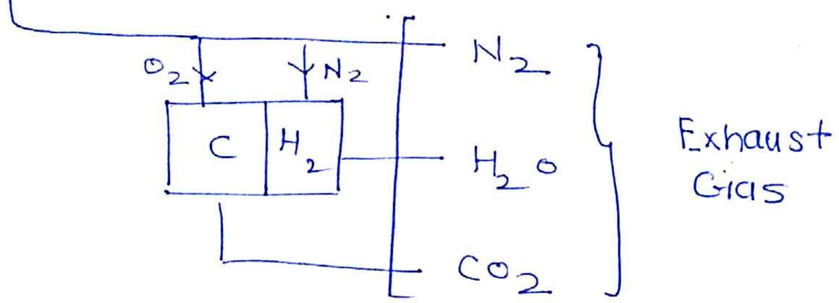
Combustion in I.C. Engine :-

Lower calorific Value (LCV)

Air	By Mass	By Volume
O_2	23 %	21 %
N_2	77 %	79 %

Air (ideal comb.)



$$\underset{\text{(Hydrocarbon)}}{\text{Fuel}} + O_2 \longrightarrow CO_2 + H_2O$$

when the steam in the exhaust Gas let of freely, than the total heat available due to the combustion of 1 kg fuel is know as the Lower Caloriefic Value.

→ The Caloriefic Value of fuel for IC engine is LCV. (we don't use steam)

Higher Caloriefic Value :- When the steam in the exhaust gas is condensed to water and the heat of condensation is utilised for useful heating, the caloriefic value of fuel is know as HCV.

→ The calorific value of fuel for stationary power plant is HCV. (we use steam)

* Stoichiometric Air fuel Ratio (AFR) :-

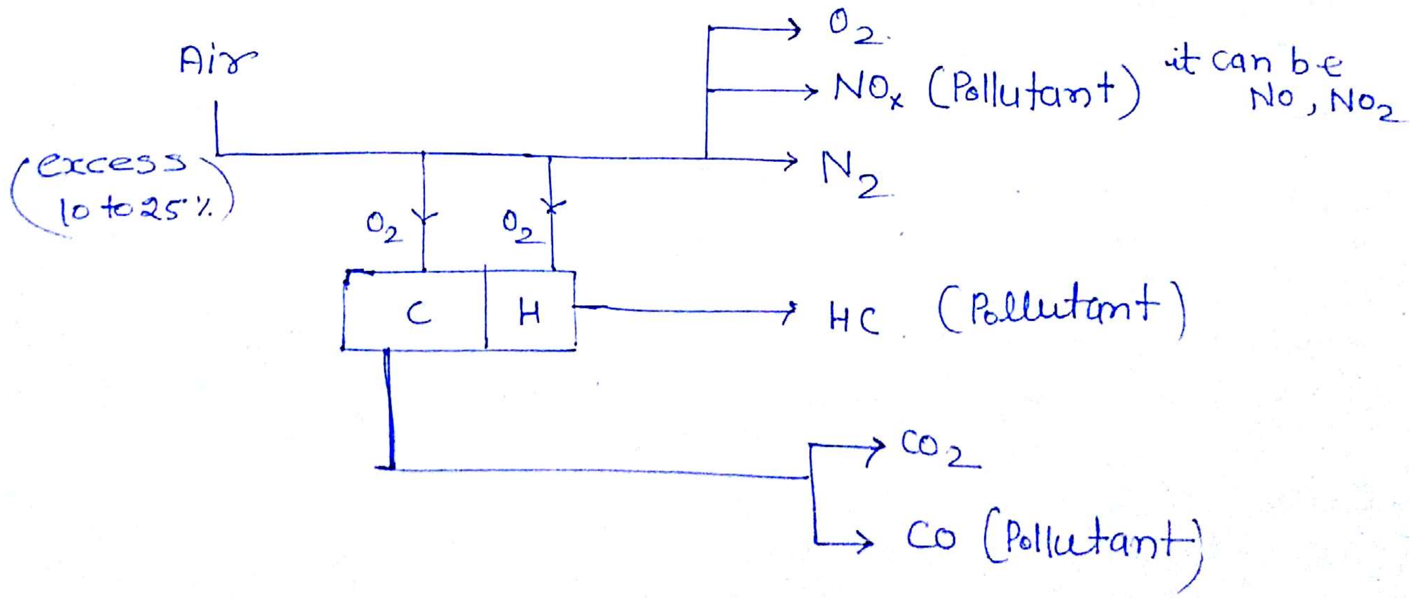
when the combustion of Air and fuel takes place in such manner that there is no free O_2 left ~~known~~ nor is any fuel remaining ~~a~~ in any form after Combustion is know ideal or perfect Combustion

The AFR for such a combustion is know as the stoichiometric AFR.

☆ stoichiometric AFR by mass → 13.4 to 15

by Volume → 9 to 9.6

Actual Combustion :-



Pollutant :-

① CO poisonous. ~~when taken~~ causes giddiness, when taken small quantity, ~~some~~

→ some time can also be fatal.

(2) HC :- Form photochemical smog when expose to Atmosphere. it causes skin cancer and affects the lungs. Also affects plants and animals.

(3) NO_x :- NO_x is form when the temp of the charge is very high

→ Other requirement are availability of free O_2 or incomplate combustion of the fuel.

→ when NO_x is expose to atmosphere the effect are the same as HC, besides there formation of ozone(O_3) at ground level. It is harmful to the extent even underwater creatures are affected.

EGR :- (Exhaust Gas ReCirculation)

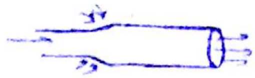
EGR is a process that, the exhaust Gas is recirculated and mix with fresh AFM that is escaping out of the outlet value during value overlap. During this recirculation the temp. of the exhaust gas decrease due to which NO_x is transform into NO & NO_2.

Method of Reducing Pollutant :-

① slightly excess air (Min 10%). $Q = m\uparrow c\, t\downarrow$ → NO_x नहीं बनेगा low temp par

② slightly lesser Compression Ratio ($t\downarrow$)

③ use of thermal Convertor. it is place in the



path of exhaust Gas. Absorbed air from outside temp. of the thermal convertor ~~but~~ is higher. It convert HC & CO to H_2O & CO_2. Thus the thermal convertor is known as a ~~two~~ 2 way convertor.

④ Use of Catalytic Convertor. ~~(IIT)~~ (PaPtRho)

(See last page)

- Palladium - CO to CO_2 → (oxidation)
- Platinum - HC to H_2O & CO_2 → (oxidation)
- ★ Rhodium - NO_x to N_2 & O_2 → (Reduction)

Imp Reduction catalytic of NOx

→ Consists of stainless steel box

→ Has alumina inside in form of honey comb.

→ Has palladium, platinum & Rhodium as catalytic agent.

★ ⇒ Orsat apparatus measures CO_2, CO, O_2, N_2 from a flue ~~fuel~~ gas sample unsaturated hydrocarbon (volumetric analysis)

Flue Gas CO_2, CO, O_2, N_2

Imp Equivalent Ratio :- (ϕ)

$$\text{Fuel Air Ratio} = \frac{m_f}{m_a} \quad (FAR)$$

it is the ratio of FAR under actual condition to FAR under ideal condition (stochiometric condition)

$$\phi = \frac{\text{Actual FAR}}{\text{Stoichiometric FAR}} = \frac{\frac{\text{Actual } m_f}{m_a}}{\frac{\text{ideal } m_f}{m_a}}$$

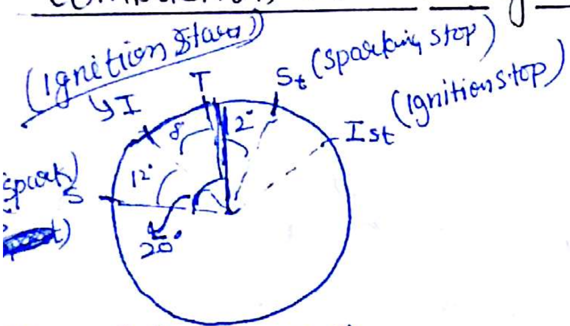
$$\phi = \frac{\text{Actual } m_f}{\text{ideal } m_f}$$

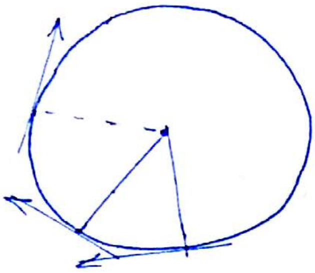
* when ϕ is less than 1 ($\phi<1$), there will be a shortage of the fuel supply. less energy will be librated from the fuel. The temp. rise will be less the power output will also be less. For Petrol engine, knocking will be less.

* when $\phi>1$, the fuel supply will be in excess, temp. of charge will be more high. The power available will also be more. for petrol engine knocking will also be High.

{ $\phi \geq 1.4$ less power, No knocking } unburn fuel, less air to burn fuel.

Combustion in SI Engine :-



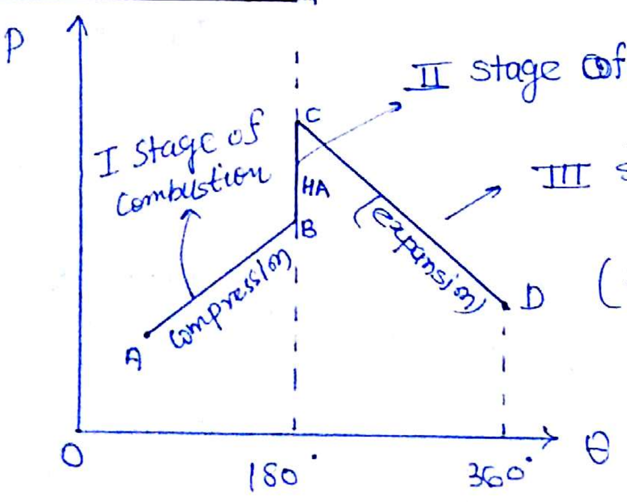


$\Delta P \propto \theta$

$\Delta P = K\theta$

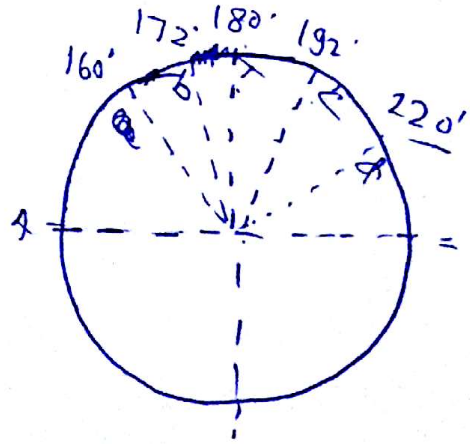
$y = mx$ (St. line)

Theoritical Dig



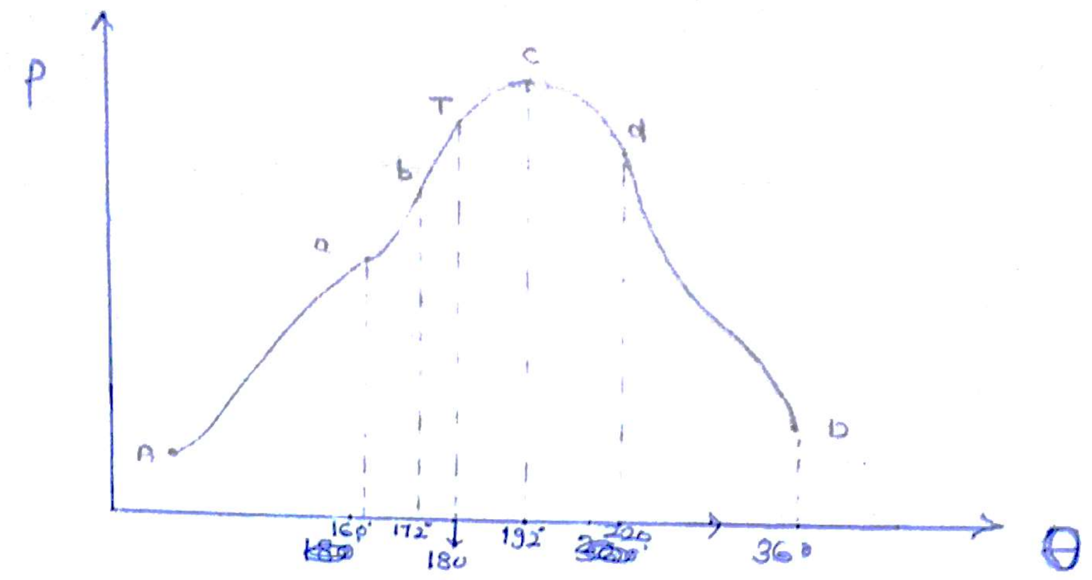
$(P_D > P_A)$

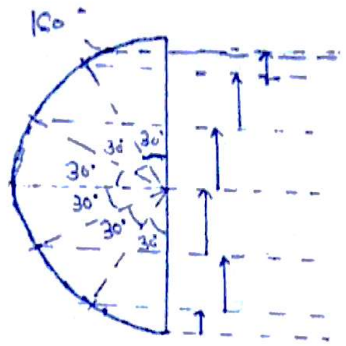
$(P_D < P_B)$

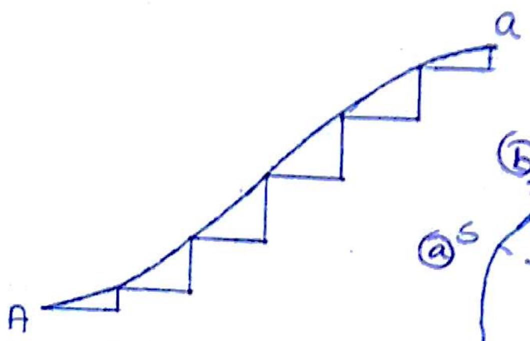


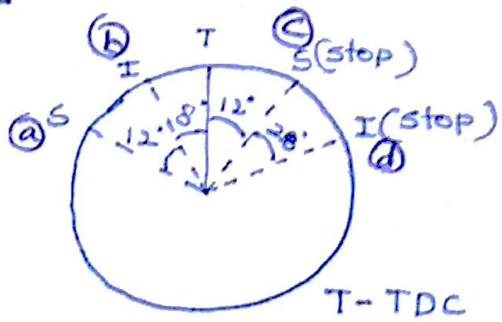
Theoritical diagram for 3 stage of Combustion

Actual Diagram:-









Piston movement as shaft rotate (Speed Varying)

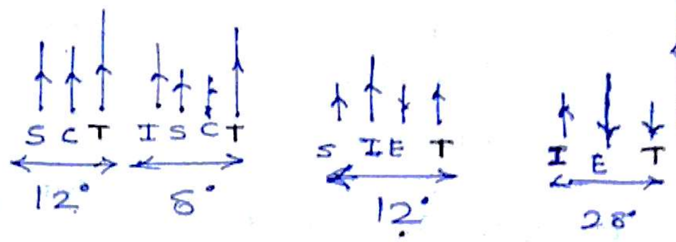
after 160°

{ Pressure change according to piston movement }

T – TDC

a	S – Sparking start
b	I – Ignition start
c	S – Sparking Stop
d	I – Ignition Stop

T-total pressure



A–a only Compression (Normal ↑ in pressure)

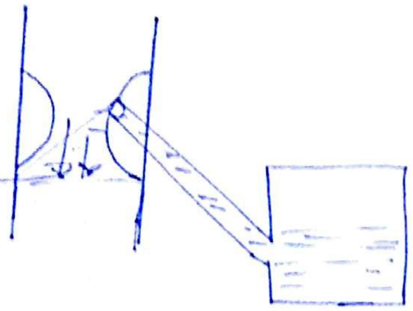
a–b 1st stage of Combustion (only sparking) High ↑ in Pressure

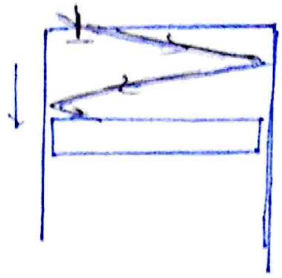
b–T 2nd Stage of Combustion (Very high ↑ in pressure)
T – c – 2nd stage of Combustion (Gradual ↑ in pressure) } sparking + Ignition

c–d – 3rd stage of Combustion (Drop in pressure) ↓ (ignition only)

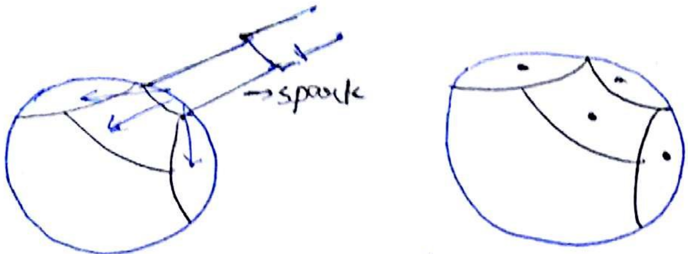
Ist stage of Combustion :-

Atomization or throttling





swirling Action (Vortex flow



* chemical Rxn occure Heat dissipated in diff for diff area } → During Heat dissipation temp will not rise }

when the spark contacts some area of fuel particle, chemical Rxn begains in this area. Heat is generated then spread to the ~~an~~ other area of the fuel chemical action begain in the other area also. There is a rise in the temp of the fuel. some heat gets store in all the different area's.

There is a propagation of Nucles of the area in which chemical action taking place.

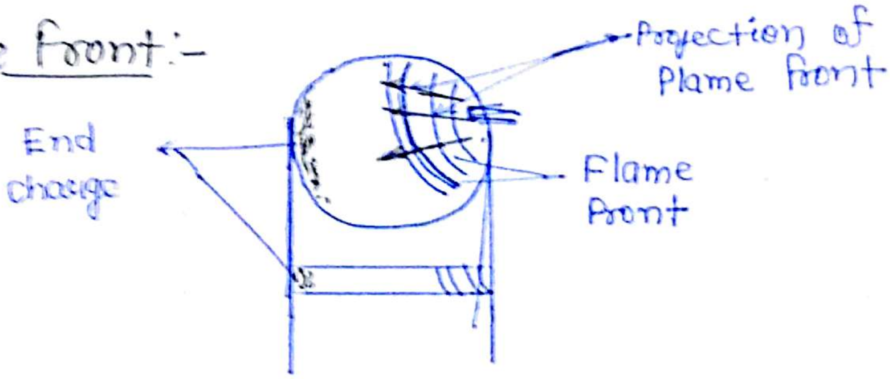
IF the temp of fuel particle is below the self ignition temp. At the end of chemical action of the entire fuel. this fuel particle does not burn and will be in circulation along with the gas until exhaust.

At the end of the chemical action of the temp of the fuel particle is equal to or above the self ignition temp. then there is distribution of heat collector in the diff area of fuel. There is no change in temp during this heat distribution when equal amount of heat gets collected in the equal diff area's of the fuel ~~the~~ particle, the fuel than get ignited.

→ The time taken from the begaining of chemical action to the begaining of the fuel ignition is know as the chemical lag. For petrol engine the chemical lag also known as the ignition lag.

→ The first stage of combustion or the chemical lag. is also known as prepatatory phase

Flame front:-



Flame front:- Due to sparking the nearby fuel particle gets ignited. The imgainary line joining the ignited fuel particle is define as the Flame front

→ After deformation of the first flame front, Heat travel from this flame front to the near by fuel particles and another flame front is formed in the mean time the fuel particle in earlier flame front get complately burn and this flame front venishes. It will thus appear that the previous flame front has only reach the new position.

This imgianarly movement of the flame front is known as the propogation of the flame front.

End charge:- The air fuel mixture at the opposite end of the flame front propogation is known as the end charge

→ The following thermodynamic event takes place for the end charge during the flame front propogation

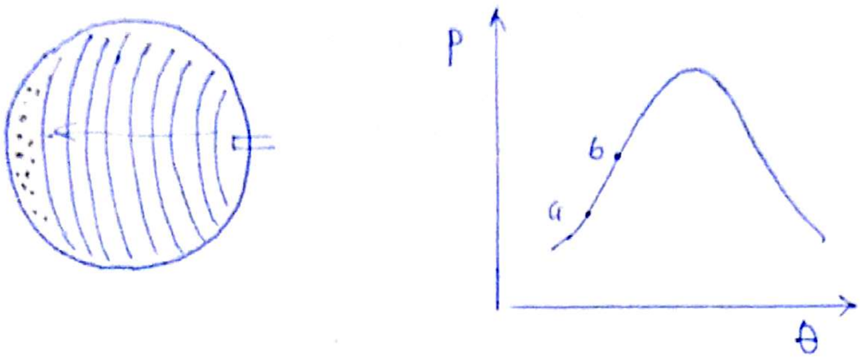
① During flame front propogation the air particle nearby the flame front expands and compresses the end charge, temp. of the end charge increases.

② Due to the continuous increase in the temp. of end charge chemical action begains for the end charge. Temp. of the end charge increases further then -

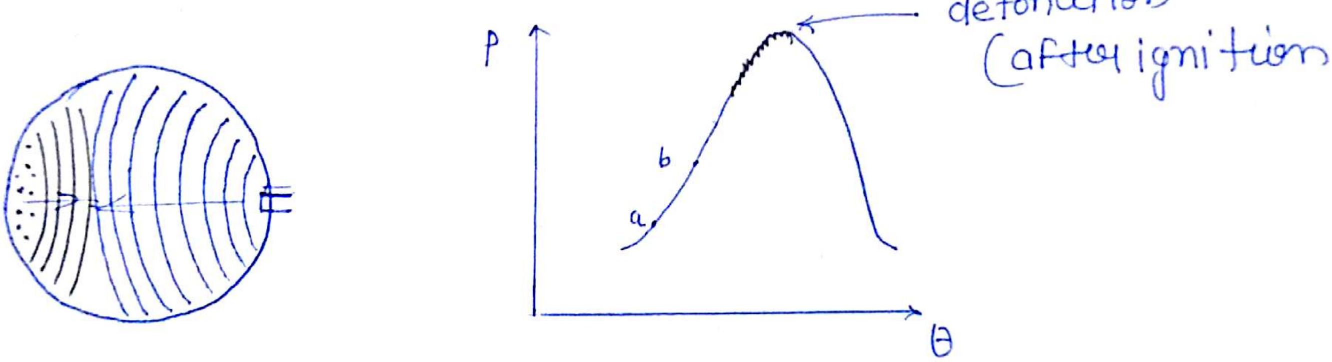
③ There is heat transfer from the flame front to the end charge. Temp of the end charge continuously to increase further.

* if the temp. of the end charge becomes equal to or above the self ignition temp, a seprate flame front form at the end charge. The two flame front move in opposite direction and collide with one another this collision is knao as detonation

→ The Following are the disadvantages of Detonation:-



Normal Combustion



Abnormal Combustion

① When detonation take place a wave is develope the point of collision this wave travel at a very high speed of about 2500-5000 cycle/sec. if this wave heat the piston, the piston then starts moving side wave and knock against the cylinder thus detonation and knocking are the same.

→ Due to knocking a crack may be develope in the piston or in the cylinder

② Due to knocking a loud Metalic sound heard known as pinging. Thus detonation ~~and~~ or knocking is also known as pinging.

(3) Mechanical Vibration are setup inside the engine due to knocking.

(4) There is loss of work.

Temp. Time Graph during the chemical action of Fuel.

(1)

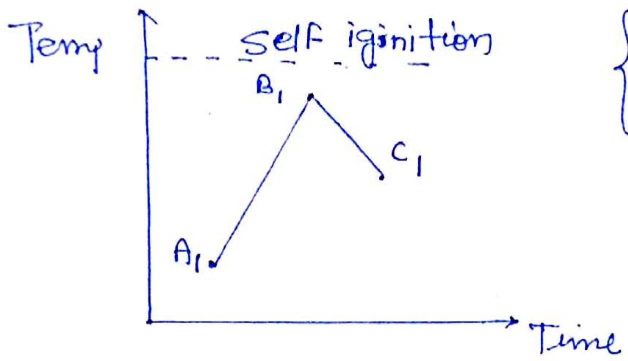


Fig (1)

{Unburn Fuel Particle (unburn hydrocarbon)}

{burn fuel से Heat unburn fuel मे आने से पहले exhaust हो जाता है so fuel unburn रह जाता है।}

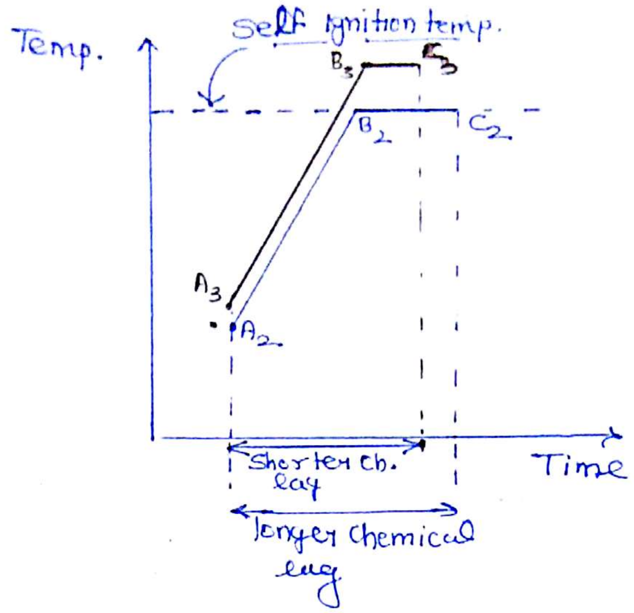
During the chemical action of the fuel particle A_1, it is found that the rise in temp and the time consumption is given by a straight line. At the end of chemical action the temp. is below the self ignition temp. (Point B_1 in the fig)

⇒ This fuel particle will remain unburn and is known as the unburn hydrocarbon (UBHC). This UBHC particle will be in circulation with

the gases & its temp decreases as the temp. will lower down for the gases during expansion after combustions. The lowering of temp. with time is also found to be a straight line (B_1C_1 in fig.) At one stage this fuel particle will be exhausted out of the engine cylinder (Point C_1)

(2) Imp

Fig (2)



* $A_2 B_2$ when temp equal to Self Ignition
* $A_3 B_2$ when temp more than self Ignition
* $B_2 C_2$ Heat distribution time (No ↑ in temp.)

Fig(2) shows the temp of the fuel particle 'A_2' being equal to the self ignition temp at the end of chemical action. For the other fuel particle 'A_3' the temp is above the self ignition temp at the end of chemical reaction. It may be seen from diagram the chemical lag for fuel particle A_2 is more than that of A_3.

→ It is thus evident, that higher the temp. of the fuel particle (Above the self Ignition temp), lesser will be the chemical lag.

→ In SI engine, it is obvious that if the temp of the end charge reaches the temp much above the self ignition temp, the chemical lag ~~in~~ of fuel particle in end charge will be much less and a seprate flame front will be definetly form in the end charge and detonation will take place.

→ It is thus clear that the temp of end charge in SI engine much be less to avoid knocking.

* Factor Affecting Detonation in SI engine! -

① **Compression ratio** :- higher compression ratio will result in the higher temp. of the charge. Tendency to detonate will increase. For this region, The compression ratio for SI engine (Petrol engine) is kept as low as between 6 to 10.

→ The effect will be the same when the inlet valve temp. is higher or a supercharger is used.

→ On using a super charger an intercooler must be provide.

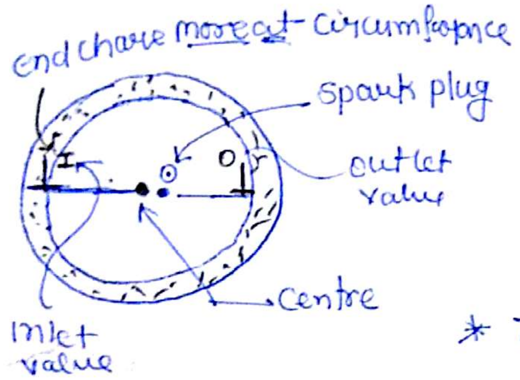
② **Increasing the Load** ! - Increasing the load or power will result in more supply of fuel. More energy will be release. The temp. of the charge will be higher thus the petrol engine must be run as less load condition

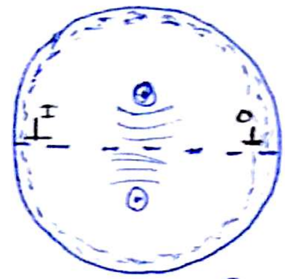
(3) **Advanceing the Spark** ! - Advancing the spark will result in more duration of spark. More energy will be receive by the charge. Temp will be higher thus the sparking should not be advance. Sparking may be retar -ded

~~Detonation~~

④ **Distance of Flame travel:-** The distance covered by the flame front must be such that by the time taken by it should be less than the chemical lag of end charge for this purpose the cylinder diameter of a S I engine is restricted to a maximum 15 cm
(अगर Power बढ़ानी हो तो dia. नहीं बढ़ाना एक और cylinder use मे लेना पड़ेगा)
(Knock हो जायेगी अगर dist ज्यादा हुई तो।)

⑤ **Location of Spark Plug:-**





Flame reaches fast at end charge (दोनो Flame के टकराने से पहले end charge जल जायेगा)

* Two spark plug (Place opposite to center line)

The spark plug must be located nearest to the centre and away from the inlet value. The reason is that of inlet value temp is higher then knocking in SI engine will increase.

⑥ **Higher Engine speed:-** Increasing the speed will result in turbulance being setup for the flame front. The flame front will reach the end charge faster in all direction. The tendency to knock will decrease.

Thus the ideal combination to prevent detonation in SI engine is high speed and low load.

(7) Air-Fuel Ratio :- (see equivalent ratio ϕ)

(8) Quality of fuel :-

Standard Fuel

{ Iso octane (zero knock)
{ Normal Heptane (Readily knocking)
n-

To determine the quality of fuel, It is compared with a Standard fuel in the Lab. The standard fuel is a mixture of two other fuel. One is Iso octane (zero knock) and the other is normal Heptane (Readily knocks). If octane in mixture is 70% that matches with the knock quality of petrol, Then petrol is said to have an octane number 70. ⇒ Higher the octane number batter is the quality of petrol.

⇒ In India, the octane number of the petrol available is between 70 - 80. For special quality fuel like extra primium, Speed the octane number is between 90 - 94.

Question (IES 2001) What is the value of fuel air ratio in the normal operation range.

(a) 0.056 to 0.083 (b) 0.083 to 0.56

(c) 0.0056 to 0.83 (d) 0.056 to 0.83

Air fuel ratio for normal operation speed

$= \frac{16}{1}$

Fuel air $= \frac{1}{16} = 0.0625$

0 – 15 km/h idling speed

15 – 65 km/h Crushing speed (Normal)

(a) $F/A = \frac{0.056}{0.083} = 0.675$ ✗

(b) $F/A = \frac{0.083}{0.56} = 0.148$ ✗

(c) $F/A = \frac{0.0056}{0.83} = 0.00675$ ✗

(d) $F/A = \frac{0.056}{0.83} = 0.0675$ ✓

Choice (D) Match with the fuel air ratio of the normal operating range.

V. Imp Question In a SI engine Combustion in stage 1 takes 1 mili second and stage 2 takes 1.5 millisecond when engine runs at 1000 rpm. If stage 1 time is independant of speed, what will the additional spark advanced when engine speed is double.

(a) 0° (b) 6° (c) 12° (d) 24°

$1 \times 10^{-3} = \frac{\theta}{360 N}$

6

Sol^n

Speed (rpm)	Stage 1	Stage 2
1000	1 m sec.	1.5 millisecond
2000	1 m sec.	?

⇒ $1000 \text{ rev/m} = \frac{1000}{60 \times 1000}$ rot./millisecond

$= \frac{360° \times 1000}{60 \times 1000}$ deg/millisecond

$= 6°$/msec. ~~Ans~~

Correct Ans: At 2000 rpm, Angle turne = $(2 \times 6°) = 12°$

therefore spark advance = $12 - 6 = 6°$ Ans

Question IES 2006: To prevent detonation in SI engine the end charge should have.

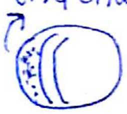
~~(a) low temp.~~ ~~(b) low density~~ (c) long Ignition delay

↓ it mean chemical delay in SI engine

$\rho = \frac{m}{V}$ ← const for end charge

ρ less so m less

So less heat trans fer so low temp.

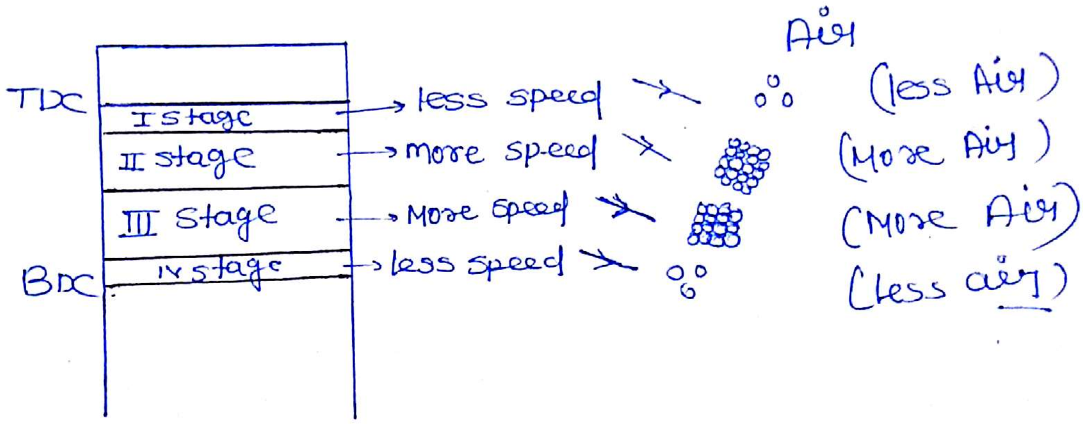


(b) Low density! – for low density of end charge the mass of the fuel in the end charge will also be less. for less quantity of fuel less heat will be develope during chemical action of fuel particle in the end charge. The temp. of ~~eng~~ end charge will also be less.

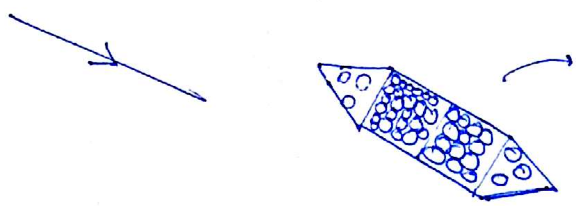
The chemical lag will be more the flame front from the spark plug will reach end charge before deformation of seprate flame front in end charge. There for detonation will be priventented.

Combustion in CI Engine:- (Diesel engine)

Four stages of suction:-

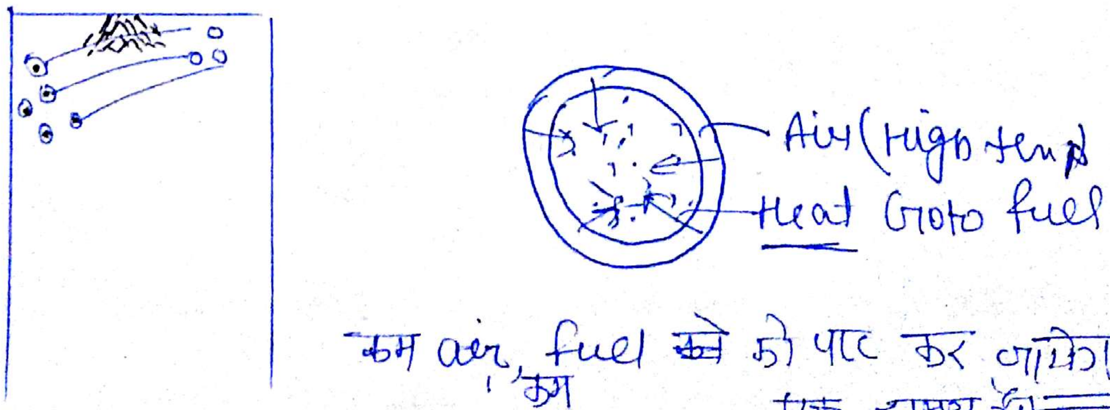


Total Air



Mixing of air will not occur because pressure is maintain

I Stage of Combustion:-



कम air, fuel को जो पार कर जायेगा।
कम
एक समय में

(i) The temp at the start of the I stage of Combustion (end of compression) will be close to the self Ignition temp

(ii) less air is circulated during the I stage of combustion hence the fuel supplied during the fuel spray is also very less.

(iii) when air is crossing the fuel spray, the air and the fuel particle will be physically in contact with one another for some time. This time taken is know as the physical delay

(iv) Thus, for diesel engine ~~Ignition delay = (ph~~

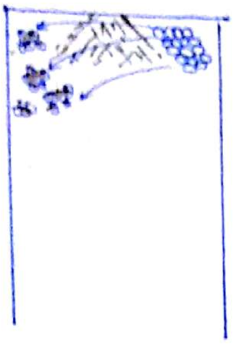
Ignition delay = (Physical delay + chemical delay)

(v) Since the temp. of the Combustion Chamber is close to the self Ignition temp. the chemical delay will be longer.

(vi) The I stage of Combustion is know as the delay period

(vii) The temp. of Combustion chamber at the end of the I stage of Combustion will be above the self Ignition temp.

II stage of Combustion :- (Knocking होगा तो यहीं होगा नहीं तो नहीं होगा)



(i) Plenty of air is under circulation. Hence mass of fuel supplied during fuel spray is also large quantity.

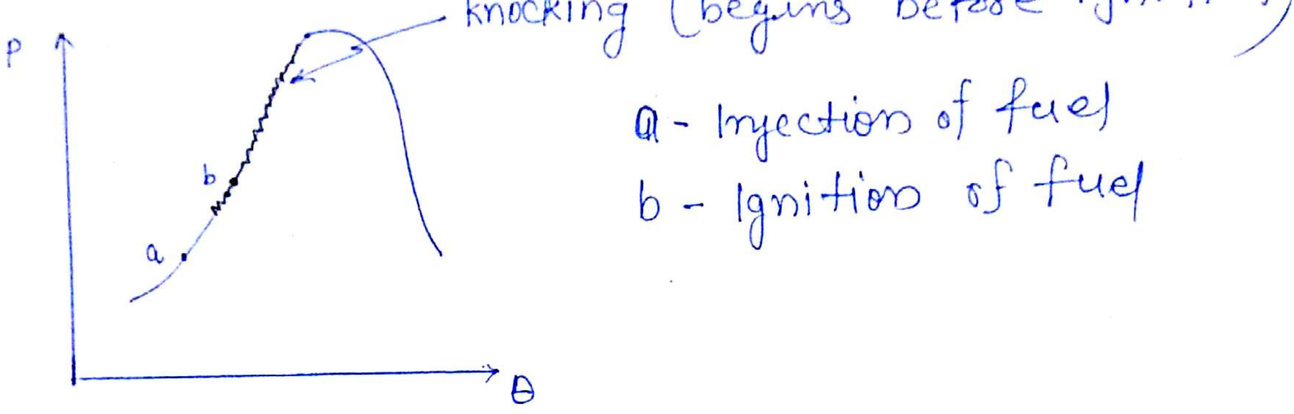
(ii) The temp. of the combustion chamber during the second stage of combustion is above the self ignition temp.

(iii) Since large mass of air under circulation hence air crosses the fuel spray in diff. batches.

iv) Due to ~~very high temp.~~ high temp. of combustion chamber combustion takes places for all the diff batches of AFM faster. If combustion in this manner till the last batch of AFM then combustion is said to be normal or smooth.

v) On the other hand if a perticular batch of air carries less fuel with it, then during chemical action less heat will be generated and the temp of charge will be close to the self ignition temp. The chemical delay will be longer in the main time more batches of ARM will get collected with this batch resulting in the combustion taking place for all the batches at the same time. Anomause amount of energy will be librated that the piston is unable to handle and knocking occurs.

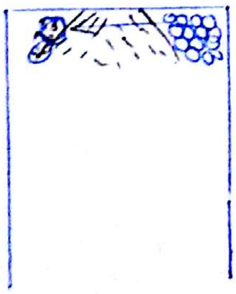
vi)



(vii) The second stage of combustion is known as uncontrolled combustion

viii) The temp at the end of the second stage of combustion is very much above the self ignition temp.

III Stage Combustion :-



Fuel को पार करते ही combustion हो जायेगा इसलिए

(i) The temp. at the start of 3rd stage of combustion is very much above self ignition temp.

(ii) Plenty of air under circulation during the 3rd stage of combustion. Thus the fuel spreade in large quantity

(iii) The air crosses the fuel spray in different batches

vi) Since the temp. of combustion chamber is much above the self ignition temp hence combustion takes place for all the batch imediatly after crossing the fuel spray.

ii) knocking does not takes place during the 3rd stage of combustion

iii) The III stage of combustion is called controlled combustion

IV <u>stage of combustion</u>:-

(i) less air is available for combustion. Hence the fuel supply is also very less.

(ii) combustion during the 4nd stage takes place from the heat transfer after buring of the fuel particle.

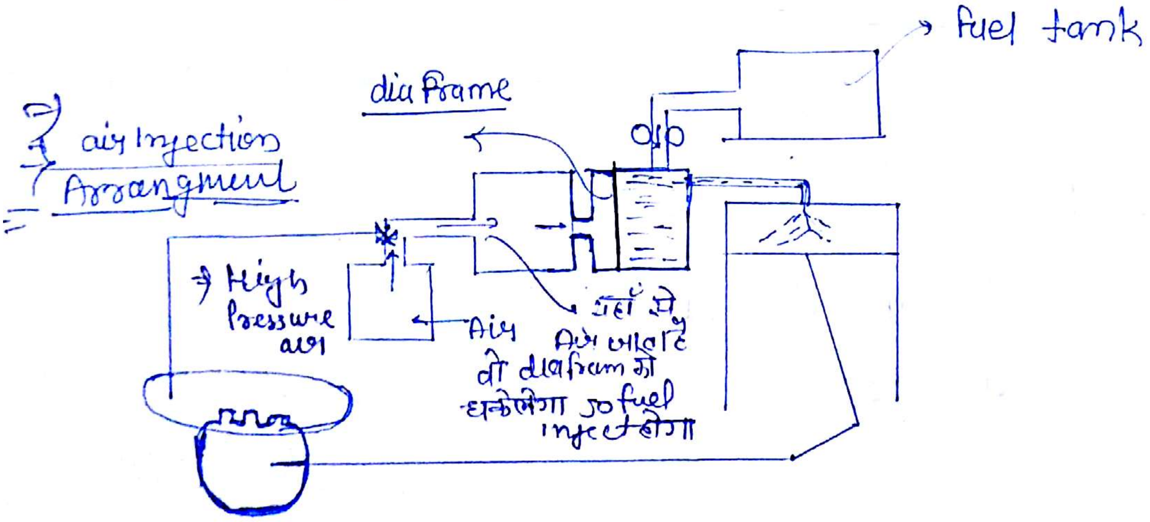
III) The 4th stage of combustion is known as after buring.

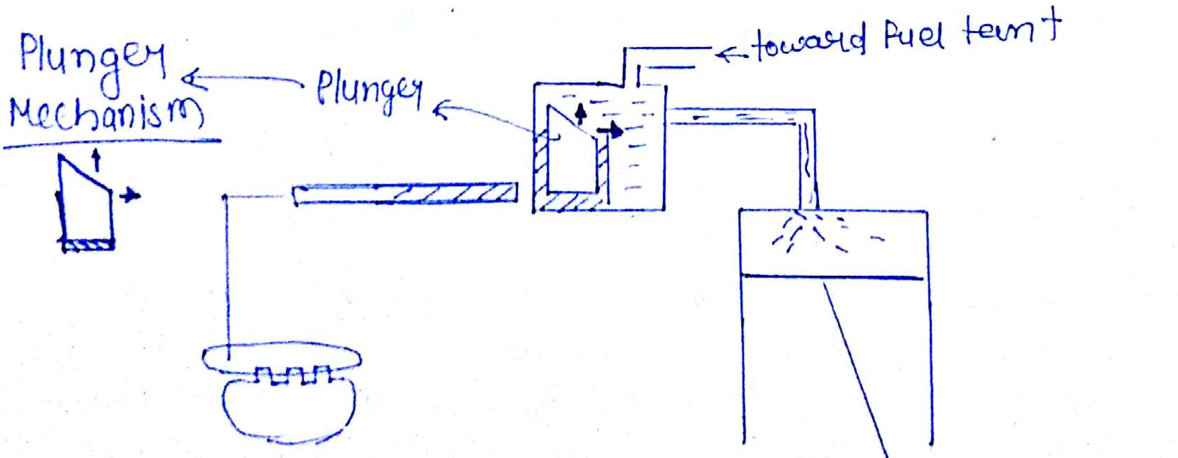
factor Affecting the knocking of CI engine :-

① **Compression Ratio :-** Higher compression ratio will result in higher temp. of the charge. Tendency to knock will be less. Due to the reason, the compression ratio of Diesel engine is as high as b/w 16 to 20.

→ same effect will be the same when inlet valve temp. is higher or supercharge is used.

② **Increasing the speed :-**





→ Solid Injection Engine (solid acting on fuel) higher engine speed will result in more fuel supplied during the first stage of combustion Hence less fuel will be available during the 2nd stage of combustion. Tendency to knock will increase. Thus Diesel engine must be run at less speed.

(3) Higher Engine load :- Higher engine load will result in more power and more fuel supplied. The temp. of ~~the~~ the charge will be higher Tendency to knock will decrease.

* Thus the ideal combination ~~for~~ to avoiding knocking in diesel engine is less speed and higher load.

(4) Atomisation :- For better atomisation, the fuel spray will cover more space. The air particles will take more time to cross the fuel spray. The physical lag will be more, Air will carry more fuel with it. Tendency to knock will be reduced.

More space, More fuel, go with air

(5) Advancing the fuel Injection :→ Advancing the fuel injection will result in lesser compression. Temp of the charge will be lesser tendency to knock will increase Thus the injection of fuel should not be advance. it may be retarted.

(6) Quality of Fuel :-

Standard Fuel

1) Normal Cetane (zero knock)
2) α - Methyl Napthalene (Readily knock)

Higher the cetane number of diesel fuel better will be the antiknock quality.

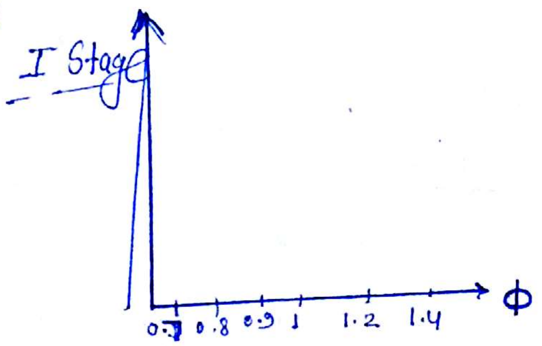
The diesel fuel available in india has a cetane number between 40 & 50.

Chap-2

Q.1

(i) when the self-ignition temp is increase the temp. of fuel particle must also be increase to the self ignition temp. for combution the preparatoy phase increase.

(ii)



{ $\phi < 1$
All fuel burn
Fuel ↑, T ↑ , ↗

कम fuel कम temp. (self Ignition के पास)

~~so chemical lag ↑~~

The $\phi < 1$, intially, when more fuel supplied at start all the fuel will burn & the temp. of charge will be above self Ignition temp the preparatoy phase ↓, later when the ϕ is 1.4 or above There will be shrortage of O_2 thus less fuel will only under go Combustion. temp of charge will be close to self ignition. the chemical delay will be longer. More time will be taken for the Combustion of the fuel. The preparatory phase will increase

Q.8
C

$\eta = 1 - \left(\frac{1}{r}\right)^{\gamma - 1}$ → constant (depends only cylinder size) Not on temp.)

$\eta = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma - 1} = 1 - \frac{T_1}{T_2}$ → Ratio will be same

Q.9

Preignition :- Unburn hydrocarbon stick to the inner value of the cylinder. when it is in circulation with Gases (After Combustion)

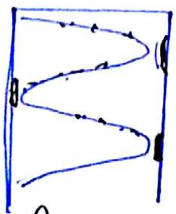


Fig. 1

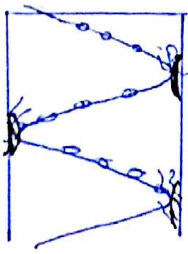


Fig. 2

At the start of the next cycle, fresh AFM will enter in. Some of fuel particle in fresh AFM will contact the UBHC sticking to the cylinder walls. Heat transfer takes place due to which Ignition may take place. for a few of the fuel particle.
This ignition is know as preignition or misfiring.

Fig 3

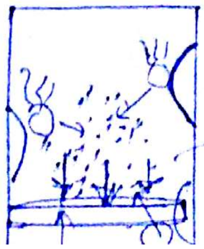


Fig ③ → The heat liberated from free ignited fuel will be take by the air particle and the air inside the cylinder will expand in all direction the air expanding downward will collide with piston moving upward during compression st[roke] due to this there is loss of work. under worst circum[stances] the entire work that ...