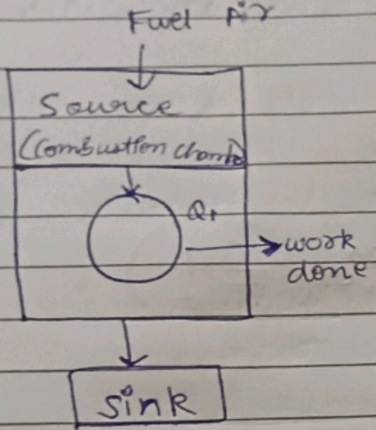
Unit - 3

Air standard cycles

Basic Principle of internal semantic combustion -



Assumptions -

Ideal / Air standard cycle Assumption.

Air cycle Analyse

working medium perfect gas throughout.

Theoretical Assumptions -

(1) Working medium is a perfect gas throughout. It follows idea gas equation

$$PV = nRT.$$

(2) Working medium is a fixed mass of air. Either contained in closed system or flowing with constant rate in a closed circuit.

(3) Physical constants of working medium are same as that of air.

(4) Working medium has constant specific heat.

(5) The working medium does not go any chemical changes throughout the cycle.

⑥ Heat is supplied and rejected in a reversible manner

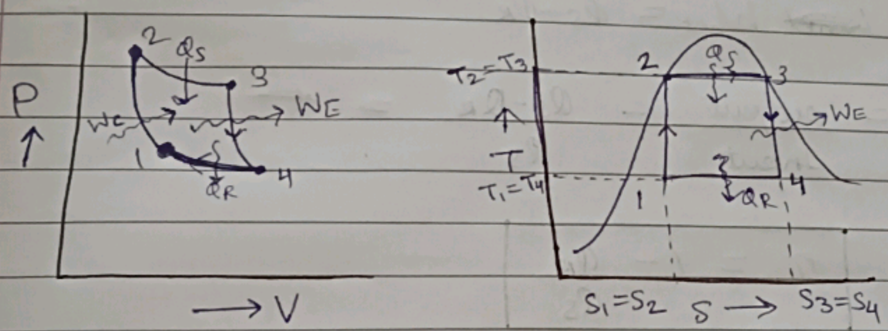
⑦ Heat is supplied and rejected instantaneously

⑧ Compression and expansion processes are reversible adiabatic. (No loss or gain of entropy, ∴ zero friction)

⑨ Kinetic and potential energies are neglected

⑩ Operation of the engine is frictionless.

Carnot Cycle -



1–2 : Reversible adiabatic compression

2–3 : Reversible isothermal Heat Addition to working fluid from external source.

3–4 : Reversible Adiabatic expansion of working fluid.

4–1 : Reversible isothermal Heat rejection in the same sink.

Change in entropy during heat supply and heat rejection is same.

$$dS = \frac{dQ}{T} \Rightarrow dQ = TdS.$$

$$\boxed{dQ_S = (S_3 - S_2)T \quad \text{and} \quad dQ_R = (S_4 - S_1)T}$$

$$Q_{S(2-3)} = m \times T_H (S_3 - S_2)$$

$$Q_{R(4-1)} = m \times T_L (S_4 - S_1)$$

T_H = Highest temp. of working fluid in cycle
T_L = Lowest temp.

Acc^n to first law:

Net work done = Net Heat transfer

$$\cancel{W_{net}}\ W_{net} = Q_S - Q_R$$

$$\eta = \frac{\text{output}}{\text{Input}} = \frac{Q_S - Q_R}{Q_S} = \cancel{1}$$

$$\boxed{\eta = 1 - \frac{Q_R}{Q_S}}$$

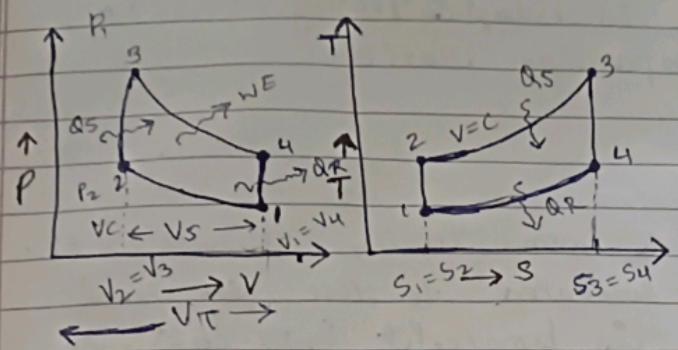
$$\eta = \frac{\cancel{m} T_H (S_3 - S_2) - \cancel{m} T_L (S_4 - S_1)}{\cancel{m} T_H (S_3 - S_2)}$$

$\because S_1 = S_2$ and $S_4 = S_3$.

$$\eta = \frac{T_H \cancel{(S_3 - S_2)} - T_L \cancel{(S_3 - S_2)}}{T_H \cancel{(S_3 - S_2)}}$$

$$\boxed{\eta = 1 - \frac{T_L}{T_H}}$$

Air standard otto cycle :-



V_s = Stroke Volume

V_T = Total volume

V_c = Clearance Volume

V_{1-2} : Air is compressed adiabatically through ~~an~~ a compression ratio:

$$\boxed{r = \frac{V_1}{V_2}} = \frac{V_T}{V_c}$$

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

V_{2-3} : Piston is momentarily at rest at TDC and heat is added to the working fluid at a constant volume with an external source which has The pressure rises through an explosion ratio:

$$\boxed{\alpha = \frac{P_3}{P_2}}$$

V_{3-4} : This increased high pressure exerts a greater amt of force on the piston and ~~pos~~ pushes the piston towards the

BDC and expansion of working fluid takes place isoentropically. This gives work. ~~The~~ The expansion ratio

V_{4-1} :

The piston is momentarily at rest at BDC and heat is rejected to the external sink, which is brought into contact with the   The process comes to V_1 and the the cycle is completed.

Thermal Efficiency :-

Let m is fixed mass of air flowing through the cycle.

Heat supplied during process $2 \to 3$:

$$Q_S = mC_v(T_3 - T_2)$$

Heat rejected during $(4 \to 1)$:

$$Q_R = mC_v(T_4 - T_1)$$

Thermal efficiency -

$$\eta = \frac{\text{output}}{\text{input}} = \frac{Q_S - Q_R}{Q_S} = \frac{mC_v[T_3 - T_2 - T_4 \ldots}{mC_v(T_3 - T_2}$$

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

At point 2 -

$$r = \frac{V_1}{V_2} \Rightarrow V_2 = \frac{V_1}{r}$$

At $1 \to 2$:-

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} \Rightarrow P_2 = P_1(r)^{\gamma}$$

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

$$T_2 = T_1 (r)^{\gamma-1}.$$

At point 3 —

$$V_3 = V_2$$

$$V_3 = \frac{V_1}{r}.$$

$$\alpha = \frac{P_3}{P_2} \Rightarrow P_3 = P_2\,\alpha.$$

$$P_3 = P_1\,\alpha\,(r)^{\gamma}$$

Between $2 \rightarrow 3$ —

$$\frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3}$$

$$T_3 = T_2\cdot\frac{P_3}{P_2} = T_1(r)^{\gamma-1}\alpha.$$

At point 4. —

$$V_4 = V_1$$

$$P_3V_3^{\gamma} = P_4V_4^{\gamma}$$

$$P_4 = P_3\left(\frac{V_3}{V_4}\right)^{\gamma} = P_3\left(\frac{V_2}{V_1}\right)^{\gamma}$$

$$P_4 = P_1\cdot\alpha\cdot\cancel{r^{\gamma}}\,\frac{1}{\cancel{r^{\gamma}}} = P_1\,\alpha.$$

$$\therefore\ P_4 = P_1\,\alpha.$$

Adiabatic expansion $(3-4)$ —

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

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

$$T_4 = T_1 \alpha \, \cancel{r^{\gamma-1}} \times \frac{1}{\cancel{r^{\gamma-1}}}$$

$$T_4 = T_1 \alpha .$$

Now, Substituting values in η -

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

$$= 1 - \frac{T_1\alpha - T_1}{T_1 \alpha r^{\gamma-1} - T_1 r^{\gamma-1}}$$

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

$$\boxed{\therefore \ \eta = 1 - \frac{1}{r^{\gamma-1}}}$$

Q. Calculate air standard efficiency of otto cycle having compression ratio 7.

$\Rightarrow$

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

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

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

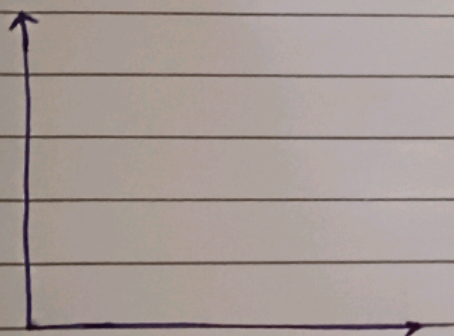
$$\frac{T_3}{T_2} - 1 = \frac{T_4}{T_1} - 1 .$$

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

$$\frac{T_4 - T_1}{T_3 - T_2} = \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma - 1}.$$

Mean effective pressure :-

Actual engine.



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

$$\frac{T_3 - T_2}{T_2} = \frac{T_4 - T_1}{T_1} \rightarrow \frac{T_4 - T_1}{T_3 - T_2} = \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

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

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

$$\boxed{\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}}$$

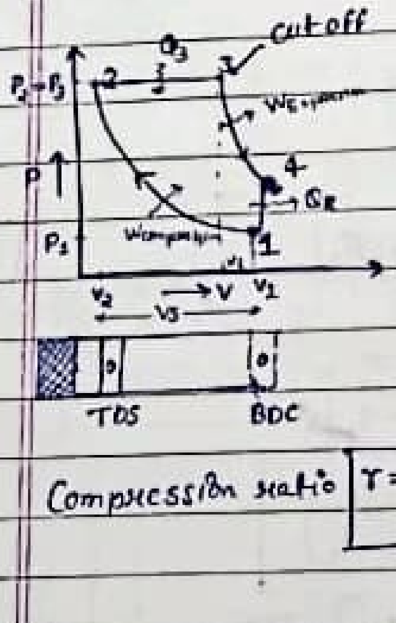
Inlet valve
Exhaust valve

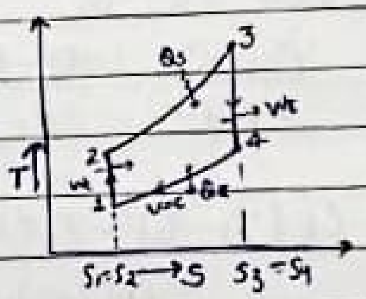
process 0-1 suction
1-2 Adiabatic compress
2-3 Constant Volume
3-4 Adia Exp.
4-1 Blown down of gas
1-0 exhaust

Mean Effective Pressure

Rudolf Diesel → name of scientist

Air Standard Diesel cycle (Corresponds to CI Engine)
Compression Ignition





Otto cycle
(SI engine)
Spark ignited

process 1 to 2
Piston move from TDS to BDS through a compression ratio $r = \frac{V_1}{V_2}$

Compression ratio $\boxed{r = \frac{V_1}{V_2}}$

$\rho =$ Cutoff ratio $= \frac{V_3}{V_2} = r_c$

process 2 to 3, Heat is added to compressed air at constant press from a external source which brought in contact with cyl. head.

point 3 heat stops This point is known as point of cut off

process 3 to 4, This increas high pressure exert a amount of force on piston & pushes piston toward BDC expansion of working fluid air take place adibaticly Work is done by system

This expansion take place through expansion ratio

$$\boxed{r_e = \frac{V_4}{V_3}}$$

process 4 to 1, Piston is momentary addressed at BDC & heat is rejected to the external sink the process is reversibley so control that ultimately the initial state 1 and cycle is completed

Consider 1 kg of working fluid Air flowing through the cycle.

Heat supplied in process 2-3

$$Q_S = 1 \times C_p (T_3 - T_2)$$

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

Heat rejected during process 4-1

$$Q_R = 1 \times C_v (T_4 - T_1)$$

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

1st law

$$W_{net} = Q_{net} = Q_S - Q_R$$

$$\eta_{Diesel} = \frac{Output}{Input} = \frac{Q_S - Q_R}{Q_S}$$

$$\frac{C_p(T_3 - T_2) - C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$$

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

$$\boxed{\eta_{\substack{Diesel \\ ASE}} = 1 - \frac{1}{\gamma}\left(\frac{T_4 - T_1}{T_3 - T_2}\right)}$$

Compression ratio $\boxed{r_k = \frac{V_1}{V_2}}$ Expansion ration $\boxed{r_e = \frac{V_4}{V_3}}$

Cutoff ratio $\boxed{r_c = \frac{V_3}{V_2}}$

$$\boxed{r_k = r_e \times r_c}$$

$$\frac{V_1}{V_2} = \frac{V_4}{V_3} \times \frac{V_3}{V_2}$$

$$\boxed{\frac{V_1}{V_2} = \frac{V_4}{V_2}}$$

process 3 to 4 Adiabatic Expansion

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

$$\frac{1}{r_e} = \frac{r_c}{r_k}$$

$$\frac{T_4}{T_3} = \left(\frac{r_c}{r_k}\right)^{\gamma-1}$$

$$\boxed{T_4 = T_3\left(\frac{r_c}{r_k}\right)^{\gamma-1}}$$

Process 1 - 2

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

$$T = T_2 \cdot \frac{1}{r_k^{\gamma-1}} = \frac{T_3}{r_c} \cdot \frac{1}{r_k^{\gamma-1}}$$

process 2-3,

$$\frac{\cancel{P_2} V_2}{T_2} = \frac{\cancel{P_3} V_3}{T_3}$$

$$T_2 = \frac{V_2}{V_3} T_3$$

$$\boxed{T_2 = T_3 \cdot \frac{1}{r_c}}$$

$$\eta_{D\,(ASE)} = 1 - \frac{1}{\gamma}\left(\frac{T_4 - T_1}{T_3 - T_2}\right)$$

$$= 1 - \frac{1}{\gamma}\left(\frac{T_3 \cdot \frac{r_c^{\gamma-1}}{r_k^{\gamma-1}} - \frac{T_3}{r_c} \cdot \frac{1}{r_k^{\gamma-1}}}{T_3 - T_3 \frac{1}{r_c}}\right)$$

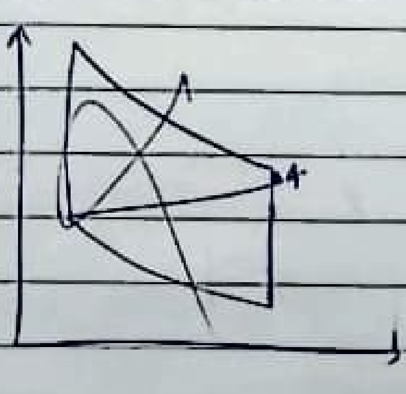
$$r_c = \frac{V_3}{V_2} > 1$$

$$= 1 - \frac{1}{\gamma r_k^{\gamma-1}}\left(\frac{r_c^{\gamma-1} - \frac{1}{r_c}}{1 - \frac{1}{r_c}}\right)$$

$$\frac{1}{\gamma}\left(\frac{r_c^{\gamma} - 1}{r_c - 1}\right) > 1$$

$$\boxed{\eta_D = 1 - \frac{1}{\gamma r_k^{\gamma-1}}\left(\frac{r_c^{\gamma} - 1}{r_c - 1}\right)}$$

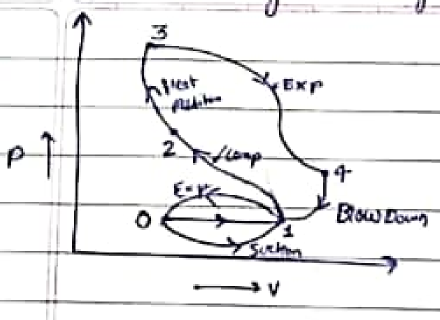
for same C·R (r) ASE of Diesel cycle will always less than the ASE of otto cycle for same CR = 15



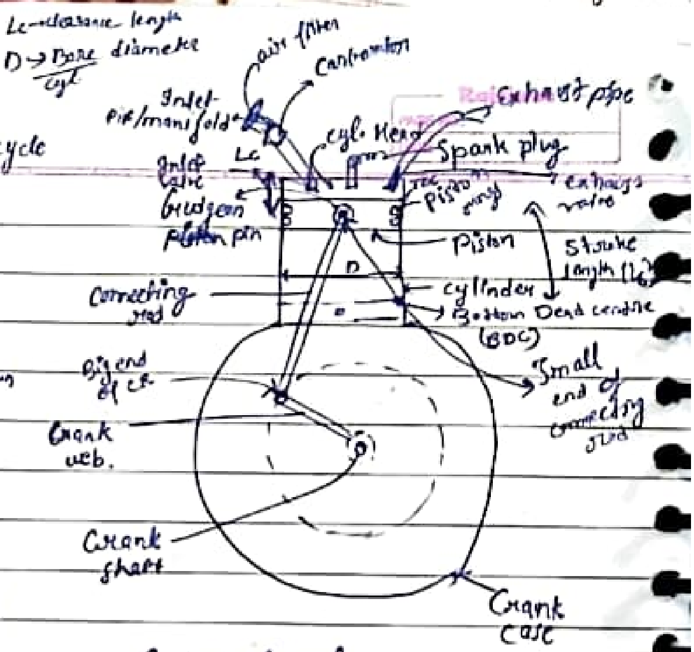
Output:

{'name': Sakshi', 'age': 20

Actual cycle otto cycle



otto cycle - SI (spark ignited)
(Petrol, gas hybrid)



Cross sectional are of cyl. $= \frac{\pi}{4} D^2$

$\boxed{\text{Stroke Vol. } V_s = \frac{\pi}{4} D^2 \times L_s}$

$\boxed{\text{Clearance Vol. } V_c = \frac{\pi}{4} D^2 \times L_c}$

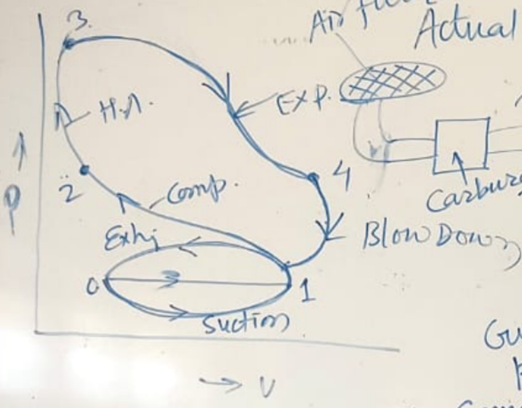
$\boxed{V_T = \text{Total volume} = \frac{\pi}{4} D^2 (L_c + L_s)}$

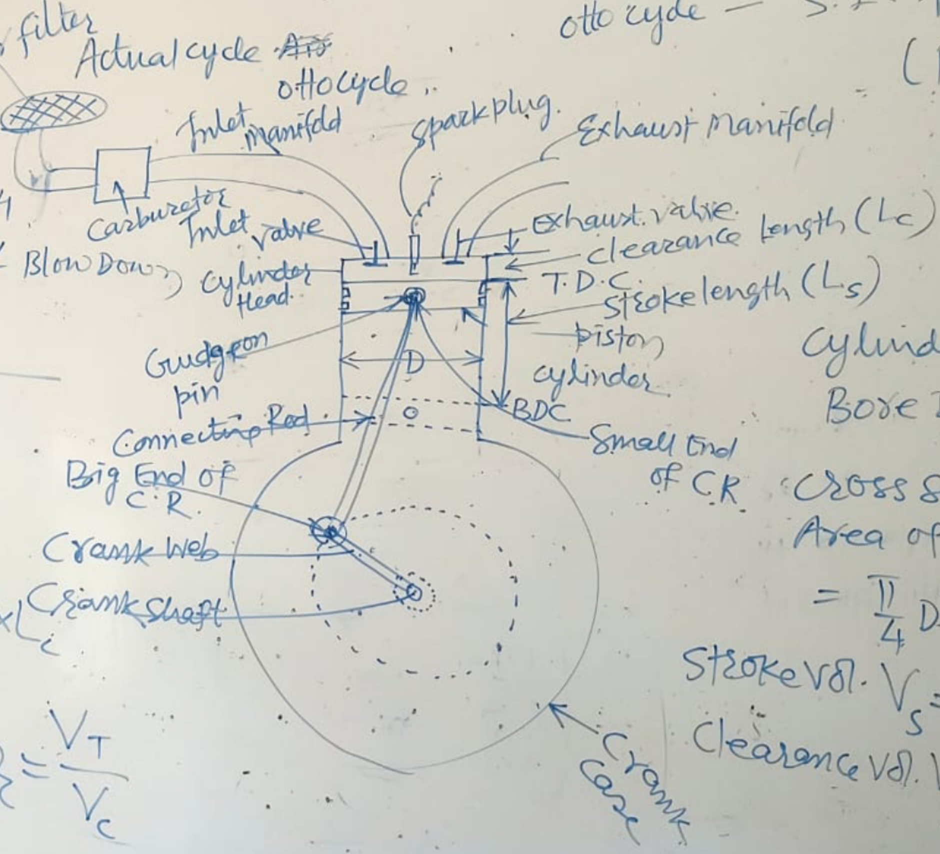
$\boxed{\text{Compression Ratio } (r) = \frac{V_T}{V_c}}$

otto cycle — S.I. Spark ignited.

(Petrol, Gas)

Hybrid





Cylinder Dia

Bore Dia = D.

Cross sectional Area of cyl.

$$= \frac{\pi}{4} D^2$$

Stroke vol. $V_s = \frac{\pi}{4} D^2 \times L_s$

Clearance vol. $V_c = \frac{\pi}{4} D^2 \times L_c$

V_T = Total vol.

$$= V_s + V_c$$

$$= \frac{\pi}{4} D^2 L_s + \frac{\pi}{4} D^2 \times L_c$$

$$V_T = V_s + V_c$$

Comp. ratio $= r = \frac{V_T}{V_c}$