacuum is called free expansion.

PRESSURE: $P = \frac{F}{A} = N/m^2 = 1 \text{ Pa}$

conduction: Heat transfer in bodies in contact

$$1000 \text{ N/m}^2 = 1000 \text{ Pa}$$

$$1 \text{ MN/m}^2 = 10^6 \text{ Pa}$$

$$1 \text{ Bar} = 10^5 \text{ Pa} = 10^5 \text{ N/m}^2 \quad 2 \text{ bodies separated by empty space or gases.}$$

$$= 100 \text{ kPa}$$

$$= 0.1 \text{ MPa}$$

Radiation: heat transfer b/w 2 bodies separated by empty space or gases.

Convection: heat transfer b/w wall and fluid.

ATMOSPHERIC PRESSURE: Pressure $\frac{\rho g}{c}$ $\frac{\rho g}{c} \propto \frac{1}{h}$

column of a fluid

$$\text{Force} = \rho g h A$$

$$\text{pressure} = \rho g h$$

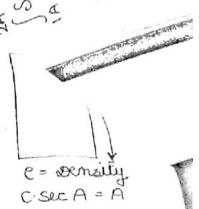
$$760 \text{ mm of Hg}$$

$$\rho = 13595 \text{ kg/m}^3$$

$$P = 13595 \times 9.8065 \times 0.760$$

$$= 101325 \text{ N/m}^2$$

$$= 1.01325 \text{ Bar}$$



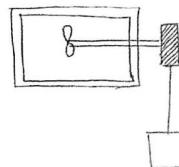
longer & shorter

LAWS OF THERMODYNAMICS:

I law of THERMODYNAMICS for control mass undergoing a cyclic change:

$$\oint dQ = \oint dW$$

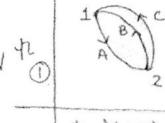
Algebraic sum of heat transfer = Algebraic sum of work done



movement of pulley.
(Work)

→ undergoing a process

$$\frac{2A}{2B} \oint dQ + \frac{1B}{1A} \oint dQ = \frac{2A}{1A} \oint dW + \frac{2B}{2B} \oint dW$$



cycle 1A2C1

$$\int_{1A}^{2A} SQ + \int_{2C}^{1C} SQ = \int_{1A}^{2A} SW + \int_{2C}^{1C} SW \quad \text{---(2)}$$

$$1B$$

$$\int_{2B}^{1B} SQ - \int_{2B}^{1C} SW = \int_{2C}^{1C} SQ - \int_{2C}^{1B} SW$$

$$2B \int_{(SQ-SW)}^{1B} = \int_{2C}^{1C} (SQ-SW)$$

$$SQ - SW = dE$$

$$= dKE + dPE + dU \quad (\text{internal energy})$$

$$SQ = dKE + dPE + dU + SW$$

(for a closed system)

$$- SW = d(KE)$$

$$SW = Fdx$$

$$= \frac{m\bar{v}}{\bar{u}t} (dx)$$

$$- Fdx = m\bar{v}d\bar{v}$$

$$Fdx = mgdz \quad (\text{P.E.})$$

$$SQ = dU + SW + m\bar{v}d\bar{v} + mgdz$$

$$SQ = dU + \bar{v}d\bar{v} + gdz + SW$$

(per unit mass)

$$q = u_2 - u_1 + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1) + w$$

$$q = (u_2 - u_1) + w$$

$$sq = dU + SW$$

(provided no change
in KE and PE)

EQUATION OF STATE Relation between P, V, T

$$PV = nRT$$

$$R = \frac{PV}{nT}$$

$$= \frac{1.0132 \times 10^5 \times 22.4136}{1 \times 273.15}$$

$$= 8314.4 \text{ J/mol K}$$

$$= 8.3144 \text{ kJ/kmol K}$$

$$n = \frac{m}{M}$$

$$PV = \frac{mR}{M}T$$

$$\frac{R}{M} = R$$

$$PV = mRT$$

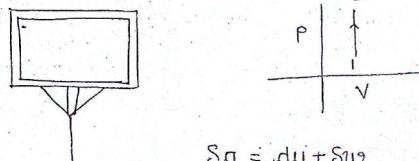
$$R_{air} = \frac{8.3144 \text{ kJ/kmol K}}{28.966}$$

$$= 0.287 \text{ kJ/kg K}$$

$$R_{water} = \frac{8.3144 \text{ kJ/kmol K}}{18}$$

$$= 0.4625 \text{ kJ/kg K}$$

CONSTANT VOLUME PROCESS:



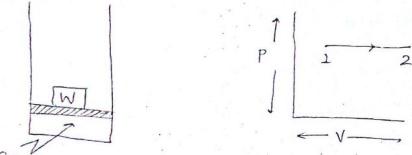
$$dq = du + SW$$

$$dq = du + PdV$$

$$dq = du$$

$$C_V dT = du$$

CONSTANT PRESSURE PROCESS.



$$\delta q = \delta u + \delta w$$

$$\delta q = \delta u + \frac{P}{V} dV$$

Enthalpy (H) (combination of properties) intensive property.

$$H = U + PV$$

$$dH = \delta u + PdV + VdP$$

For $P = \text{constant}$

$$dH = \delta u + PdV$$

$$\text{Heat transfer (dh)} = C_p dt$$

$$C_p = \left(\frac{dh}{dt} \right)_P = \text{constant}$$

$$h = U + PV$$

$$dh = \delta u + R dt$$

$$\frac{dh}{dt} = \frac{\delta u}{dt} + R$$

$$C_p = C_v + R$$

$$R = C_p - C_v$$

CONSTANT TEMPERATURE PROCESS

$$\delta q = \delta u + \delta w$$

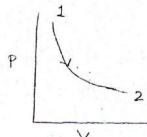
$$\delta q = \delta w$$

$$\int \delta w = \int P dV$$

$$\int \delta w = \int \frac{P_1}{V} dV$$

$$= \nu \ln \frac{V_2}{V_1}$$

$$= P_1 V_1 \ln \frac{V_2}{V_1}$$



ADIABATIC PROCESS

$$\delta q = \delta u + \delta w$$

$$\delta q = 0$$

$$\delta u = -\delta w$$

$$C_V dt = -P dV$$

$$dt = -\frac{P dV}{C_V}$$

$$P dV + V dP = R dt$$

$$P dV + V dP = R \left(-\frac{P dV}{C_V} \right)$$

$$C_V P dV + C_V V dP = (C_P - C_V) (-P dV)$$

$$C_V P dV + C_V V dP = -C_P P dV + C_V V dP$$

$$C_V V dP + C_P P dV = 0$$

$$V dP + \gamma P dV = 0$$

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

$$\frac{dP}{P} = -\gamma \frac{dV}{V}$$

$$\gamma V^{\gamma} = \text{constant}$$

$$\delta w = \gamma V dP$$

$$\gamma V^{\gamma} = \text{constant}$$

$$P = \frac{C}{V^{\gamma}}$$

$$\int \delta w = \int \frac{C}{V^{\gamma}} dV$$

$$= C \left[\frac{V_1^{1-\gamma} - V_2^{1-\gamma}}{1-\gamma} \right]$$

$$\gamma V_1^{\gamma} = \gamma V_2^{\gamma}$$

$$W = \frac{\gamma V_2 - \gamma V_1}{1-\gamma} = \frac{R T_2 - R T_1}{1-\gamma}$$

$$\delta w = \frac{R dt}{1-\gamma}$$

+ → work is done by system

- → work is done on system

ISOTROPIC PROCESS

$$pV^n = \text{constant}$$

$$n=0 \quad p_1 = c$$

$$n=1 \quad pV = \text{constant}$$

$$n=\gamma \quad pV^\gamma = \text{constant}$$

$$n=\infty \quad [pC = V]$$

$$dq = du + dw$$

$$dq = C_V dt + pdv$$

$$\int dw = \frac{p_1 V_1 - p_2 V_2}{n-1} = R \frac{\ln t}{1-n}$$

$$dq = C_V dt + \frac{R dt}{1-n}$$

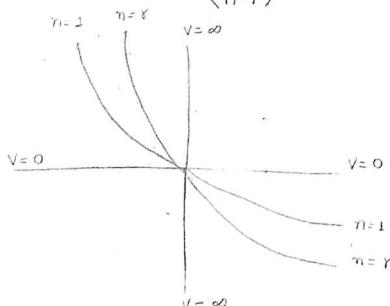
$$dq = \left[C_V + \frac{R}{1-n} \right] dt$$

$$dq = \left[C_V + \frac{C_P - C_V}{1-n} \right] dt$$

$$= \left[1 + \frac{\gamma-1}{1-n} \right] C_V dt$$

$$= \left[\frac{\gamma-n}{1-n} \right] C_V dt = C_n dt$$

$$\text{where } C_n = \left(\frac{n-\gamma}{n-1} \right) C_V$$

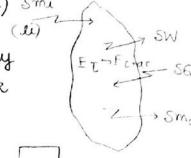


First law of thermodynamics for a control volume:

(open system) \dot{S}_{mi}

- flow energy
- flow work

this will happen over dT



fluid carries with it kinetic, thermal & potential energy

$$\begin{aligned} W &= PA \times l \\ &= PV \end{aligned}$$

unsteady flow

$$dq + \dot{S}_{mi}(e_i) = \dot{S}_{mi}(e_o) + dw + (E_i + dE - E_i)$$

$$dq + \dot{S}_{mi}(u_i + p_i v_i + \frac{v_i^2}{2} + g z_i)$$

$$= \dot{S}_{mi}(u_o + p_o v_o + \frac{v_o^2}{2} + g z_o) + dw + (E_i + dE - E_o)$$

dividing by dT

$$\dot{Q} + \dot{m}_i(u_i + p_i v_i + \frac{v_i^2}{2} + g z_i)$$

(internal energy + work done)

$$= \dot{m}_o(u_o + p_o v_o + \frac{v_o^2}{2} + g z_o)$$

$$+ \dot{W} + \left(\frac{dE}{dT} \right)_T$$

At steady state, thermodynamic property will have fixed value with time

steady state steady flow equation (SSSFE)

$$1. \quad \dot{m}_i = m_o \neq f(T)$$

$$2. \quad \frac{dE}{dT} = 0 \quad (\text{any particle in any position in direction will have same energy})$$

$$3. \quad \dot{Q} \neq \dot{W} \neq f(T)$$

$$\dot{Q} + \dot{m}_i(u_i + \frac{v_i^2}{2} + g z_i) = \dot{W} + \dot{m}_o(u_o + \frac{v_o^2}{2} + g z_o)$$

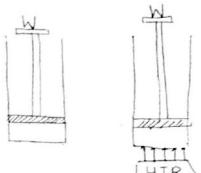
$$\dot{Q} = \dot{m}(h_o - h_i + \frac{v_o^2 - v_i^2}{2} + g(z_o - z_i)) + \dot{W}$$

perfect gas.

SECOND LAW OF THERMODYNAMICS

High Temp reservoir
↓
Low Temp reservoir

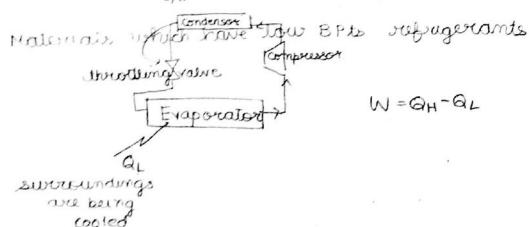
Heat engine:-



- Thermodynamic cycle
- undergoes work (+ve)
- some heat must be rejected ($HTR \rightarrow LTR$)
- heat can be converted to work only if some heat is rejected

$$\eta_{HE} = \frac{Q_H - Q_L}{Q_H}$$

$$= 1 - \frac{Q_L}{Q_H}$$

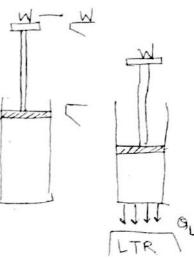


$$\text{Coef. of Performance} = \frac{Q_H}{Q_H - Q_L}$$

Heat Pump (Refrigerator)

$$\text{Coef. of Refrigerator} = \frac{Q_L}{Q_H - Q_L}$$

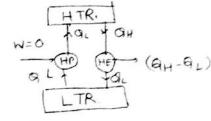
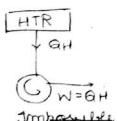
1st law → moderation
work = heat
+ n × work.



KELVIN PLANK STATEMENT:-

It is impossible to construct a device working in a thermodynamic cycle

- does a net +ve work with single reservoir
- pass heat from LTB to HTR without doing external work
- all heat cannot get converted into work.



- we cannot have any machine with 100% efficiency

Reversible Process:- which when once takes place can be retraced back and does not leave any change in the system or surroundings

- work is done very slowly
- equilibrium b/w system and surroundings is maintained

Reasons for Irreversibility

- friction
- mixing of 2 gases
- heat transfer through a finite temperature difference
- electric supply through air resistance wire
- unrestrained expansion

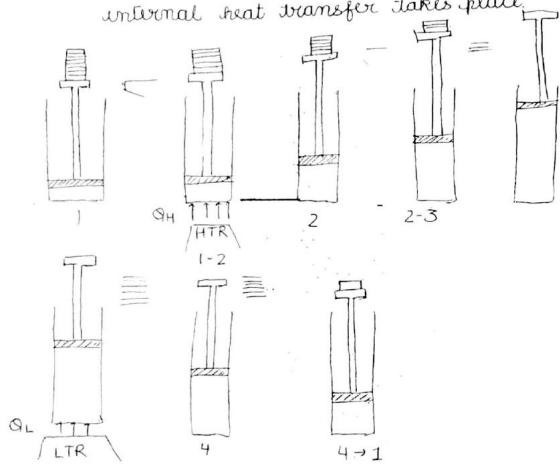
Carnot Cycle:

Two reversible → Isothermal Adiabatic

Adiabatic Process

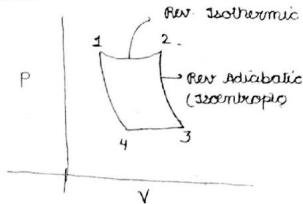
Reversible - no heat transfer - internal and external to the system

Irreversible - no external heat transfer
internal heat transfer takes place



1-2 and 3-4 isothermal reversible
2-3 4-1 adiabatic reversible

P-V Diagram

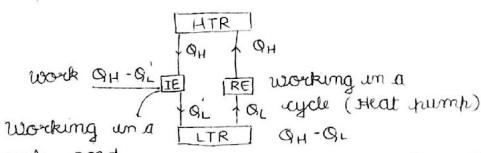


$$\eta = \frac{Q_H - Q_L}{Q_H}$$

$$= 1 - \frac{Q_H - Q_L}{Q_H}$$

CARNOT THEOREM

- 1) It is impossible to construct an engine that operates between 2 given reservoirs and is more efficient than the reversible engine operating between the 2 reservoirs.



$Q_H - Q_L < Q_H' - Q_L'$

From LTR we get a +ve work done as $Q_L - Q_L'$.

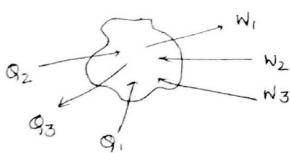
- 2) All reversible engines operating between the two given constant temp reservoir will have the same efficiency.

FIRST LAW FOR A CLOSED SYSTEM UNDERGOING A CHANGE OF STATE

If a system undergoes a change of state during which both the heat transfer and work transfer are involved, the net energy transferred is not zero and the remaining energy will be accumulated in the system.

$$Q - W = \Delta E$$

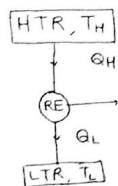
$\Delta E \rightarrow$ increase in energy of system



$$(Q_2 + Q_1 - Q_3) = \Delta E + (W_1 - W_2 - W_3)$$

Clausius inequality

$$\oint \frac{dQ}{T} \leq 0$$



$$\oint \frac{dQ}{T} = \frac{Q_H}{T_H} - \frac{Q_L}{T_L}$$

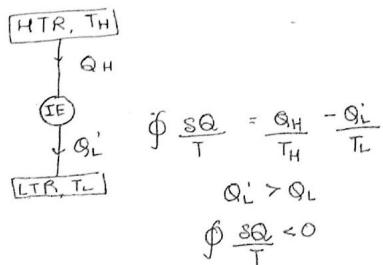
Absolute temp. scale

$$\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$$

$$\text{or } \frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

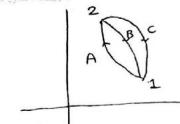
$$\oint \frac{dQ}{T} = 0$$

most efficient
as reversible
engine



$$\oint \frac{dQ}{T} = \frac{Q_H}{T_H} - \frac{Q_L'}{T_L}$$

$$\oint \frac{dQ}{T} < 0$$



$$\oint \frac{dQ}{T} = \int_{1A}^{2A} \frac{dQ}{T} + \int_{2B}^{1B} \frac{dQ}{T} = 0 \quad (i)$$

(Cycle 1A2B1)

cycle (1A2B1)

$$\oint \frac{dQ}{T} = \int_{1A}^{2A} \frac{dQ}{T} + \int_{2C}^{1C} \frac{dQ}{T} = 0 \quad (ii)$$

From eq. (i) and (ii) we get

$$\int_{2B}^{1B} \frac{dQ}{T} = \int_{2C}^{1C} \frac{dQ}{T}$$

$\Rightarrow \frac{dQ}{T}$ is not path dependent. It is a path function. It is a property will depend on the state of the system

$\frac{dQ}{T} \rightarrow$ entropy

$$\frac{dQ}{T} = dS$$

entropy difference b/w 2 states undergoing a reversible or irreversible process remains same.

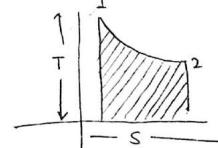
Tds equation

$$dQ = TdS$$

$$dQ = TdS$$

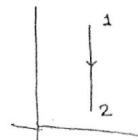
$$\int_1^2 dQ = \int_1^2 TdS$$

$$Q = \int_1^2 TdS$$

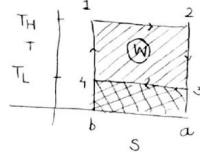


entropy change for a reversible process

1. Isothermal process
2. Reversible Adiabatic



Representation of Carnot cycle on Temperature Entropy diagram



Two Tds equation

$$dq = du + pdv$$

$$\frac{dq}{T} = \frac{C_V dT}{T} + \frac{pdv}{T}$$

$$ds = C_V \frac{dT}{T} + R \frac{dv}{v}$$

$$S_2 - S_1 = C_V \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1}$$

$$dq = du + pdv$$

$$dh = du + pdv + vdp$$

$$dh = du + pdv - vdp$$

$$dq = du + pdv$$

$$\frac{dq}{T} = \frac{dh}{T} - \frac{vdp}{T}$$

$$ds = \frac{C_p dT}{T} - \frac{R dp}{P}$$

$$S_2 - S_1 = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

Change in Entropy for an irreversible process

For a reversible process

$$\oint \frac{dq}{T} = 0$$

$$\int_{1A}^{2A} \frac{dq}{T} + \int_{2B}^{1B} \frac{dq}{T} = 0$$

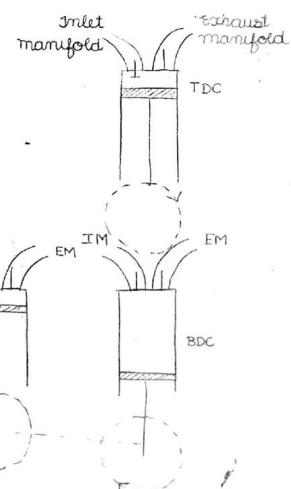
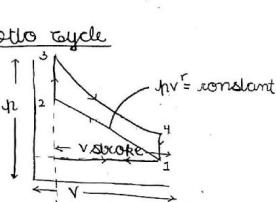
For irreversible process

$$\int_{1A}^{2A} \frac{dq}{T} + \int_{2C}^{1C} \frac{dq}{T} < 0$$

$$\int_{2C}^{1C} \frac{dq}{T} \Rightarrow \int_{2B}^{1B} \frac{dq}{T}$$

$$\int_{2C}^{1C} \frac{dq}{T} = \int_{2B}^{1B} \frac{dq}{T} + \int_{1}^{\infty} ds$$

OTTO cycle



$$\eta_{ratio} = \frac{\text{Heat Added} - \text{Heat Rejected}}{\text{Heat Added}}$$

$$\text{Heat Added} = C_V [T_3 - T_2]$$

$$\text{Heat Rejected} = C_V [T_4 - T_1]$$

$$\eta_{ratio} = \frac{C_V [T_3 - T_2] - C_V [T_4 - T_1]}{C_V [T_3 - T_2]}$$

$$= 1 - \frac{(T_4 - T_1)}{T_3 - T_2}$$

$$= 1 - \frac{T_1}{T_2} \left[\frac{T_4/T_1 - 1}{T_3/T_2 - 1} \right] \quad (1)$$

compression ratio

$$\sigma = \frac{V_1}{V_2}$$

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

$$\frac{T_2}{T_1} = (\sigma)^{r-1}$$

between 3 and 4

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

$$\frac{T_3}{T_4} = (\sigma)^{r-1}$$

$$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

Putting this eq in (1)

$$\eta = 1 - \frac{1}{\sigma^{r-1}}$$

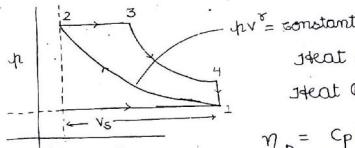
→ quality of fuel is determined by octane no.

→ compression ratio is around -10.

→ octane no. is incl by TEL - ultra ethyl lead.

→ σ is decided by quality of fuel.

Diesel cycle



pV^{γ} = constant

$$\text{Heat Added} = C_P (T_3 - T_2)$$

$$\text{Heat Rejected} = C_V (T_4 - T_1)$$

$$\eta_D = \frac{C_P (T_3 - T_2) - C_V (T_4 - T_1)}{C_P (T_3 - T_2)}$$

$$= 1 - \frac{C_V (T_4 - T_1)}{C_P (T_3 - T_2)}$$

$$= 1 - \frac{1}{\gamma} \frac{T_1}{T_2} \left(\frac{T_4/T_1 - 1}{T_3/T_2 - 1} \right) \quad (2)$$

$$\sigma_{compression} = \frac{V_1}{V_2} \quad (18-21)$$

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

$$\sigma_c \text{ (cut off ratio)} = \frac{V_3}{V_2}$$

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = \sigma_c^{r-1}$$

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

$$= \left(\frac{V_4}{V_2} \times \frac{V_2}{V_3} \right)^{r-1}$$

$$= \left(\frac{\sigma_c}{\sigma} \right)^{r-1}$$

$$\frac{T_4}{T_1} = \frac{T_4 \times T_3 \times T_2}{T_3 \times T_2 \times T_1}$$

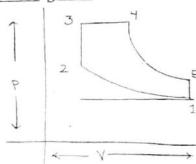
$$= \left(\frac{\sigma_c}{\sigma} \right)^{r-1} \times \sigma_c \times (\sigma)^{r-1}$$

Putting in eq - (1) = σ_c^r

$$\eta_D = 1 - \frac{1}{\gamma(\alpha)^{\gamma-1}} \left[\frac{\alpha_c - 1}{\alpha_c + 1} \right]$$

α_c → should be large, α_c should be low.

Quality of diesel is decided by - cetane no.
diesel cycle

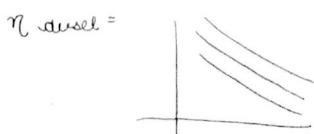
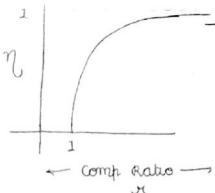


$$\alpha_c = \frac{V_1}{V_2}$$

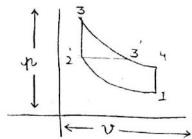
$$\alpha_{cp} = \frac{V_4}{V_3}$$

$$\eta_{diesel} = \frac{1}{\alpha_c^{\gamma-1}} \gamma \left[\frac{\alpha_p \alpha_c - 1}{\alpha_p [\alpha_c - 1] + \alpha_p - 1} \right]$$

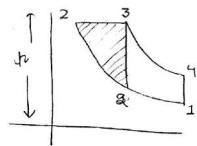
$$\eta_{otto} = 1 - \frac{1}{\alpha_c^{\gamma-1}} \gamma \rightarrow \text{gain is not much as we go above 10(\alpha)}$$



Comparison of Otto cycle and Diesel cycle
For the same compression ratio



- 1 2 3 4 → Otto cycle
- 1 2 3' 4 → Diesel cycle
- heat rejected is same
- Otto cycle is more efficient for same compression ratio
- Diesel engines have lower comp. ratio.



Diesel is more efficient

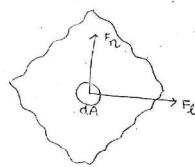
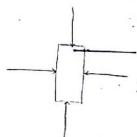


FLUID MECHANICS

Fluid → It is a substance which deforms continuously under the application of shear stress.

stress → two types Force/Area
longitudinal and shear

Free Body Diagram of the fluid particle



Mechanics means essentially the application of laws of motion.

Properties of the fluid

1. Density (mass density)

$$\rho = \frac{\text{mass of the fluid}}{\text{volume of the fluid}}$$

2. Specific weight (weight density)

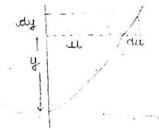
$$W = \frac{\text{wt. of the fluid}}{\text{volume of the fluid}} = \rho g$$

3. Specific volume = $\frac{\text{volume of the fluid}}{\text{mass of the fluid}}$

4. Specific gravity (s) = $\frac{1}{\rho}$

$$= \frac{\text{wt. density of the fluid}}{\text{wt. density of water}}$$

Viscosity → defined as property of fluid which offers resistance to the movement of one layer of fluid over the other layer of fluid.



$$\text{shear stress} \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

$$\mu = \frac{\tau}{du/dy}$$

Newton's Law of Viscosity

$$\tau = \mu \frac{du}{dy}$$

$$N = \mu \frac{m/s}{m^2}$$

$$\eta = \frac{N \cdot sec}{m^2} = 10 \text{ poise}$$

$$\mu = \frac{\text{dyne} \times \text{sec}}{\text{cm}^2} (\text{poise})$$

Variation of viscosity with temperature

1. viscosity of liquid ↑ temp ↑ vis (resistance b/w 2 layers)
2. viscosity of gases ↑ temp ↑ viscosity

1. In liquids cohesive forces play a dominant role and cohesive force decrease with increase in temp.
2. molecular collision provides the internal stresses so ↑ temp ↑ molecular activity in gases.

Variation

$$\text{liquids } \mu_T = \mu_0 \left[\frac{1}{1 + \alpha t + \beta t^2} \right]$$

$$\text{gases } \mu_T = \mu_0 [1 + \alpha t + \beta t^2]$$

Kinematic viscosity

$$V = \frac{u/c}{\rho} = \text{Stoke}$$

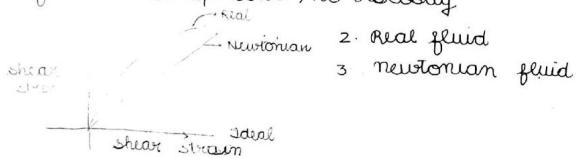
$$= \frac{\text{cm}^2}{\text{sec}}$$

Ques - Determine the intensity of shear force it is used for lubricating the clearance b/w shaft of $d = 10\text{ cm}$ and its general bearing is 10 mm dia and shaft rotates at 1500 rpm . 52.33 N/m^2

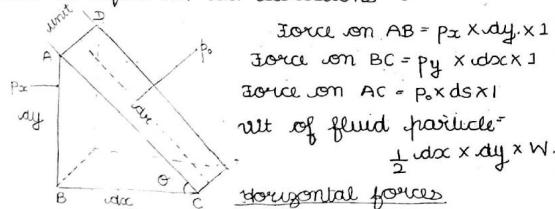
Ans - A plate 0.025 mm from a fixed plate moves at 60 cm/sec and requires a force of 2 N/m^2 to maintain this speed. Determine the fluid viscosity b/w plates.

Type of fluids

1. Ideal fluid - incompressible, no viscosity



Pascals law It states that the intensity of pressure at a point is equal in all directions



Vertical force

$$\int y dx = \frac{1}{2} \sin \theta dy \times w + P_0 ds \cos \theta$$

$$P_y dx = P_0 ds \cos \theta$$

$$\text{Force on AB} = P_x \times dy \times 1$$

$$\text{Force on BC} = P_y \times dx \times 1$$

$$\text{Force on AC} = P_0 \times ds \times 1$$

$$\text{wt of fluid particle} = \frac{1}{2} dx \times dy \times w$$

Horizontal forces

$$\int x dy = P_0 ds \sin \theta$$

$$P_x dy = P_0 dy$$

$$P_x = P_0$$

Pressure variation at a point in fluid

True fluid surface



Cross sectional Area ΔA

pressure force acting on AB

$$\rho g \times \Delta A$$

pressure force acting on CD

$$= (P + \frac{\partial P}{\partial z} \Delta z) \Delta A$$

wt of the fluid = $\Delta A \times \Delta z \times w$

$$\rho g \times \Delta A + \Delta A \times \Delta z \times w - (P + \frac{\partial P}{\partial z} \Delta z) \Delta A = 0$$

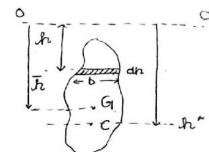
$$\frac{\partial P}{\partial z} = \rho g$$

$$\Delta P = \rho g \Delta z$$

Total Pressure and centre of pressure on a vertical surface immersed in a fluid

Intensity of pressure on the elementary strip = $\rho g h$

$$\text{Force on the strip} = \rho g h \times b \times dh = \rho g h dA$$



Total force on the vertical plane = $\int \rho g h dA$

$$\text{Force} = \rho g \int h dA = \rho g A \cdot h$$

center of pressure

Moment of a force about an axis equal to sum of the moment of the component about the same axis

$$= \rho g h \times b \times dh \times h$$

$$= \int \rho g h^2 \times b dh$$

$$F \times h^* = \int \rho g dA h^2$$

$$= \rho g \int h^2 dA$$

$$= \rho g I_{yy}$$

$$\rho g h A \cdot h^* = \rho g I_{yy}$$

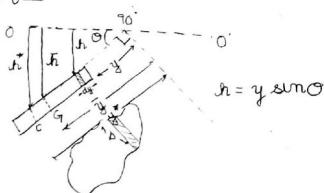
$$h^* = \frac{I_{yy}}{Ah}$$

$$I_{yy} = I_{GG} + A\bar{h}^2$$

$$h^2 = \frac{I_{GG} + A\bar{h}^2}{Ah}$$

$$h^* = \frac{I_{GG} + \bar{h}}{Ah}$$

Inclined surface:-



Intensity of pressure = ρgh
Force on strip = $\rho gh dA$

Total force on inclined plane

$$= \int \rho g y \sin \theta dA$$

$$= \rho g \sin \theta \int y dA$$

$$= \rho g \sin \theta \bar{y} A$$

$$= \rho g A \bar{h}$$

Moment of force on elementary strip about O-O
= $\rho g y \sin \theta dA y$

Total moment of force on the Area

$$= \int \rho g y^2 \sin \theta dA$$

$$= \rho g \sin \theta \int y^2 dA$$

$$F \times y^* = \rho g \sin \theta I_{yy}$$

$$\rho g h A \times y^* = \rho g \sin \theta I_{yy}$$

$$\frac{h^*}{\sin \theta} = \frac{\sin \theta I_{yy}}{Ah}$$

$$h^* = \frac{\sin \theta I_{yy}}{Ah}$$

$$h^* = \frac{\sin^2 \theta [I_{GG} + A\bar{y}^2]}{Ah}$$

$$h^* = \frac{\sin^2 \theta I_{GG}}{Ah}$$