ARYAN SCHOOL OF ENGINEERING & TECHNOLOGY

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LECTURE NOTE

SUBJECT NAME- THERMAL ENGG-II

BRANCH – MECHANICAL ENGINEERING

SEMESTER – 4TH SEM

ACADEMIC SESSION - 2022-23

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Chapter-2 Gas power Cycle Th-II

Syllabus: —

I. Concept of IC Engine.
II. Otto cycle.
III. Diesel cycle.
IV. Dual cycle.
V. Comparision of otto, diesel, & dual cycle.
VI. 2 stroke and 4-stroke engine and difference thereof.

Introduction of IC Engine: —

The word IC means Internal Comburstion.

→ Those engine which Comburstion takes place Inside the engine cylinder Is known as Internal Comburstion engine.

→ The gas engine are designed most Frequantly as Internal Comburstion engine.

→ "Air" Is Working as working Fluid.

→ The air also serves as the oxidant For the hydroCarbon Fluid Fired.

→ IC Engine transforms the chemical energy of the Fuel to thermal energy. which Is then Converted by the engine to the mechanical Work output.

Otto Cycle: —

The First Successful engine working on this cycle was built by a otto, these days, many gas, petrol and many of the oil engines run on this cycle.

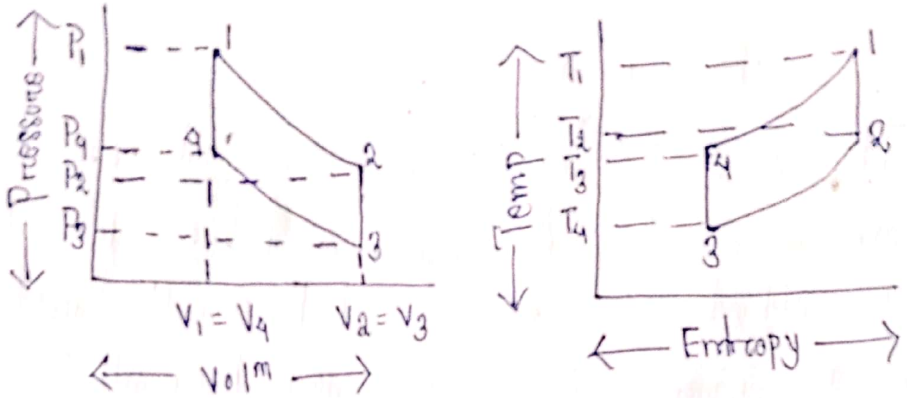
→ Otto cycle also known as "Constant Volume cycle" as the heat Is received and rejected at a Constant Volume.

→ The air Is assumed to be the working Substance.

→ The engine Convinced by otto has air enclosed In a cylinder. whose walls are perfectly non- Conductor of heat.

→ There is also a hot body or cold body and an Insulati[ng] cap. which are alternately brought in contact with the bottom of the cylinders.

→ The Ideal otto cycle consist of two constant volm and two reversible adiabatic or Isentropic process.



Let the engine cylinders contain m kg of air at point 1.

At point 1 —

P_1 = Pressure of air
T_1 = Temprature " "
V_1 = Volume " "

1. 1st stage [Reversible adiabatic or Isentropic expansion]

The air is expanded reversibly and adiabatically from initial temp T_1 to a temp T_2 as shown by the curve 1-2. In this process.

→ No heat is absorbed or rejected by the air.

2. 2nd stage [Constant Volume Cooling]

The air is cooled at constant volm from temp T_2 to T_3 as shown by the curve 2-3.

→ Heat rejected by the air during this process

$$Q_{2-3} = m \cdot C_v [T_2 - T_3]$$

3. Third stage. [Reversible adiabatic or Isentropic Compression]

The air is compressed reversibly and adiabatically from temp T_3 to T_4. as shown in Fig by the curve 3-4.

→ No heat is absorbed or rejected by the air.

4. Fourth stage [Constant Volume heating]

The air is now heated at constant Volm from temp T_4 to T_1. as shown by the curve 4-1.

→ Heat absorbed by the air during this process.

$$Q_{4-1} = m \cdot C_v [T_1 - T_4]$$

We see that the air has been brought back to its original conditions of pr, Volm and temp thus completing the cycle.

Workdone = Heat absorbed - Heat rejected.

$$= m \cdot C_v [T_1 - T_4] - m \cdot C_v [T_2 - T_3]$$

$$\text{Ideal efficiency} = \frac{\text{Workdone}}{\text{Heat absorbed}}$$

$$= \frac{m \cdot C_v [T_1 - T_4] - m \cdot C_v [T_2 - T_3]}{m \cdot C_v [T_1 - T_4]}$$

$$= \frac{M \cdot C_v [T_1 - T_4]}{M \cdot C_v [T_1 - T_4]} - \frac{M \cdot C_v [T_2 - T_3]}{M \cdot C_v [T_1 - T_4]}$$

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

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

Notes:-

Oxidant-

In chem oxidizing agent is a substance that has the ability to oxidize other substances. Cause them to lose electrons. Common oxidizing agents are oxygen, hydrogen peroxide & the halogen.

We know that for reversible adiabatic or Isentropic expansion process 1-2.

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left[\frac{1}{r}\right]^{\gamma-1} \quad \text{— (II)}$$

r = Expansion ratio = V_2/V_1.

Similarly, for reversible adiabatic or Isentropic Compression 3-4.

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left[\frac{1}{r}\right]^{\gamma-1} \quad \text{—— (III)}$$

r = Compression ratio = $\frac{V_3}{V_4} = \frac{V_2}{V_1}$.

From equation (II) & (III) we find that —

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left[\frac{1}{r}\right]^{\gamma-1} = \frac{1}{(r)^{\gamma-1}} \quad \text{or} \quad \frac{T_1}{T_4} = \frac{T_2}{T_3}$$

Substituting the value of T_1/T_4 in eqn (I) —

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

$$\text{----} \left[\frac{T_3}{T_4} = \frac{T_2}{T_1}\right] \text{-- (IV)}$$

Eg. 1. An engine, working on otto cycle, has a cylindrical diameter of 150 mm and a stroke of 225 mm. The clearance volume is 1.25×10^{-3} m³. Find the air standard efficiency of this engine. Take $\gamma = 1.4$.

Solution → Data given as —

d = 150 mm = 0.15 mtr.

l = 225 mm = 0.225 mtr.

$V_c = 1.25 \times 10^{-3}$ m³.

γ = 1.4.

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We know that Swept Volume—

$$V_s = \frac{\pi}{4} \times d^2 \times l = \frac{\pi}{4} \times (0.15)^2 \times (0.225)$$

$$= 3.976 \times 10^{-3}\ m^3.$$

Compression ratio —

$$r_c = \frac{V_s + V_c}{V_c}$$

where V_s = Swept Vol^m.
V_c = clearance Vol^m.

$$r_c = \frac{1.25 \times 10^{-3} + 3.976 \times 10^{-3}}{1.25 \times 10^{-3}} = 4.18$$

We know air standard efficiency —

$$\eta = 1 - \frac{1}{(r_c)^{\gamma - 1}} = 1 - \frac{1}{(4.18)^{1.4-1}} = 0.436 \times 100$$
$$= 43.6\%$$

Eg. 2 A Certain quantity of air at a pre. of 1 bar and temp 70°C Is Compressed reversibly and adiabatically Until the pre Is 7 bar In an otto cycle. 460 kJ of heat per kg of air added at Const Vol^m.

determine:—

I. Compression ratio of the engine.
II. Temp at the end of Compression.
III. Temp. at the end of heat addition.

Take for air C_p = 1 kJ/kg.
C_v = 0.707 kJ/kg.k.

Sol^n → Data given as.

P_3 = 1 bar

T_3 = 70°C. = 70 + 273 = 343 K

P_4 = 7 bar.

Q_{4-1} = 460 kJ

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$m = 1\,kg$

$C_p = 1\ kJ/kg.k$

$C_v = 0.707\ kJ/kg.k$

We know that ratio of specific heats.

$$\gamma = \frac{C_p}{C_v} = \frac{1}{0.707} = 1.41$$

1. Compression ratio of the engine: —

Let r_c = Compression ratio of the engine

$$r_c = \frac{V_3}{V_4}$$

We know that $P_3 V_3^{\gamma} = P_4 V_4^{\gamma}$

$$\frac{V_3}{V_4} = \left(\frac{P_4}{P_3}\right)^{1/\gamma} \Rightarrow r_c = \left(\frac{7}{1}\right)^{\frac{1}{1.41}}$$

$$= (7)^{0.709}$$

$$= 3.97$$

2. Temprature at the end of Compression: —

Let T_4 = Temp at the end of Compression.

$$\left(\frac{T_3}{T_4}\right) = \left(\frac{V_4}{V_3}\right)^{\gamma - 1} = \left(\frac{1}{r_c}\right)^{\gamma - 1} = \left(\frac{1}{3.97}\right)^{1.41-1}$$

$$= 0.568$$

$$T_4 = \frac{T_3}{0.568} = \frac{343}{0.568} = 604\,K \text{ or } 331^\circ C.$$

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3. Temprcaturre at the end of heat addition.

Let T_1 = temp at the end of heat addition

We know that heat added at Const Volm —(Q4-1)

$$460 = m \cdot C_v [T_1 - T_4]$$

$$= 1 \times 0.707 [T_1 - 604] \text{ KJ}$$

$$T_1 = 1255 \text{ k or } 982°C.$$ Ans

Diesel cycle

→ This cycle was devised by Dr. Rudolph Diesel In 1893.

→ The Ist Concept of diesel engine Is —

i) Higher thermal efficiency.

ii) Higher Compression ratio.

→ This Is an Important cycle on which all the diesel engine works.

→ It is also called Constant pressurre cycle. due to heat is rreceived at Constant prr.

→ The engine has airr enclosed In the cylinderr. whose walls arre perrfectly non-conductorr of heat but bottom Is perrfect Conductorr of heat.

→ Therre Is an Insulating Cap, hot body and Cold body which arre alterrnately brrought In Contact with the Cylinderr.

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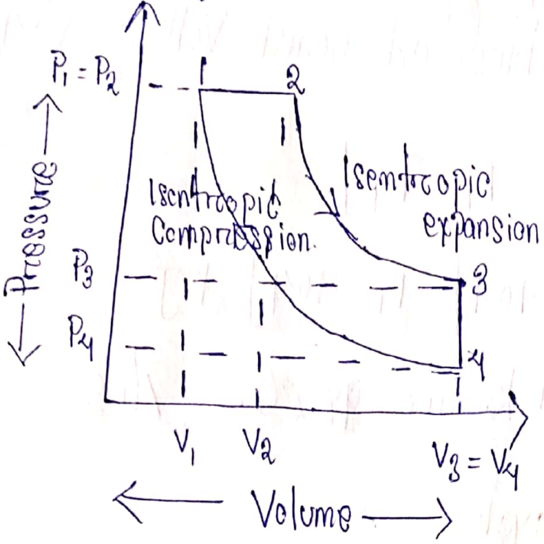
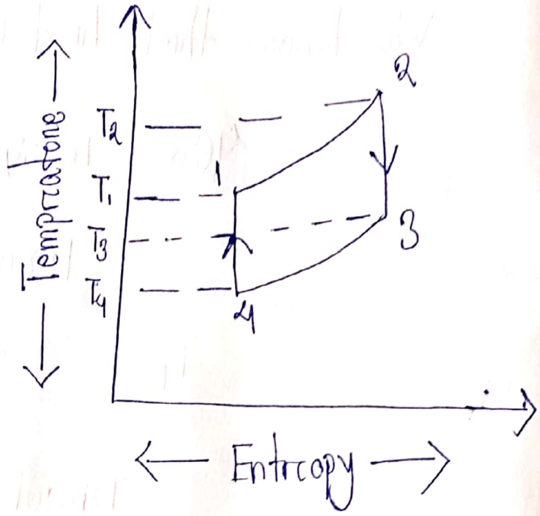
The Ideal diesel cycle consist of two reversible adiabatic or Isentropic. a Constant prc and a Constant Volm process.





At this point let $P_1 \rightarrow$ Prc, $V_1 \rightarrow$ Volm, T_1 - Temp of the air.

1. First stage. - Constant pressure heating.

The air Is heated at Const prc From Initial temp T_1 to a temp T_2. represented by the Curve 1-2.

2. Second stage :— [Reversible adiabatic or Isentropic expansion]

The air Is expanded reversibly and adiabatically From temp T_2 to T_3 as shown by Curve 2-3.

→ In this process No heat absorbed or rejected by the air.

3. Third stage - Constant Volm Cooling.

The air Is now cooled at Constant Volm From temp T_3 to T_4. as shown by Curve 3-4.

Heat rejected by the air $Q_{3-4} = m \cdot C_v [T_3 - T_4]$

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4. Fourth stage – Reversible adiabatic or Isentropic Compression.

The air is Compressed reversibly or adiabatically from temp T_4 to T_1 represented by Curve 4-1.

-> In this process no heat is absorbed or rejected by the air,

We see that the air has been brought back to its Original Condition of pr, Volm, & temp, thus Completing the Cycle.

Workdone = Heat absorbed – Heat rejected.

$$= mC_p[T_2 - T_1] - m \cdot C_v[T_3 - T_4]$$

Air standard efficiency :—

$$\eta = \frac{\text{Workdone}}{\text{Heat absorbed}} = \frac{M \cdot C_p[T_2 - T_1] - m \cdot C_v[T_3 - T_2]}{m \cdot C_p[T_2 - T_1]}$$

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Air standard efficiency = η = $\frac{\text{Workdone}}{\text{Heat absorbed}}$

$$= \frac{m \cdot C_p[T_2 - T_1] - m \cdot C_v[T_3 - T_4]}{m \cdot C_p[T_2 - T_1]}$$

$$= 1 - \frac{C_v[T_3 - T_4]}{C_p[T_2 - T_1]} = 1 - \frac{1}{\gamma}\left[\frac{T_3 - T_4}{T_2 - T_1}\right] \quad \text{— (I)}$$

Now let Compression ratio $r = \frac{V_4}{V_3}$.

Cut off ratio $\rho = \frac{V_2}{V_1}$.

Expansion ratio $= r_1 = \frac{V_3}{V_2} = \frac{V_4}{V_2} \quad \because (V_3 = V_4)$.

$$= \frac{V_4}{V_1} \times \frac{V_1}{V_2} = r \times \frac{1}{\rho} = \frac{r}{\rho}.$$

We know for constant pr. heating process 1-2 —

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow T_2 = \frac{V_2 \times T_1}{V_1} = T_1 \times \frac{V_2}{V_1}$$

$$= T_1 \times \rho \quad \text{— (II)}.$$

Similarly for reversible adiabatic or Isentropic expansion process 2-3.

$$\frac{T_3}{T_2} = \left(\frac{V_2}{V_3}\right)^{\gamma-1} = \left(\frac{1}{r_1}\right)^{\gamma-1} = \left(\frac{\rho}{r}\right)^{\gamma-1}$$

$$T_3 = T_2\left(\frac{\rho}{r}\right)^{\gamma-1} = T_1 \times \rho \cdot \left[\frac{\rho}{r}\right]^{\gamma-1} \quad \text{— (III)}.$$

For reversibly adiabatic or Isentropic Compression process 4-1.

$$\frac{T_1}{T_4} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} = (r)^{\gamma-1} \quad \text{or} \quad T_1 = (T_4)(r)^{\gamma-1} \quad \text{— (IV)}.$$

Substituting the value of T_1 in eqn (II) & (III) —

$$T_2 = T_4 \cdot (r)^{\gamma-1} \times \rho \quad \text{— (V)}$$

$$T_3 = T_4 \cdot (r)^{\gamma-1} \times \rho \cdot \left(\frac{\rho}{r}\right)^{\gamma-1} = T_4\, \rho^{\gamma} \quad \text{— (VI)}$$

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Now Substituting the Values of T_1, T_2 and T_3 In eq (1) —

$$\eta = 1 - \frac{1}{\gamma}\left[\frac{(T_4 \rho^{\gamma}) - T_4}{T_4 \cdot (r)^{\gamma-1}(\rho) - T_4 (r)^{\gamma-1}}\right]$$

$$= 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right] \quad \text{— (VIII).}$$

Notes: —

i) Efficiency of Ideal diesel cycle Is lower than otto cycle. F the Same Compression ratio.

ii) Due to cut-off ratio (ρ) Is always greater than (and hence the term within the eqn (VII) Increases wi Increase cut off ratio. Thus engine term Increses an efficiency reduced.

Eg. 1. In a diesel engine, the Compression ratio Is 13:1 and th Fuel Is Cut-off at 8% of stoke. Find the air standard eff of the engine. Take γ for air Is 1.4.

Solution → Data given as —

$$r = \frac{V_4}{V_1} = 13.$$

$$\gamma = 1.4.$$

Since Cut-off takes place at 8% of the stroke, there Volm at Cut-off.

$$V_2 = V_1 + 8\% \text{ of stroke Vol}^m.$$

$$= V_1 + 0.08\left[V_4 - V_1\right]$$

Let Us assume clearance Volm $(V_1) = 1\,m^3$.

$$V_4 = 13\,m^3 \qquad \left[\frac{V_4}{V_1} = 13\right]$$

and stroke Volm $V_4 - V_1 = 13 - 1 = 12\,m^3$

Volume at Cut-off $V_2 = V_1 + 0.08[V_4 - V_1]$

$= 1 + 0.08[12]$

$= 1.96\ m^3.$

We know Cut off ratio $= (\rho) = \frac{V_2}{V_1} = \frac{1.96}{1} = 1.96.$

Air standard efficiency —

$$\eta = 1 - \frac{1}{(r_c)^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$$

$$= 1 - \frac{1}{(13)^{1.4-1}}\left[\frac{(1.96)^{1.4}-1}{1.4(1.96-1)}\right] = 0.583$$

$= 58.3\%.$

mple-2

In an diesel engine the temp at the begining and end of Compression is 57°C and 603°C. The temp at the begining and end of expansion are 1950°C and 870°C. Determine the ideal efficiency of the cycle. $\gamma = 1.4$.

IF Compression ratio is 14 and the pre at the begining of the Compression is 1 bar. Calculate max pre in the cycle.

ution → Data given as —

$T_4 = 57°C = 57 + 273 = 330\ K.$

$T_1 = 603°C = 603 + 273 = 876\ K.$

$T_2 = 1950°C = 1950 + 273 = 2223\ K.$

$T_3 = 870°C = 870 + 273 = 1143\ K.$

$\gamma = 1.4.$

$r_c = V_4/V_1 = 14.$

$P_4 = 1\ bar.$

deal efficiency of the cycle —

$$\eta = 1 - \frac{1}{\gamma}\left[\frac{T_3 - T_4}{T_2 - T_1}\right] = 1 - \frac{1}{1.4}\left[\frac{1143 - 330}{2223 - 876}\right]$$

$= 0.569 = 56.9\%.$

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(ii) Max pre in the cycle:—

Let P_1 = Max pre in the cycle.

We know that For reversible. Compression —

$$P_1 V_1^{\gamma} = P_4 V_4^{\gamma}$$

$$P_1 = P_4 \cdot \left(\frac{V_4}{V_1}\right)^{\gamma} = 1 \times (14)^{1.4} = 40.23 \text{ bar.}$$

Eg.3 An Ideal diesel cycle has a dia 150 mm and stroke 200 mm. The clearance Volm is 10 percent of the Swept Volm. determine the Compression ratio and the air standard efficiency of the engine if the cut-off takes place at 6 % of stroke.

Solution → Data given as:—

d = 150 mm = 0.15 m.

l = 200 mm = 0.2 m.

V_c = 10 % of V_x = $0.1 V_x$.

Compression ratio —

We know that stroke Volume:—

$$V_s = \frac{\pi}{4} d^2 \cdot l = \frac{\pi}{4} \times (0.15)^2 \times 0.2 = 3.53 \times 10^{-3} m^3$$

$$V_c = 0.1 V_s = 0.1 \times 3.53 \times 10^{-3} = 0.353 \times 10^{-3} m^3$$

We know that Compression ratio —

$$r = \frac{\text{Total Volm}}{\text{clearance Volm}} = \frac{V_s + V_c}{V_c} = 11.$$

Air standard efficiency —

Since the cut off takes place at 6 % of the stroke therefore Volm of Cut off —

$$V_2 = V_1 + 0.06 V_s = V_c + 0.06 V_s$$

$$= 0.353 \times 10^{-3} + 0.06 \times 3.53 \times 10^{-3}$$

$$= 0.565 \times 10^{-3} \text{ m}^3.$$

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Cut-off ratio $\rho = \frac{V_2}{V_1} = \frac{V_2}{V_c} = \frac{0.565 \times 10^{-3}}{0.353 \times 10^{-3}} = 1.6$

We know that air standard efficiency —

$$\eta = 1 - \frac{1}{(r_c)^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$$

$$= 1 - \frac{1}{(r)^{1.4-1}}\left[\frac{(1.6)^{1.4}-1}{1.4(1.6-1)}\right] = 0.579$$

$= 57.3\%$ **Ans**

Dual Comburestion cycle: —

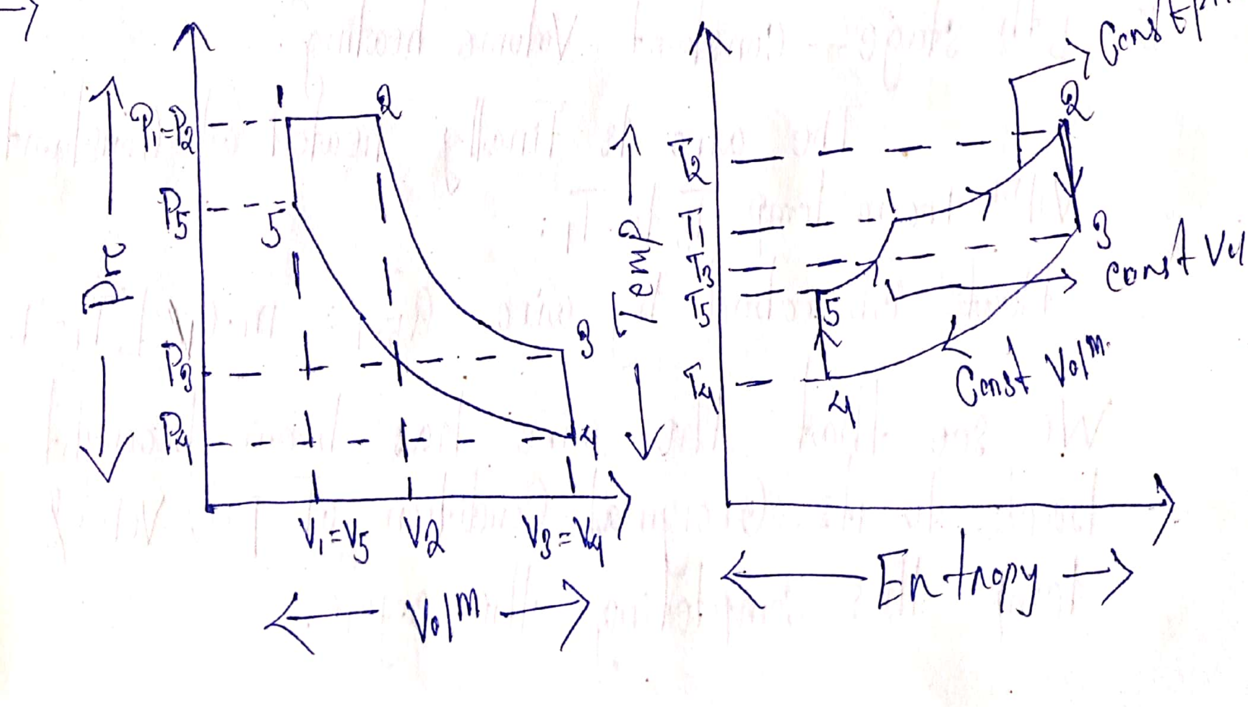
→ This cycle is a combination of otto and diesel cycle.

→ It is sometimes called semi diesel cycle bcz semi-diesel engine work on this cycle.

→ Heat is absorbed partly at a constant volm and partly at a constant prc.

→ Ideal dual comburestion cycle consist of two reversible adiabatic or isentropic, two constant volm and a constant prc process.

→



Let the engine cylinder contain m kg of air at point 1.
→ At this point let P_1, T_1, V_1 be the prc, volm & temp of the air.

1. 1st stage :— Constant prc heating.
The air is heated at constant prc from initial temp T_1 to a temp T_2 represented by curve 1-2 in Fig.
Heat absorbed by air = $m \cdot C_p [T_2 - T_1]$

2. 2nd stage — Reversible adiabatic or Isentropic expansion —
The air is expanded reversibly and adiabatically from temp T_2 to T_3. as shown by curve 2-3.

3. 3rd stage — Constant volm cooling.
The air is now cooled at constant volm from temp T_3 to T_4, as shown by curve 3-4.
Heat rejected by air $Q_{3-4} = m \cdot C_v [T_3 - T_4]$

4. 4th stage — Reversible adiabatic or Isentropic Compression.
The air is compressed reversibly and adiabatically from temp T_4 to T_5.
In this process, No heat is absorbed or rejected.

5. 5th stage — Constant Volume heating.
The air is finally heated at constant volm from temp T_5 to T_1.
Heat absorbed by air $Q_{5-1} = m \cdot C_v [T_1 - T_5]$

We see that the air has been brought back to its original condition of prc, volm & temp thus completing the cycle.

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We know Workdone = Heat absorbed - Heat rejected.

$$= m \cdot C_p[T_2 - T_1] + m \cdot C_v[T_1 - T_5] - M\, C_v[T_3 - T_4]$$

Comparision of otto, diesel and dual cycle :—

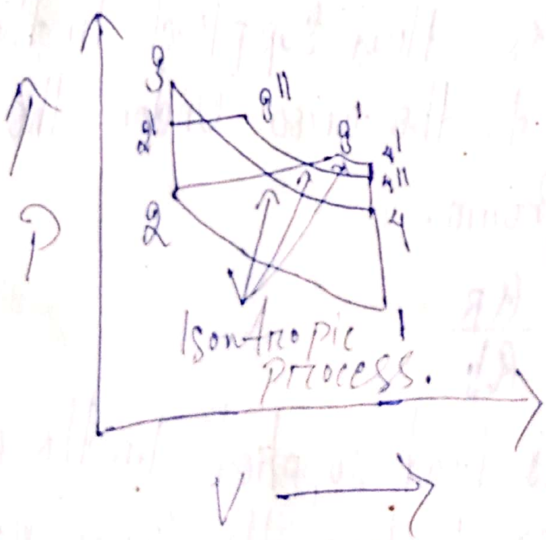
The Important Variable Factors which are used as the basis for Comparision of the cycle.

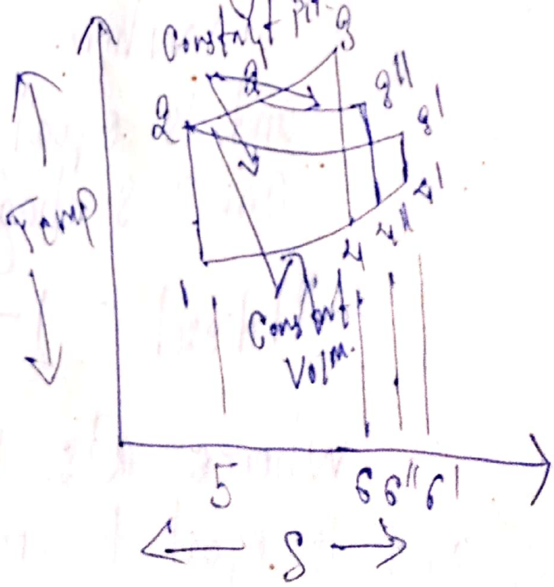
i) Compression ratio.
ii) Peak pressure.
iii) Heat addition.
iv) Heat rejection.
v) Net Work.

Same Compression Ratio and Heat addition :—

The otto cycle 1-2-3-4-1, the diesel cycle 1-2-3-4-1 and the dual cycle 1-2''-3''-4''-1 are shown Fig.

For the T-S diagram it Can be Seen that the area 5236 = Area 5236 = area 52236 as this area represents the heat Input which Is Same for all cycles.





All the cycles start from the Same Initial state point 1 and air is Compressed from state 1 to 2. as the Compression ratio is Same.

→ It is Seen from the T-S diagram for the Same heat Input, the heat rejection in otto cycle (area 5146) is minimum and heat rejection in diesel cycle (5146) is Maximum.

→ Otto cycle has highest work output & efficiency.

→ Diesel cycle has lowest efficiency. for Same Compression ratio. and heat addition.

→ otto cycle allows the working medium to expand more where as diesel cycle is least in respect of reason is heat is added before expansion in case of otto cycle last portion of heat is supplied to the fluid has relatively short expansion in case of diesel cycle.

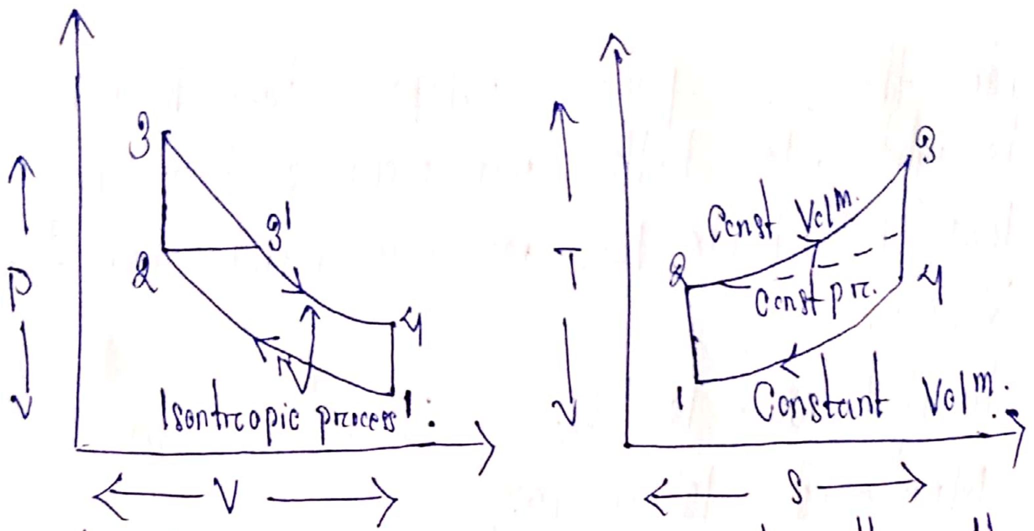
Same Compression ratio and heat rejection: —

$$\eta_{otto} = 1 - \frac{Q_R}{Q_S}$$

where Q_S = Heat Supplied In the otto cycle. and is equal to the area under the Curve 23. On T-S diagram.

$$\eta_{diesel} = 1 - \frac{Q_R}{Q'_S}$$

where Q'_S is heat Supplied In the diesel cycle and is equal to area under the Curve 23' on TS diag



The diesel cycle efficiency is greater than the otto cycle efficiency when both engines are built to with stand the same thermal and mechanical stress, same peak pr, temp and heat rejection.

Advantages and disadvantages of two stroke over four stroke cycle engine:—

1) Two stroke cycle engine gives two power stroke than four stroke cycle engine at same engine speed.

Notes → Two stroke cycle engine devlops 1.7 to 1.8 times the power developed by four stroke cycle engine of same dimension and speed.

2) For the same power developed a two stroke cycle engines are twice than the four stroke cycle engine. So the turning moment of a two stroke cycle engine is more uniform. two stroke cycle engine lighter flywheel thus it leads higher mechanical efficiency.

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iii) For the same power developed two stroke cycle engine is lighter, less bulky, and occupies less floor area thus it suitable for marine engine and other light vehicle.

iv) Initial cost is less.

v). Mechanism is simple.

vi) Much easier to start.

Disadvantages:—

i). Due to less compression ratio thermal efficiency less.

ii). Overall efficiency is also less, Inlet and exhust ports remain open simentaneously

iii) Consumption of lubricating oil is large bcz of high operation temp.

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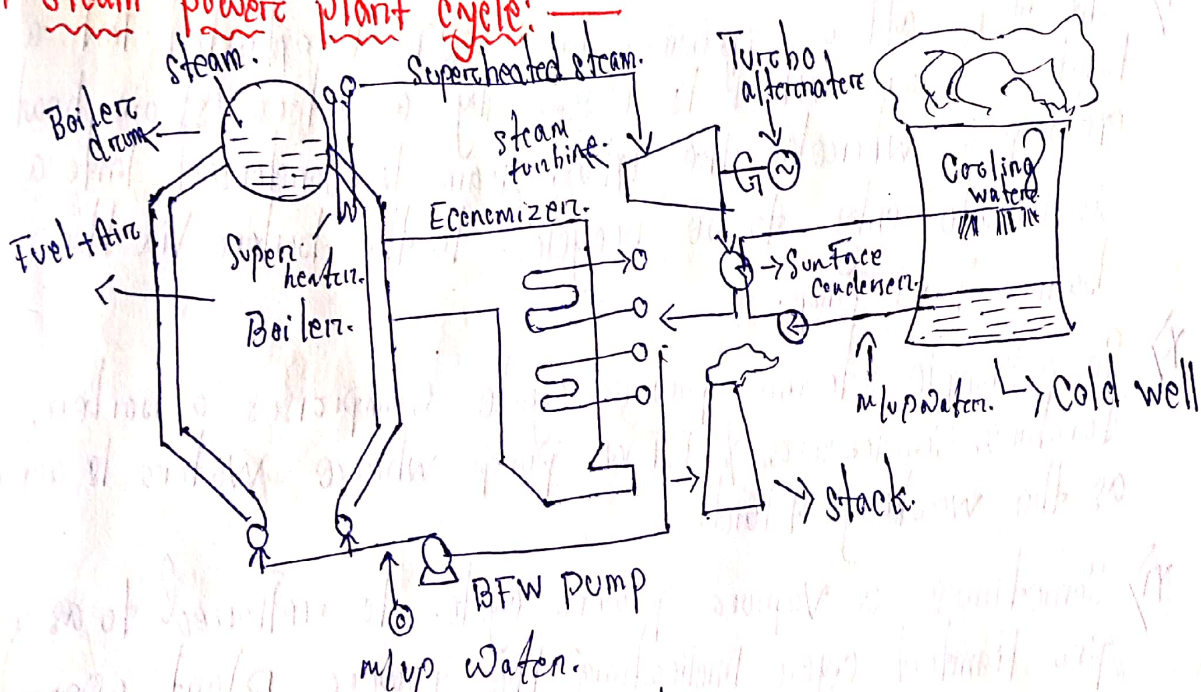
Chapter-1 Vapour Power cycle

Syllabus:—

1. Steam power plant layout.
2. Steam power plant cycle.
3. Carnot cycle.
4. Rankine Vapour cycle.
5. Modifications to Rankine Vapour cycle.
6. Qualities of Ideal Working Fluid for Vapour power cycle.
7. Binary Vapour cycle.

1. Steam power plant cycle:—



i) Water is the working Fluid.

ii) It undergoes a change of phase in the Course of cycle.

iii) Energy is released by the Continuous burning of the fuel in the Combustion chamber of the steam generating plant that Includes a boiler and Superheater.

iv). The working Fluid is charged to the boiler via a BFW Feed pump.

v) Heat is transferred to the water in the boiler where upon a high pr. & high temp saturated steam is generated in the boiler.

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vi) The dry saturated HP steam is converted into a HP superheated steam in the superheater.

vii). The high prc and high temp superheated steam is then allow to expand through steam turbine.

viii) As the steam passes over the blades of the turbine it sheds its enthalpy which is converted into shaft work of the turbine which then generates power from the turbo alternator coupled to the turbine.

ix) The steam after expansion in the S.T is exhusted into a total condenser which is essentially a water steam heat exchanger wherein the exhust steam is condensed into a condensate only to be recycled to the boiler via the boiler feed pump.

x) So a simple steam power cycle comprises a boiler, turbine, condenser, & BFW pump where water is acting as the working fluid.

xi) Sometimes a vapour power cycle is reffered to as a prc limited cycle indicating the power plant operates betn the prc limits.

The higher prc limit is the boiler prc.
The lowest prc limit is the condenser prc.

As the case of first approximation, the steam power plant cycle is idealized as a quasi-static process approximating an ideal heat engine cycle.

$$\sum_{cycle} Q_{net} = \sum_{cycle} W_{net}.$$

$$\text{or } Q_1 - Q_2 = W_T - W_P.$$

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Where Q_1 = Heat Input to water In the SGP

[BFW preheater + boiler + Superheater] In kJ/kg.

Q_2 = Heat rejected From the working Fluid.

[In the Surface Condenser] kJ/kg.

W_T = The work output [the shaft work on the steam turbine] kJ/kg.

W_P = The mechanical Work Input [the BFW pump Work] kJ/kg.

The efficiency of the Ideal Vapour Power cycle.

$$\eta_{cycle} = \frac{\Sigma_{net}}{Q_1}$$

Thermal efficiency:—

Thermal efficiency Is an Important Index of performance of a heat engine or steam power plant cycle.

→ It is obtained From 1st law $\eta = \frac{W}{Q_{input}}$.

Carnot cycle:—

An Ideal Vapour cycle would Follow a Carnot Vap cycle that Compromises two Isothermal & two adiabatic process.

→ In the Vap cycle the working Substance changes phases, these are attainably by two Internally reversible Isothermal process In the Form of boiling of the liq and Condensation of Vapour.

→ But the heat transfer From a high temp.

→ Reservoir as well as From the Condensing Vap to a low temp. reservoir will remain

→ externally Irreversible.

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Process 4-1 → Isothermal heat addition of water. The water is converted into a dry saturated steam.
Heat added = Q_{add}.

Process 1-2:— Isentropic expansion of the steam in the steam turbine i.e the steam is expanding adiabatically.
Heat interaction = Nil.
Positive work output = W.

Process 2-3 :— Isothermal heat rejection. Heat is extracted from the waste steam exhausted by the steam turbine to the condenser.
Heat rejected = Q_{rej}

Process 3-4 :— The steam water mixture is pumped to the boiler.
Input work = Pump work = W_p.
Net work output W_{net} = $W_{output} - W_p$.

Therefore $\eta = \frac{W_{net}}{Q_{add}} = \frac{Q_{add} - Q_{rej}}{Q_{add}} = 1 - \frac{Q_{rej}}{Q_{add}}$

$= 1 - \frac{m[h_2 - h_3]}{m[h_1 - h_4]}$

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

Rankine cycle:—

A rankine vapour cycle is based on a modified Carnot cycle to overcome its limitati
→ It consist of four steady flow process as b
Pred.

Important Notes: —

1) **Adiabatic process** — An adiabatic process occur without transfer of heat or Mass of substance betn a thermodynamic System and its Surrounding.
Only energy transfered to the Surrounding only.

2) **Isentropic process** — A process during which the entropy remains Constant is called Isentropic process.

3) **Reversible adiabatic process** —
Adiabatic process occurs without heat transfer with its Surrounding. In Isentropic process entropy remain Constant it is known as reversible adiabatic process.

4) **Isothermal process:** — An Isothermal process is a change of a System in which temp remain Constant. ($\Delta T = 0$).
→ This typically occur when a system in Contact with an outside thermal reservoir.

5) **polytropic process:** — In polytropic process any reversible process or any open or closed system of gas or Vapour which Involves both heat & work transfer. Such that a specified Combination of properties were maintained throught the process.

Rankine cycle with Superheated steam: —

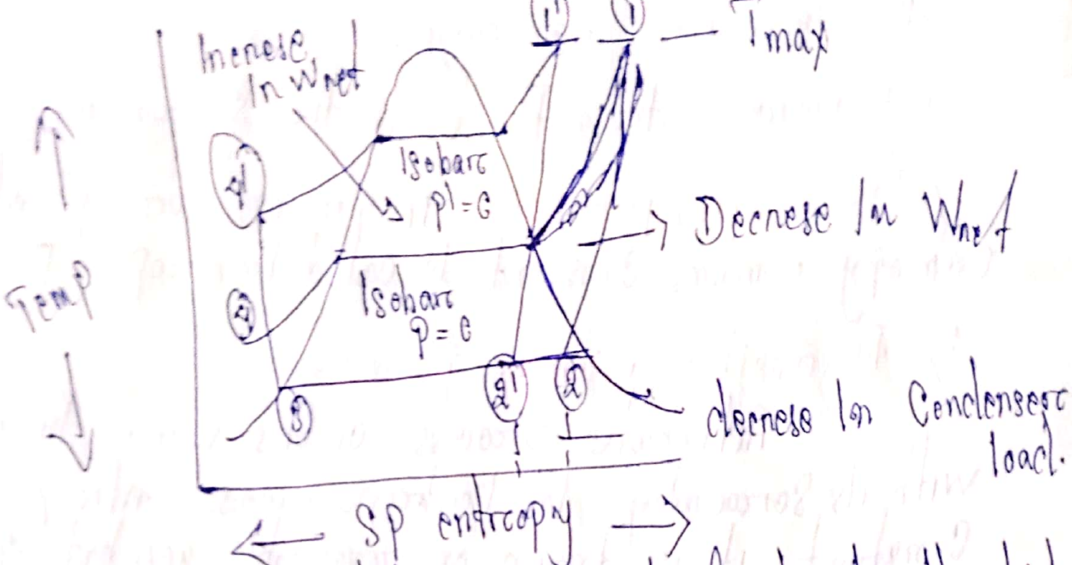
Effect of Increasing prc while being temp Constant —

The steam prc at the SHP exit is Increased from P to P' while maintaining a Constant Superheated steam temp i.e $T_1 = T_1'$.
The operating Condition of the Condenser remain Unchanged.
The Work output remains nearly the Same i.e there is

no drastic gain in the work output.

$\Delta W_{output}.P$ = area 1-2-3-4-1 Δ output P'

= area 1'-2'-3'-4'-1' $\Delta W_{output} P \approx \Delta W_{output}$



However, the heat rejected area is reduced due to the higher Pr, steam utilization 2-2'-5-6.

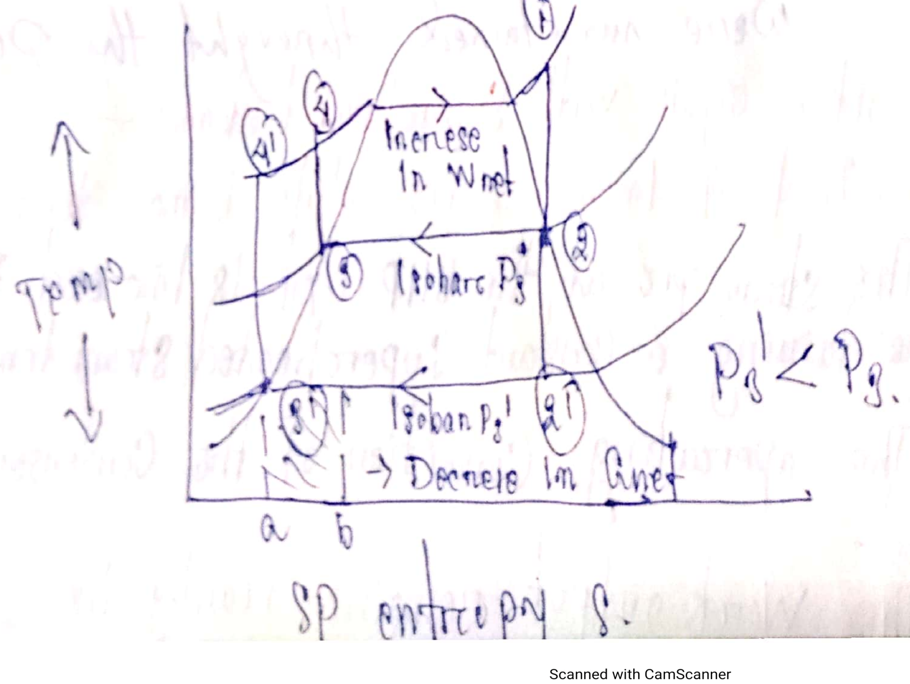
This Increase the efficiency of the cycle.

$$\eta = \frac{Q_{add} - Q_{rej}}{Q_{add}} = 1 - \frac{Q_{rej}}{Q_{add}}.$$

Rankine cycle with Superheated steam:-

Effect of reducing Const Pr:-

If the Condenser pr is reduced the net work is Increased by area 2-2-2'-3'-4'-4-3-2.



When the operating prc of the Condenserc Is decresed. the heat added area automatically Imcrese and at the Same time Rrej Is also decreses with the net effect. the cycle efficiency Imcreses.

Qualities of Ideal Working Fluid For Vapour Power cycle—

The described characteristics of the working Fluid Im a Vapour Power cycle to ensure the best thermal efficiency of the cycle are:—

1) The max permissible limits of operating prc and temp Is set by the metallurgy boiler and super heaters tubes, pipes lines, and headers. The working Fluid should better have a high critical temp. So that the saturation prc at the max permissible working temp Is relatively low. It should have a large enthalpy of evaporation at that prc.

2) To draw Vaccum Im the Condenser Is another Costly setup that Calls For adequate maintainance as less than the desired Vaccum level will tell On the overall cycle efficiency. So it Is better that the Saturation prc at the temp of heat rejection should lie above the atm prc.

3) The sp heat of liq should be low so as to boil It out with a relatively little heat transfer. However low sp heat means a low enthalpy Content - not a desirable Criterion For a high cycle efficiency.

4) The Freezing point of the working Fluid should be below the ambient temp. to avert pipeline chocking due to Freezing.

5) The Working Fluid must be abundantly available to buy economy.

6) It must be non-toxic, non-Corrossive, and not excessively Viscous.

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Binary Vapour Power cycle:— A binary cycle comprises two differ cycle working in tandem with two different fluids so that the sink of one becomes the source of other.

The highest achivable efficiency is that of Carnots –

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

which necessiates heat absorption at a const temp. T_1.
Heat rejection at a const temp = T_2.

Now the efficiency is fixed by T_1 as T_2 is fixed by the natural sink.

This makes its ~~impressive~~ rative that T_1 should be as large as possible consisting with the vap being saturated.

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Chapter - 3 Fuels & Combustion

Syllabus:—
i) HydroCarbon Fuels
ii) Combustion reaction [Explanation only]
i) Concept of Stoichiometric Combustion, Complete Combustion and InComplete Combustion.
iii) Enthalpy of Formation, enthalpy of reaction.
iv) Heating Values of Fuels
v) Quality of IC Engine, Fuels octane No & Cetane No.

HydroCarbon Fuels:—

Carbon and Hydrogen Combine In different proportion and molecular structure to Form a hydro Carbon fuels.

ii) The Carbon to hydrogen ratio which Is the One of the Important parameter and their nature of the bonding determine the energy characteristics of the hydro Carbon Fuels.

iii) Hydro Carbon Fuels depends upon the no of Carbon and hydrogen atoms the petrolium products are classified Into different groups.

iv) Difference of physical & chemical properties betn the different types of hydro Carbon depend on their chemical Composition and affect mainly the Combustion process.

v) The properties of Fuel and air required In the engine.

	Family of hydrocarbon	General Formulla	Mol st	sat/unsat	stability
1)	ParaFinn.	C_nH_{2n+2}	Chain	Sat	stable.
2)	OleFin	C_nH_{2n}	chain	Unsat	Un stable.
3)	Nephthence	C_nH_{2n}	Ring	Sat	stable.
4)	Aromatic	C_nH_{2n-6}	Ring	Highy. Unsat.	Most Unstable.

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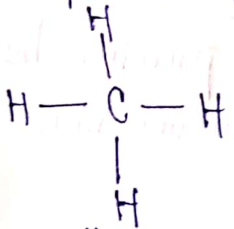
1) Parrafinn Series :—

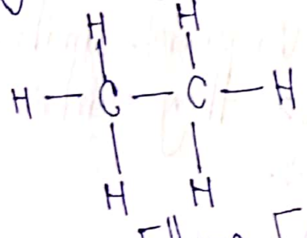
i) Normal parrafin hydro Carbon are of straight chain molecular structure.

ii) Represented by ch. Formulla C_nH_{2n+2}.

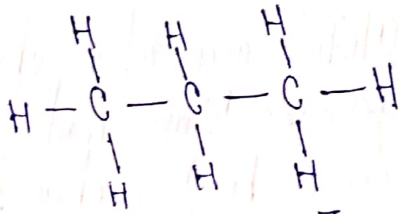
iii) The molecular structures of the 1st Few members of the parrafin Family of hydro-Carbons are —



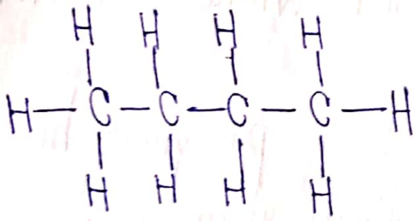
Methane [CH_4]



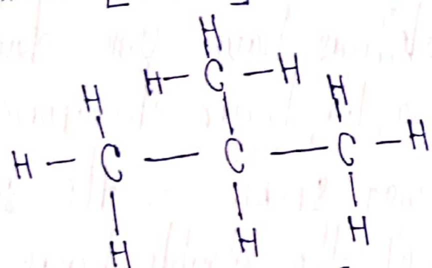
Ethane [C_2H_6]



Propane [C_3H_8]



Butane [C_4H_{10}]



Isobutane [C_4H_{10}]

In these hydro Carbon the valency of all the Carbon atoms Is Fully Utilized by Single bonds with hydrogen atoms.

→ Parrafin hydro Carbons are saturated Compounds and the characteristically Very stable.

→ A Variation of the parrafin Family Consist of an open chain structure with an attached branch and Is Usually termed a branched chain parrafin.

→ The hydro Carbons which have the Same chemical Formulla but different structural Formulae known as Isomers.

→ Isobutane has the Same general ch Formula and Molecular Weight as butane but a different molecular structure and physical characteristics.

→ It is called an Isomer of butane and Is known as Isobutane.
Isoparrafins are also stable Compounds.

Assignment —

i) what is Molecule.

ii) what Is molecular weight.

ii) Olefin Series —

1) Olefin are also chain Compound. Similar to parrafin bcz ~~of the~~ ~~presence~~ Unsaturated, bcz they Contain One or more double bonds betn Carbon atoms.

2) ch. Formulla Is C_nH_{2n}.

3) Mono-olefins have One double bond where as diolefin have two In their structure.

4) It is not stable as the single bond parafins bcz of the presence of the double bonds In their structure.

5) These are readily Oxidize In storage to Form gummy deposites.

6) Hence olefin Content In Certain petrolium product Is kept low by specification.

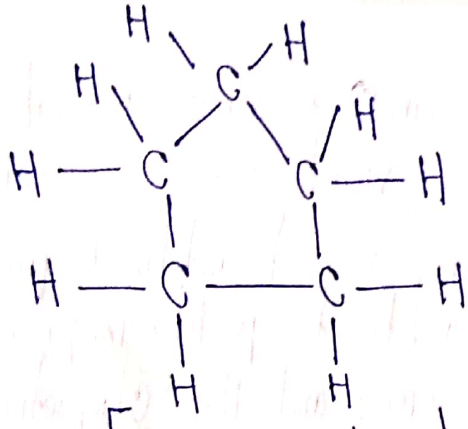
iii) Naphthene series: —

i) Napathene have the Same ch. formulla as olefin Series of hydro Carbons but hv a ring structure and there Fore. they called cyclo-parrafins.

ii) They are saturated and tends to be stable.

iii) Napathenes are saturated Compounds where as olefins are Un-saturated.

iv). Cyclo pentane Is One of the napathene Series. [C_nH_{2n}



[C_5H_{10} Cyclopentane]

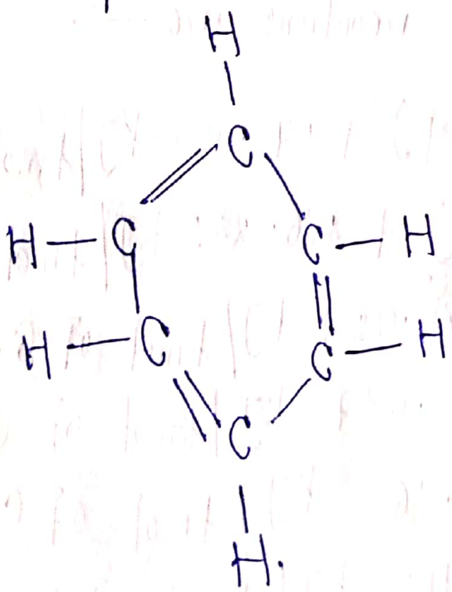
Notes —
peculiar —
Toluene -

v) Atomic structure are ring saturated having a benzene molecule as their central structure, and hv a ch formula C_nH_{2n-6}.

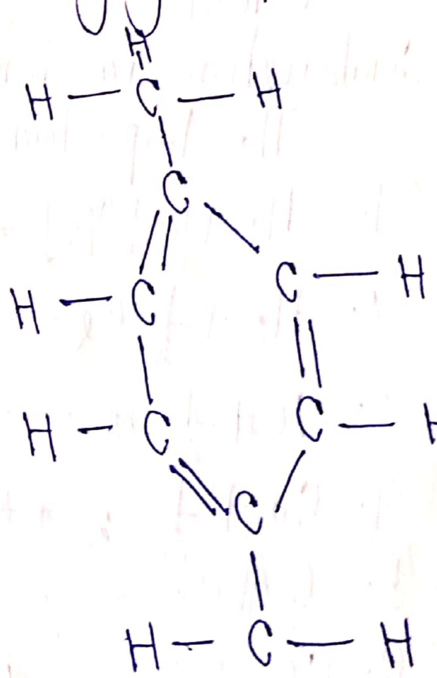
vi) Presence of double bond indicates that they are unsaturated. peculiar nature of these double bonds cause them to be more stable than other unsaturated compounds.

vii) Various atomic structure are formed by replacing one or more of the hydrogen atoms of the benzene molecules with an organic radical such as parrafins, Naphothenes, and olefins.

viii) By adding methyl group (CH_3) benzene, is converted to toluene ($C_6H_5CH_3$), the base of the preparation of Trinitrotulene (TNT) which is a highly explosive compound.



[Benzene]



[Toluene]

The above Families of hydro Carbons Some general characteristics due to their molecular structure which are summarised below.

1). Normal paraffins exhibit the poorest antiknock quality when used in an SI engine. but the antiknock quality improves with the increasing no of Carbon atoms and the compactness of the molecular structure. The atomics offer the best resistance to knocking in SI Engines.

ii) For CI engines, the order is reversed i.e the normal parafins are the best Fuels and aromatic are the least desirable.

iii) As the no of atoms in the molecular structure increases, the boiling temp increases, Thus Fuels with fewer atoms in the molecule tend to be more volatile.

iv) The heating value generally increases as the proportion of hydrogen atoms of Carbon atoms in the molecule increases due to higher heating value of hydrogen then Carbon, Thus parafins have the highest value and the aromatics the least.

Combustion reactions:—

The Important Combustion reactions are —

1. $H_2 + O_2[1/2] \longrightarrow H_2O(vap) + 242.050$ kJ/kmol of H_2
2. $H_2 + \frac{1}{2} O_2 \longrightarrow H_2O(liq.) + 286.223$ kJ/kmol of H_2
3. $Co + \frac{1}{2} O_2 \longrightarrow Co_2 + \sout{285}\ 283.637$ kJ/kmol of C.
4. $Co + \frac{1}{2} O_2 \longrightarrow Co_2 + 285.637$ kJ/kmol of Co.
5. $C + O_2 \longrightarrow Co_2 + 408.860$ kJ/kmol of C.
6. $Co_2 + C \longrightarrow 2Co - 162.413$ kJ/kmol of C.
7. $C + H_2O \longrightarrow Co + H_2 - 118.827$ kJ/kmol of C.

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8. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 805.597$ KJ/kmol of CH_4.

9. $C_2H_2 + 2\frac{1}{2}O_2 \rightarrow 2CO_2 + H_2O + 1308.019$ KJ/kmol of C_2H_2.

10. $C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O + 1447.864$ KJ/kmol of C_2H_4.

11. $H_2S + 1\frac{1}{2}O_2 \rightarrow H_2O + SO_2 + 522.747$ KJ/kmol of H_2S.

12. $S + O_2 \rightarrow SO_2 + 299.252$ KJ/kmol of S.

Stichometric Comburstion :—

i) Stichometric Comburstion takes place in a stichometric mixture of a Fuel & Oxygen.

2) A stichometric mixture of a Fuel and oxygen Contain the precise amount of oxygen to Completely burn out all the Comburstion elements present in the Fuel.

3) This Implies Conversion of all Contemt to CO_2 and all H Content to H_2O.

4) There is neither an excess or nor deficiency of oxygen present in the reaction of mixture and as a result there is no free oxygen present in the reaction products. while all the Combustibles in the Fuel are Completely Oxidized. For Instance the stichometric of Comburstion of n butane is.

$$C_4H_{10} + 6\frac{1}{2}O_2 = 4CO_2 + 5H_2O.$$

The equation is balanced with respect to all elements and present the prices

Complete Comburstion :—

Complete Comburstion means Complete Conversion of all Combustible element of a Fuel into its stable oxides and as such as the enter Carbon of the Fuel now exists CO_2 and hydrogen H_2O in the products of Comburstion.

ii) All practical Comburstion process Use air as a Source of oxygen, the oxidizer of the Fuel, with 1 kmol of oxygen, there are 79/21 kmol of nitrogen.

Comburstion eqn of Hydrogen :—

$2H_2 + O_2 \rightarrow 2H_2O$ becomes.

$2H_2 + O_2 + \frac{79}{21} N_2 \rightarrow 2H_2O + \frac{79}{21} N_2$.

2 Vol 1 Vol $\frac{79}{21}$ Vol 2 vol 79/21 Vol [by Volm]

2 mol 1 mol 79/21 mol 2 mol $\frac{79}{21}$ mol [by Mole]

4 kg 32 kg $\frac{79}{21} \times 28$ kg 2×18 kg $\frac{79}{21} \times 28$ kg [By Mass]

That is

4 kg of H_2 + 32 kg of O_2 + $\frac{79}{21}$ kg of N_2

$\rightarrow 2 \times 18$ kg H_2O + $\frac{79}{21} \times 28$ kg of N_2.

1 kg H_2 + 8 kg O_2 + 26.33 kg $N_2 \rightarrow$ 9 kg H_2O + 26.33 kg

2. The Complete Comburstion eqn of Carbon —

$C + O_2 + \frac{79}{21} N_2 \rightarrow CO_2 + \frac{79}{21} N_2$.

0 Volm 1 Volm $\frac{79}{21}$ Vol $\rightarrow$ 1 Vol $\frac{79}{21}$ Vol

1 mol 1 mol $\frac{79}{21}$ mol $\rightarrow$ 1 mol $\frac{79}{21}$ mol. [by mol]

12 kg 32 kg $\frac{79}{21} \times 28$ kg $\rightarrow$ 44 kg $\frac{79}{21} \times 28$ kg [By Mass]

That Is

12 kg C + 32 kg O_2 + $\frac{79}{21} \times 28$ kg N_2

$\hookrightarrow$ 44 kg CO_2 + $\frac{79}{21} \times 28$ kg N_2.

1 kg C + 2666 kg O_2 + 8777 kg N_2

$\hookrightarrow$ 3666 kg CO_2 + 8777 kg N_2.

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Concept of black body — A black body is an object that absorbs all the radiant energy reaching its surface.

→ No actual body is perfectly black, a black body has following properties —

1. It absorbs all the incident radiation falling on it and doesn't transmit or reflect regardless of wavelength and dirⁿ.
2. It emits max amount of heat radiation at all wavelength at any specified temp.
3. It is a diffuse emitter.

Kirchhoff's law :

The law states that any temp the ratio of total emmisive power E to the total absorptivity α at is a constant for all substances which are in thermal equlibrium with enviroment.

Let us consider a large radiating body of surface area A with which encloses a small body of surface area A_1.

Let the energy fall on unit surface of the body at a rate E_b by considering generality of bodies.

$$E_b = \frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E}{\alpha}$$

Also, as per the defination of emmisivitye, we have

$$\boxed{\varepsilon = \frac{E}{E_b}} \qquad \boxed{\varepsilon = \alpha}$$

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Absorption, Reflection & transmission :—

When Incident radiation is called Irradiation Impinges on Surface, three things happen, a part is reflected back, a part is transmitted through and the remainder is absorbed, depending upon the characteristic of the body.

By Conservation of energy particle $G_a + G_r + G_t = G$.
dividing both Sides by G we get $\frac{G_a}{G} + \frac{G_r}{G} + \frac{G_t}{G} = \frac{G}{G}$.

$$\boxed{\text{So } \alpha + \rho + \tau = 1}$$

Black body → For perfectly absorbing body. $\alpha = 1, \rho = 0, \tau = 0$. Such a body is Called black body.
→ It is one in which neither reflect nor transmit any part of the Incident radiation but absorb all of it.

White body →
If all the Incident radiation Falling on a body are reflected. it is called white body.
→ It is one which ~~neither~~ gases such as hydrogen, oxygen, nitrogen have a transmitivity of practically Unity.

Gray body → If the radiative properties of a body are assumed to be Uniform over the entire wavelength spectrum. then Such a body is called gray body.
- It is also defined as the One whose absorptivity of a Surface does not vary with temp and Wavelength. of the Incident radiation.

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Planck's law:— In 1900 Max planck showed by quantum arguments that the spectral distribution of the radiation Intensity of a black body is given by—

$$(E_\lambda)_b = \frac{2\pi c^2 h \lambda^{-5}}{\exp\left(\frac{ch}{\lambda k T}\right) - 1}$$

where $(E_\lambda)_b$ = Emmisive power of a black body.
c = Vel of light in Vaccum, $2.998 \times 10^8 = 3 \times 10^8$ m/s.
h = planck's Constant $= 6.625 \times 10^{-34}$ J
λ = Wavelength, μm.
k = Boltzman Constant. $= 1.3805 \times 10^{-23}$ J/K.
T = abs temp K.

Unit of $(E_\lambda)_b$ = w/m². μm.

Quite often the planck's law is Written as—

$$(E_\lambda)_b = \frac{C_1 \lambda^{-5}}{\exp\left[\frac{C_2}{\lambda T}\right] - 1}$$

$C_1 = 2\pi c^2 h. = 3.742 \times 10^8$ w. μm⁴/m².

$C_2 = \frac{ch}{k} = 1.438 \times 10^4$ μmK.

It provides quantitative results for the radiation from a black body.

Maxwell eqn:—

Now let us derive the maxwell eqn—
We know that for a system Undergoing an Infinitesimal reversible process from one equilibrium state to another.

1. Internal energy — $du = dq - dw$.

$= T \cdot ds - p \cdot dv$. — (I)

The above eqn (I) is of the Form —

$dz = M dx + N dy$.

$M = T \cdot N = -P$ ($x = s$ and $y = v$).

$$\left(\frac{dT}{dv}\right)_s = \left(\frac{\partial s}{\partial s}\right)_v \quad \text{—— (II)}$$

2. Enthalpy $dH = du + p(dv)$.

$= du + pdv + v \cdot dp$.

$= (Tds - pdv) + pdv + v \cdot dp$. [$du = Tds - p \cdot dv$]

$= Tds + v \cdot dp$. —— (III)

The above eqn (III) is of the Form —

$dz = M \cdot dx + N \cdot dy$.

$M = T$, $N = V$, $x = S$, and $y = p$.

$$\left(\frac{dT}{dp}\right)_x = \left(\frac{\partial v}{ds}\right)_p \quad \text{— (IV)}$$

3. Helmoholtz Function (A) —

$dA = du - Tds$

$= du - Tds - SdT$

$= (Tds - pdv) - Tds - SdT$ [$du = Tds - pdv$]

$= -p \cdot dv - s \cdot dT$ — (V).

The above eqn (V) is of the Form -

$dz = M \cdot dx + N \cdot dy$.

$M = -P$, $N = -S$, $x = V$, $y = T$

$$-\left(\frac{\partial P}{\partial T}\right)_V = -\left(\frac{\partial s}{\partial v}\right)_T$$

$$-\left(\frac{\partial P}{\partial T}\right)_V = -\left(\frac{\partial s}{\partial v}\right)_T \quad \text{— (VI)}$$

4. Gibbs Function (G) —

$dG = dH - d(TS)$

$= dH - Tds - SdT$

$= (Tds + v \cdot dp) - Tds - SdT$

$= v \cdot dp - s \cdot dT$. — (VII)

The above eqn (VII) is of Form -

$dz = M \cdot dx + N \cdot dy$.

$M = V$, $N = -S$, $x = P$, $y = T$

$$\left(\frac{dv}{dT}\right)_P = -\left(\frac{\partial s}{\partial p}\right)_T \quad \text{— (VIII)}.$$

Eq (II), (IV), (VI), & (VIII) known as Maxwell's eqn in thermodynamics.