

IC-ENGINES

mean @nil
Sir

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Reference Book :

I. Automobile Mechanics by Joseph Heitner

II) I.C Engines by V. Ganeshan.

III) I.C Engines by Mathur and Sharma.

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CYCLE :

- # When a system after undergoing a no. of processes is able to attain its original condition (original pressure, volume, & Temp) it is then said to be completed a cycle.

↳ Temp. is defined as degree of Hotness and Coldness.

- IF two parameters become equal to original condition then all parameters are equal at original condition.

- IF volume increases or decreases within a cylinder then mass will be constant.

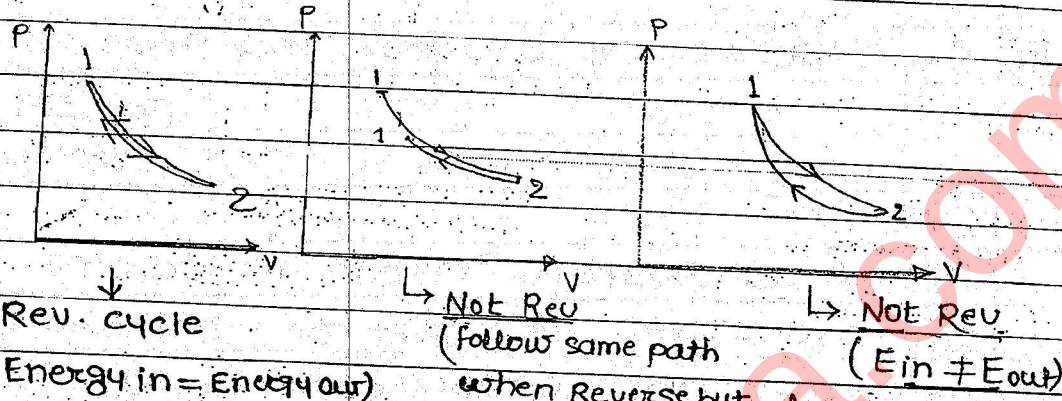
- order of Heat addition, Heat Rejection, Expansion and compression are fixed if we change order then cycle is not completed

HA > Expansion - HR - comp.

↳ order in Engine

and opposite order in Refrigeration & HP.

- Rev. process is theoretical (No loss, No Friction etc) and Irr. process is actual.



→ If the cycle is not completed then continuous work can not be obtained.

→ The Different operation required for a complete cycle are:

Heat addⁿ - Heat Rejection - Expansion - Compression

→ The order in which the different operation must be carried out must be follow.

Heat addⁿ

Expansion (work output)

Heat Rejected.

Compression.

IDEAL CYCLE :-

→ An ideal cycle is a cycle in which the expansion & compression processes are Rev. and adiabatic (Isentropic)

→ No completed
→ अंतिम → at Rest:

Quasi-static process:-

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→ Theoretical process, not actual.
→ Not possible. (only use for calculation become more easy)

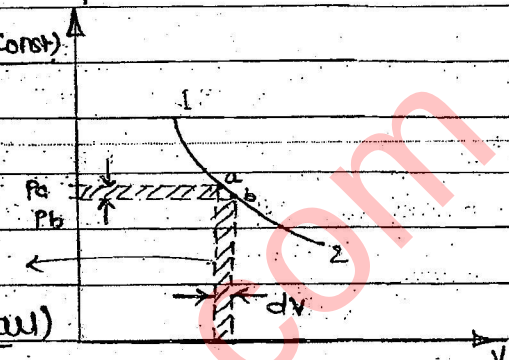
$P_a - P_b = \text{negligible (so take as const.)}$

$dW = P dv$

$W = \int_1^2 P dv$

$dx \rightarrow 0$

changes: → ZERO (very small)



→ When a system undergoes in a such the manner that the final condⁿ is nearest to original or equilibrium condition — then process is defined as quasi-static process.

→ It is to be noted that the quasi-static process is the same as a differential small change in calculus.

→ Quasi-static process is used under condⁿ when a value is which is to remain const. keep on varying.

REV. and IRR. CYCLE

For 1st Law of TD, work and Heat are mutual transfer for a cycle. ($\text{cyc} dQ = \text{cyc} dW$)

i.e. $dQ_1 + dQ_2 + dQ_3 + dQ_4 + \dots = dW$

→ For addition = +ve
For Rejection = -ve.

$\therefore \{ (dQ_1) + (dQ_3) \} - \{ - (dQ_2 + dQ_4) \} = dW$

→ Heat added — Heat Rejected = work.

→ Only Carnot cycle is Rev. cycle. (Otto cycle, Diesel cycle, Rankine cycle etc is a 2 ideal cycle but not a Rev. cycle)

I. ↳ Externally Reversible cycle:-

When there is the energy balance b/w system and surrounding then the cycle is called externally Rev. cycle.

In this case: (Heat addⁿ - Heat Rejection = work done) should be completely satisfied

II) ↳ Internally Rev. cycle:-

When the temp. Remains const during the heat addⁿ & heat Rejection process then cycle is said to be internally Rev. cycle.

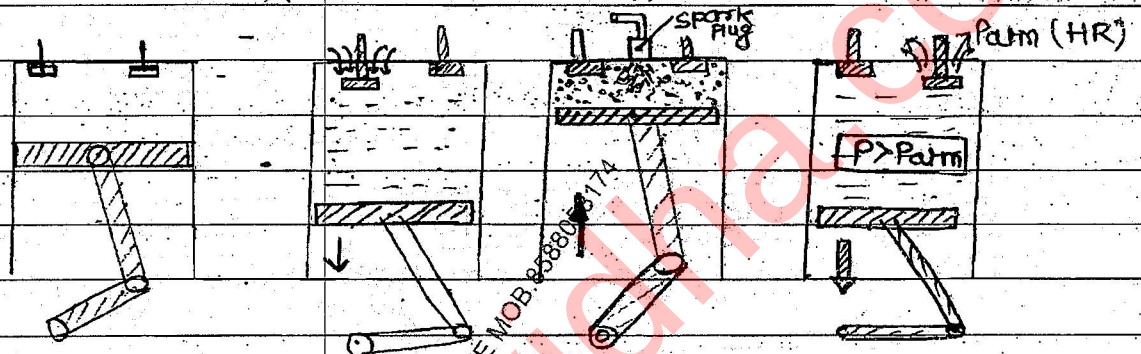
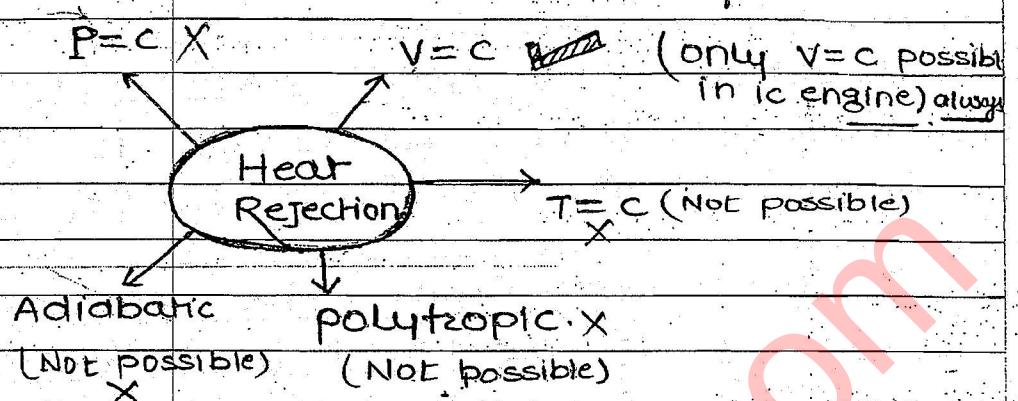
↳ When a cycle is internally & Externally Rev. it is then said to be completely Rev. cycle.

↳ Only Carnot cycle is an ideal Rev. cycle. All other ideal cycle are (including Otto cycle, Diesel cycle, Dual cycle etc) irreversible.

- Polytropic process occurs automatically when the process is adiabatic & some amount of heat is transfer then it becomes polytropic process.

→ piston is always in motion, which takes energy from gas (fuel) OR flywheel.

- which process is preferred for Heat Rejection:-



- @ → HR is possible only in const. vol^m. because when piston is at ^SBDC then 90-95% gases escape which is at const vol^m exhaust
- In compression stroke, only 5-10% gas is remain to forced by piston 90-95% gas is remove before the piston changing dirⁿ.

Different Ideal cycles for IC Engines :-

- The following operation is common for all

- i) isentropic expansion
- ii) Heat Rejection at const. vol^m.
- iii) Isentropic compression.

It is only the heat addⁿ that will be different for 2 ideal cycle.

↳ when Heat addⁿ is takes place on const vol^m the cycle is known as const vol^m process or Otto cycle.

→ When the heat addⁿ takes place at const. press, the cycle is known as the const. press. cycle, OR "DIESEL cycle"

→ In another cycle, the heat addⁿ takes place 1st at const vol^m & then at const press. Such a cycle is known as the "Dual compression cycle" OR "semi-Diesel cycle".

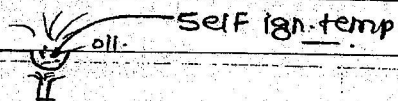
→ Temp. in Diesel cycle is 2-2.5 times more than petrol engine. (because comp. Ratio is 2-3 times)

— Temp ↓ → Knocking

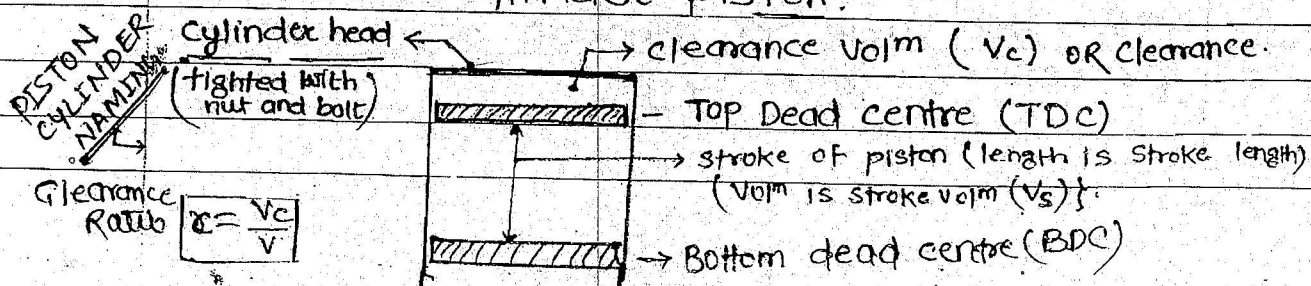
→ Spark plug is not present in Diesel engine necessary condⁿ

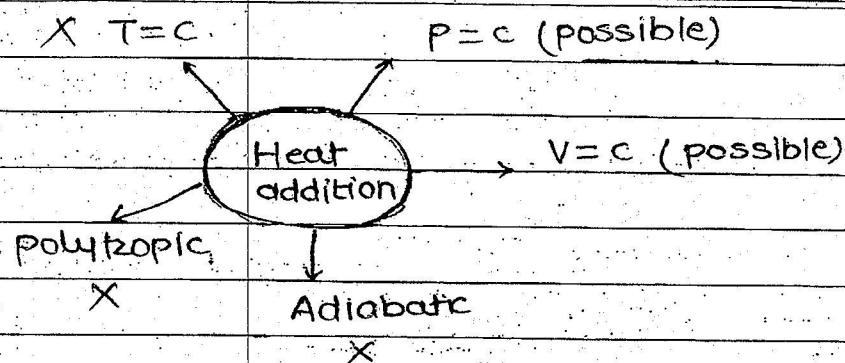
— Fuel injector is also known as nozzle

— The temp. at which fuel is burnt is called self ignition temp.



— when we sent^{more} fuel in piston cylinder then press & vol^m both increases and if sent less fuel then vol^m increases but some prep provide the increase the vol^m so prep decrease so at max^m & min^m a point occurs at const prep occurs which amount of fuel is sent to cylinder piston.





— Spark plug is not compulsory. Spark plug is used when the temp is not reached at self ignition temp. of fuel.

— In dual cycle, Heat addⁿ is at const vol^m and const press. If we use concept of petrol engine ($v=c$) a spark plug is used so in this way we use a spark plug in dual cycle at const vol^m process which is wrong (wrong).

WORKING OF "CONST. VOL^m" OR THE "OTTO CYCLE":—

I) The adiabatic compression process (1-2)

(V =decreases, P =increases, T =inc, S =const)

II) The const. vol^m Heat addⁿ process (2-3).

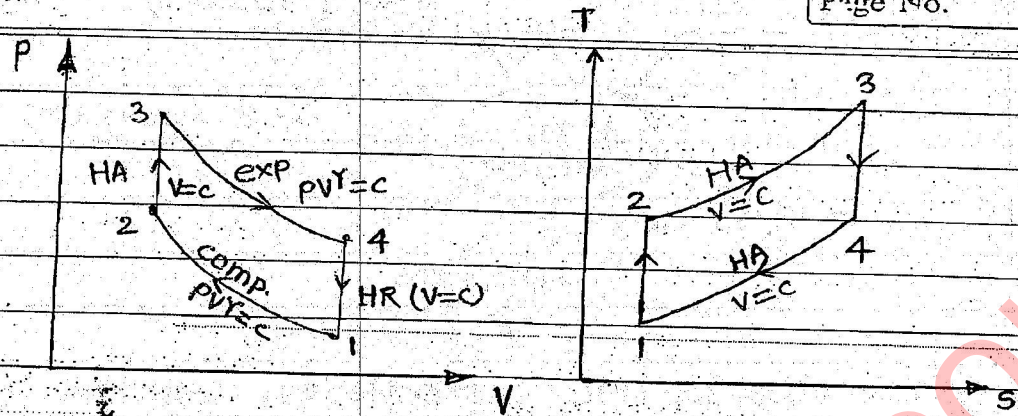
($V=c$, P =increases, T =inc, S =inc.)

III) The ^{adiabatic} Expansion process (3-4)

(V =inc, P =dec, T =dec, S =const)

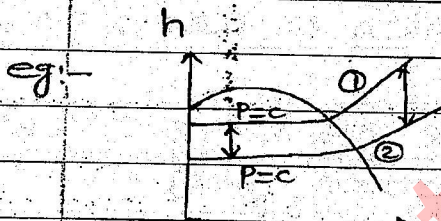
IV) The const. vol^m Heat Rejection process (4-1)

($V=c$, P =dec, T =dec, S =dec.)



- IF we show two adiabatic process from two point then the graph is not exactly same but shape looks like same (slope diffn)

- The line 2-3 is greater length than 4-1 in PV dig if same then $HA = HR$ & $WD = 0$



same graph b) and c) but slope changes

Take a example

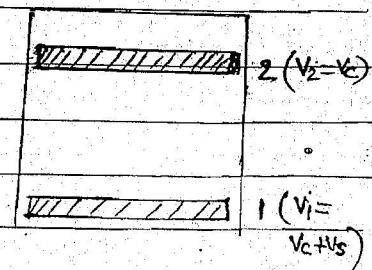
from example
 ΔP at (12 & 10) & (3 & 1)
is same i.e 2 mpa
but vol^m changes
about 20 times

P	Vol ^m
12 mpa	0.083
10	0.162
3	0.91
1	1.73
	0.04
	0.8

Clearance Ratio :

$$C = \frac{V_c}{V_s}$$

Vol^m Ratio : Large vol^m
Less vol^m



Compression Ratio: (γ)

$$\gamma = \frac{V_1}{V_2} = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c} \quad ***$$

$$\Rightarrow \frac{V_s}{V_c} = (\gamma - 1)$$

Expansion Ratio:

$$\frac{V_4}{V_3} = \frac{V_1}{V_2} = \gamma \quad ***$$

i.e. comp. Ratio = Expansion Ratio [In Otto cycle]

Efficiency of cycle :-

$$\eta_v = \frac{WD}{HA} = \frac{HA - HR}{HA} = 1 - \frac{HR}{HA}$$

$$\text{Now } HR = -dQ = -mc_v(T_1 - T_4) \\ = mc_v(T_4 - T_1)$$

$$\therefore \eta_v = 1 - \frac{mc_v(T_4 - T_1)}{mc_v(T_3 - T_2)} \quad (i)$$

Now: from process: 1-2 ($pV^\gamma = c$)

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

and from process 3-4 ($pV^\gamma = c$)

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

 $\Rightarrow$ from (ii) and (iii)

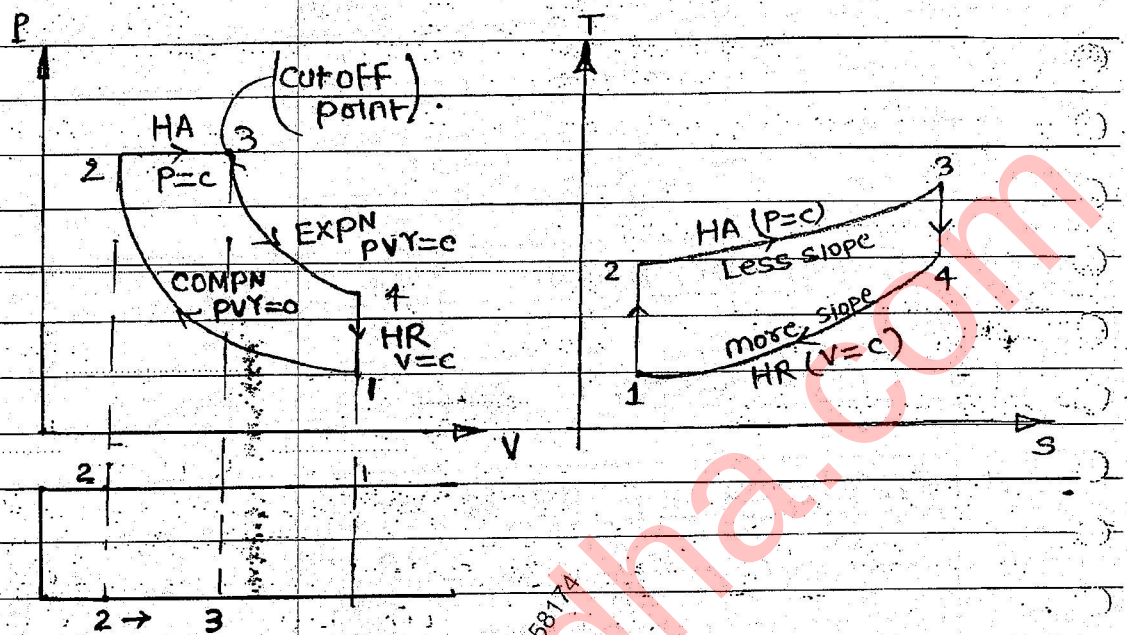
$$\frac{T_1}{T_2} = \frac{T_4}{T_3} \Rightarrow \frac{T_4 - T_1}{T_3 - T_2} = \frac{T_1}{T_2} = \frac{T_4}{T_3} \quad \left(\text{from comp \& dividendo}\right)$$

$$\therefore \eta_v = 1 - \left(\frac{1}{\gamma}\right)^{\gamma-1} \quad *****$$

* CONST. PRESS OR DIESEL CYCLE

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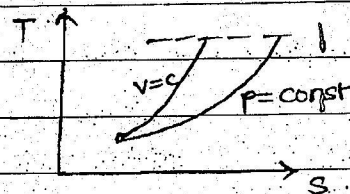
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→ In const. press, expansion point (3) which is greater than that of const. volm process.

$$\# \quad ds_p = mc_p \ln \frac{T_2}{T_1}$$

$$ds_v = mc_v \ln \frac{T_2}{T_1}$$



→ at cut-off point, the supply of fuel is cut.

$$\# \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1} \quad \therefore T_2 = T_1 \cdot (\gamma)^{\gamma-1} \quad \text{--- (1)}$$

where $\gamma = \frac{V_1}{V_2}$: comp. Ratio

$$\# \quad \text{Also: } \frac{V_3}{V_2} = \rho : \text{cut off Ratio}$$

$$\therefore \text{The expansion Ratio} = \frac{V_4}{V_3} = \frac{V_1}{V_2} \times \frac{V_2}{V_3} = \frac{\gamma}{\rho}$$

$$\# \quad \frac{T_3}{T_2} = \frac{V_3}{V_2} = \rho \quad \left\{ \because p=c \text{ from process 2-3} \right\}$$

$$\therefore T_3 = T_1 \gamma^{\gamma-1} \times \rho \quad \text{--- (2)}$$

process : 3-4

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} \Rightarrow T_4 = T_1 \cdot \gamma^{\gamma-1} p$$

$$\Rightarrow T_4 = T_1 \cdot \gamma^{\gamma-1} \cdot p \times \left\{\frac{p}{\gamma}\right\}^{\gamma-1}$$

$$\Rightarrow \boxed{T_4 = T_1 \cdot p^{\gamma}} \quad \text{--- (3)}$$

Efficiency of cycle :-

$$\eta_p = 1 - \frac{H_R}{H_A} = 1 - \frac{m c_v (T_4 - T_1)}{m c_p (T_3 - T_2)}$$

$$\Rightarrow \eta_p = 1 - \frac{1}{\gamma} \left\{ \frac{T_1 e^{\gamma} T_4}{T_1 \gamma^{\gamma} p - T_1 \gamma^{\gamma-1}} \right\}$$

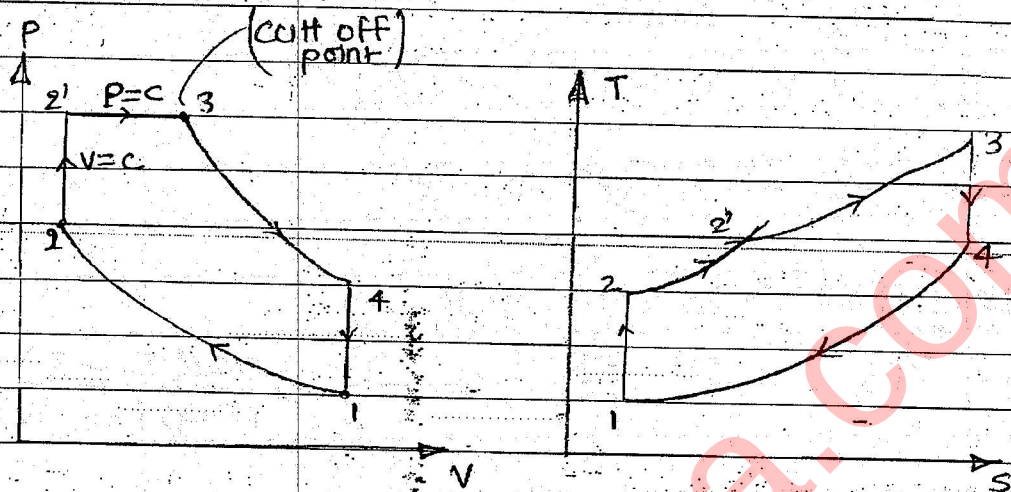
$$\boxed{\eta_p = 1 - \left(\frac{1}{\gamma}\right)^{\gamma-1} \frac{p^{\gamma-1}}{\gamma(p-1)}} \quad ***$$

DUAL CYCLE OR SEMI-DIESEL CYCLE :-

→ Fuel is match

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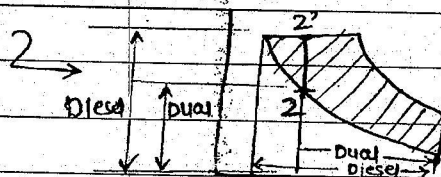


→ IF we add heat 1st at const press and then const volm then piston stop at b/w TDC & BDC for const volm Heat addn which is undesirable (not possible)

→ Heat Supplied at const volm is lesser than const. press. otherwise bursting occurs and eff. is lower.

→ IF we want to eff. increases, then heat addn at const press is 2-3 times more than that of const. volm.

→ Diesel cycle eff is more because area is more.



— In this day various diesel engine uses dual cycle

* — In Dual cycle engine, Diesel is used so called semi-Diesel cycle

- when press. increases at time of compression more sound is produce but at time of heat addⁿ press is normal.

II Dual Engine

- Small Engine Size
- press Rise is less

Diesel Engine

- Large engine size
- more

- i) $\rightarrow$ For the Dual cycle, Heat addⁿ takes place 1st at const. vol^m and then at const. press.
- ii) $\rightarrow$ If heat addⁿ takes place first at const. press and then at const. vol^m, then the eff. of cycle Reduced. Besides, the piston has to be stop at middle of its motion, when Heat addⁿ takes place at ($v=c$), which is not possible in practice.
- iii) $\rightarrow$ If the heat addⁿ at const. vol^m is higher then either the cylinder will be explored or the comp. Ratio must be reduce (eff will be less)
- 4) $\rightarrow$ ~~when~~ heat addⁿ at const. press. is 2-3 times more than the heat addⁿ at const. vol^m.
- v) $\rightarrow$ The Ratio of the press. during the const vol^m Heat addition is called explosion Ratio $\left(\frac{P_2}{P_1} = \alpha \right)$ The explosion Ratio.

- * 6) For the same peak press, the eff. of Diesel cycle is higher than of dual cycle due to higher comp. Ratio (γ)
- 7) For the Diesel cycle taken $\gamma = 16$ to 20
For the Dual cycle : $\gamma = 12$ to 16
- 8) The Dual cycle engine is smaller in size thus it is more compact & can be used for smaller vehicle
- 9) The sound pollution is much higher in a Diesel cycle than that of Dual cycle engine.
- 10) Maintenance is easier than dual cycle engine & maintenance cost is also less.

II Efficiency of Dual cycle :-

Let: $\frac{P_2'}{P_2} = \alpha$, the explosion Ratio

& $\frac{V_1}{V_2} = \gamma$; the comp. Ratio.

Also, $\beta = \frac{V_3}{V_2'} = \frac{V_3}{V_2}$; the cut off Ratio.

$\therefore$ The exp. Ratio is $\frac{V_4}{V_3} = \frac{V_1}{V_2} \times \frac{V_2}{V_3} = \frac{\gamma}{\beta}$

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

$$\frac{T_2'}{T_2} = \left(\frac{P_2'}{P_1}\right) = \alpha \therefore T_2' = T_1 (\gamma)^{\gamma-1} \cdot \alpha \quad \text{--- (2)}$$

$$p=c \Rightarrow \frac{T_3}{T_2} = \frac{V_3}{V_2}$$

$$\therefore T_3 = T_1 \cdot r^{r-1} \cdot \alpha^{\frac{1}{\gamma}} \quad \text{--- (3)}$$

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

$$\therefore T_4 = T_1 \cdot r^{\gamma-1} \cdot \alpha^{\frac{1}{\gamma}} \left(\frac{r}{\alpha} \right)^{\gamma-1}$$

$$\Rightarrow T_4 = T_1 \cdot \alpha^{\frac{1}{\gamma}} \quad \text{--- (4)}$$

Efficiency of Dual cycle :

$$\eta_s = 1 - \frac{HR}{HA} = 1 - \frac{mc_v(T_4 - T_1)}{mc_v(T_2' - T_2) + mc_p(T_3 - T_2')}$$

$$\Rightarrow \eta_s = 1 - \frac{T_1 \alpha^{\frac{1}{\gamma}} - T_1}{(T_1 r^{\gamma-1} \alpha^{\frac{1}{\gamma}} - T_1 r^{\gamma-1}) + \gamma (T_1 r^{\gamma-1} \alpha^{\frac{1}{\gamma}} - T_1 r^{\gamma-1} \alpha)}$$

$$\eta_s = 1 - \left[\frac{1}{r} \right]^{\gamma-1} \frac{\alpha^{\frac{1}{\gamma}} - 1}{(\alpha-1) + \gamma(\frac{r}{\alpha}-1)\alpha} \quad **$$

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

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Mean effective pressure :

↳ When we consider an imaginary const. pressure which will gives us the same work done for the same change in vol^m like that of actual cycle then the imaginary press. is known as the mean effective press. of the cycle.

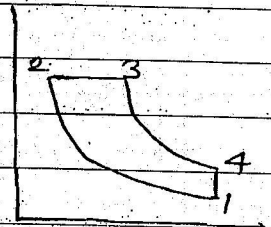
↳ The work done by taking MEP in account is given by.

$$W = P_m \times V_s \quad **$$

@:- cut off Ratio :

$$r = \frac{\text{comp. Ratio}}{\text{Expansion Ratio}}$$

WHERE exp. Ratio = $V_4/V_3 = V_1/V_2$ ($\because V_4 = V_2$)



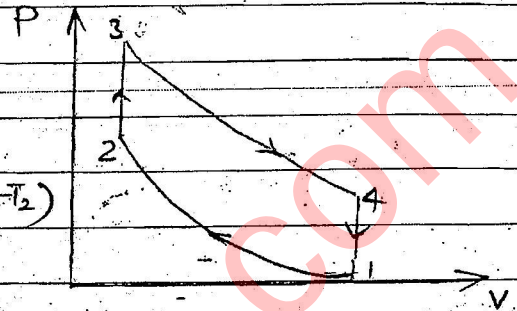
$$W = P_m \times V_s \quad **$$

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For the cycle shown below, show that the mean effective press. is given by

$$P_m = \frac{\eta_v (\Delta P)}{(\gamma-1)(\gamma-1)}$$

$$\text{where } \Delta P = (P_3 - P_2)$$



$$\# \therefore \eta_v = \frac{WD}{HA} = \frac{P_m \times V_s}{m c_v (T_3 - T_2)}$$

$$\Rightarrow \eta_v = \frac{P_m \times V_s}{C_v \left[\frac{P_3 V_3 - P_2 V_2}{R} \right]}$$

$$\Rightarrow \eta_v = \frac{P_m \times V_s (C_p - C_v)}{(P_3 V_3 - P_2 V_2)}$$

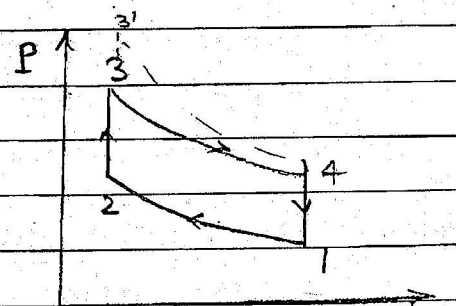
H.W
Find P_m For Diesel cycle

$$= \frac{P_m V_s (\gamma - 1)}{(P_3 - P_2) V_c} = \frac{P_m (\gamma - 1) (\gamma - 1)}{\Delta P}$$

$$\Rightarrow \boxed{P_m = \frac{\eta_v \Delta P}{(\gamma-1)(\gamma-1)}} \quad \text{proved}$$

Ques:- For the dig. shown, show that $T_2 = T_4 = \sqrt{T_1 T_3}$ for maxm work done.

$$\begin{aligned} \text{Work done} &= HA - HR \\ &= m c_v (T_3 - T_2) - m c_v (T_4 - T_1) \end{aligned}$$



→ we can not change T_1 and T_3 because T_1 is atm. Temp. &

if we increase T_3 then WD will be increase but HA also increase so we can not change T_3 also.

From process 1-2

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

and process 3-4 :

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{1}{\gamma}\right)^{\gamma-1}$$

$$\Rightarrow \frac{T_4}{T_3} = \gamma^{1-\gamma}$$

$$\therefore W_D = m C_V [(T_3 - T_1 \gamma^{\gamma-1}) - (T_4 - T_3 \gamma^{1-\gamma} - T_1)]$$

For max W_D :

$$d(W_D) = 0$$

$$d(\gamma)$$

$$\Rightarrow -T_1 (\gamma-1) \gamma^{\gamma-2} - T_3 (1-\gamma) \gamma^{-\gamma} = 0$$

$$\Rightarrow +T_1 \gamma^{\gamma-2} = T_3 \gamma^{-\gamma}$$

$$\frac{T_3}{T_1} = (\gamma)^{2(\gamma-1)}$$

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

$$\Rightarrow \boxed{T_2 = \sqrt{T_1 T_3}} \text{ proved}$$

also: $\left(\frac{T_4}{T_3}\right)^2 = \left(\frac{T_3}{T_1}\right)$

$$\Rightarrow \boxed{T_4 = \sqrt{T_1 T_3} = T_2} \text{ proved}$$

Ques:- The comp. Ratio for a Otto cycle is 7. The

initial value of the Ratio of sp. heat is 1.4.

Def. the %age change in the eff. of cycle when the sp. heat at const vol^m increases

by 1%

Sol:- $\gamma = 7, \quad \gamma_1 = 1.4 \text{ (initially)} = \frac{C_p}{C_v}$

$$\Rightarrow C_p = 1.4 C_v$$

$C_{v2} = 1.01 C_{v1}$, then η_{o2} change in $\eta_{o1} = ?$

$$\eta_1 = 1 - \left(\frac{1}{r}\right)^{\gamma-1} = 1 - \left(\frac{1}{7}\right)^{1.4-1} = 0.5408$$

Now $C_{p1} - C_{v1} = R = C_{p2} - C_{v2}$

$$\Rightarrow C_{p1} - C_{v1} = C_{p2} - C_{v2}$$

$$1.4 C_{v1} - C_{v1} = C_{p2} - 1.01 C_{v1}$$

$$\Rightarrow 0.4 C_{v1} + 1.01 C_{v1} = C_{p2}$$

$$\Rightarrow C_{p2} = 1.41 C_{v1}$$

$$\therefore \gamma_2 = \frac{C_{p2}}{C_{v2}} = \frac{1.41 C_{v1}}{1.01 C_{v1}} = 1.39$$

$$\therefore \eta_2 = 1 - \left(\frac{1}{r}\right)^{\gamma-1} = 1 - \left(\frac{1}{7}\right)^{1.39-1} = 0.5318$$

$\therefore$ %age change (decrease)

$$\frac{\eta_2 - \eta_1}{\eta_1} \times 100 = 1.66\% \text{ Ans}$$

Ques:- when the work done of a diesel cycle is increase then its eff will

a) increase b) same c) decrease d) Any thing possible.

→ any problem Related to eff. Then start with eqn of eff.

$$\eta_D = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \frac{\rho^\gamma - 1}{\gamma(\rho-1)} = \frac{WD}{HA}$$

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

→ IF work done and heat both decreases then eff always decreases.

→ for a given comp.

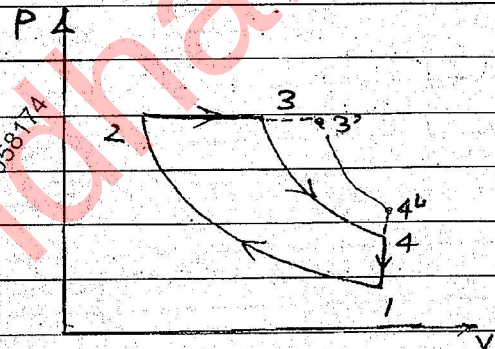
For Conventional use calculator only even small calculation

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→ Since work done (Numerator.) the HA even more hence there is no -ve term in denominator hence eff. will only decrease.
∴ Ans - (C)

** The comp. Ratio of the Diesel cycle is 14.
Det. the %age change in eff. of the cycle when the cut-off changes from 5 to 15% of the stroke

$\gamma = 14$
 $\frac{V_c + V_s}{V_c} = 14$
⇒ $V_c + V_s = 14 V_c$
⇒ $V_s = 13 V_c$



and $V_3 - V_2 = \frac{5}{100} V_s$
⇒ $V_3 - V_c = \frac{5}{100} V_s$ ⇒ $V_3 = V_c + 0.05 V_s$ (Note: $V_c = V_2$)
⇒ $V_3 = V_c + 0.05 \times 13 V_c = 1.65 V_c$

∴ $\beta = \frac{V_3}{V_2} = \frac{1.65 V_c}{V_c} = 1.65$

∴ $\eta_D = 1 - \left(\frac{1}{\gamma}\right)^{\gamma-1} \cdot \frac{\beta^\gamma - 1}{\gamma(\beta - 1)}$
 $= 1 - \left(\frac{1}{14}\right)^{14-1} \times \frac{1.65^{14} - 1}{14(1.65 - 1)} = 0.6115$

When cut-off changes to 15%.

$V_3' - V_2 = \frac{15}{100} V_s$
⇒ $V_3' = V_c + 15 \times 13 V_c = 2.95 V_c$