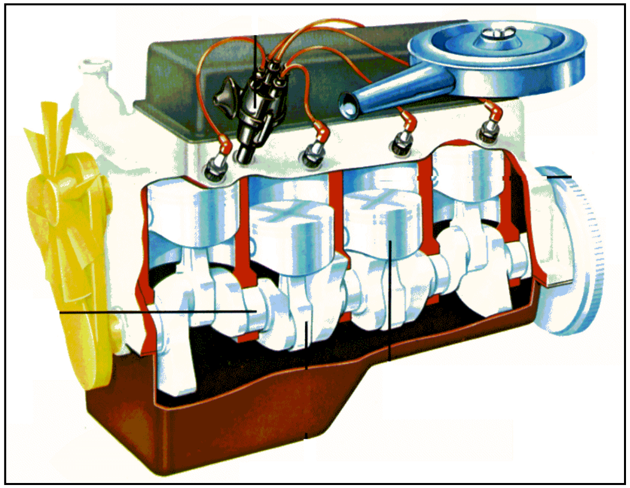
COMBUSTION IN SPARK IGNITION ENGINES

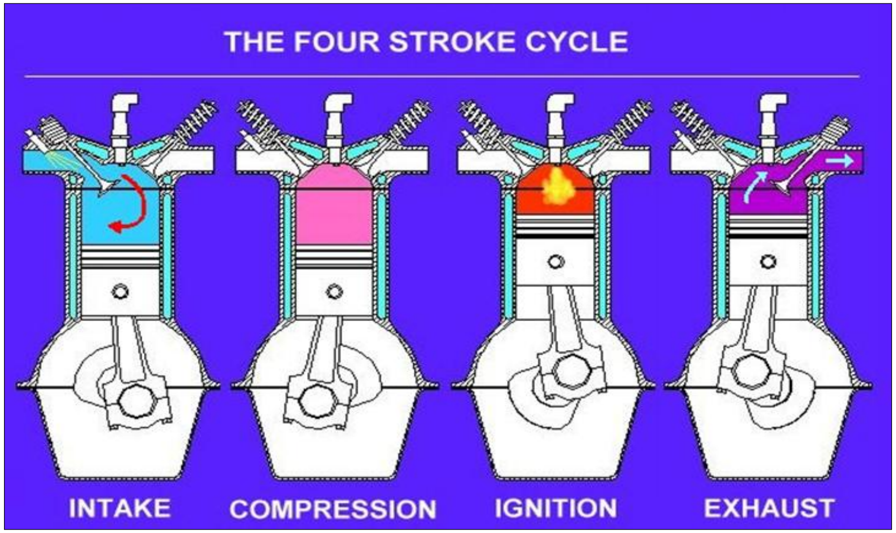
Introduction of SI Engine

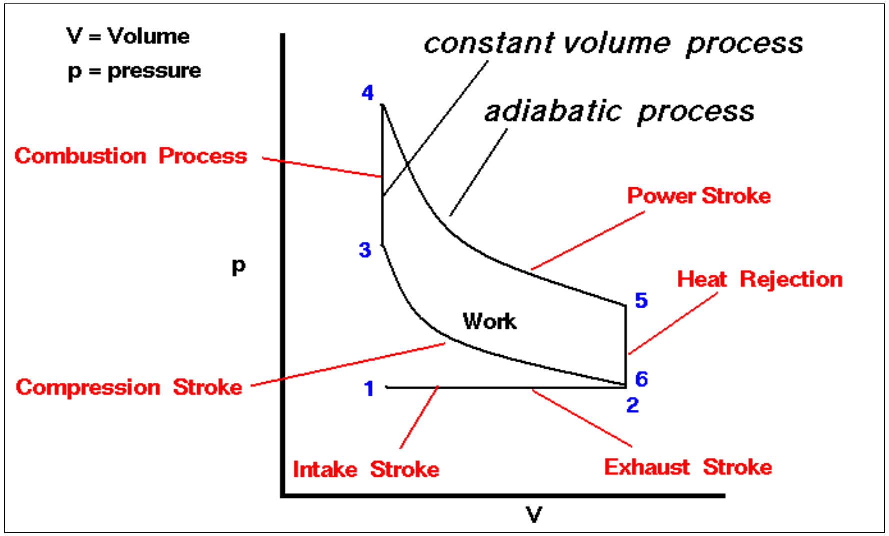


- Combustion may be defined as a relatively rapid chemical combination of hydrogen and carbon in the fuel with the oxygen in the air resulting in liberation of energy in the form of heat.
- The conditions necessary for combustion are;
  - The presence of a combustible mixture,
  - Some means of initiation of combustion,
  - Stabilization and propagation of flame in the combustion chamber,
- In SI engines the combustible mixture is generally supplied by the carburetor and the combustion is initiated by an electric spark given by a spark plug.
- A chemical equation for combustion of any hydrocarbon can be written as follows:

$$C_8H_{18} + 12.5\,O_2 = CO_2 + 9\,H_2O$$

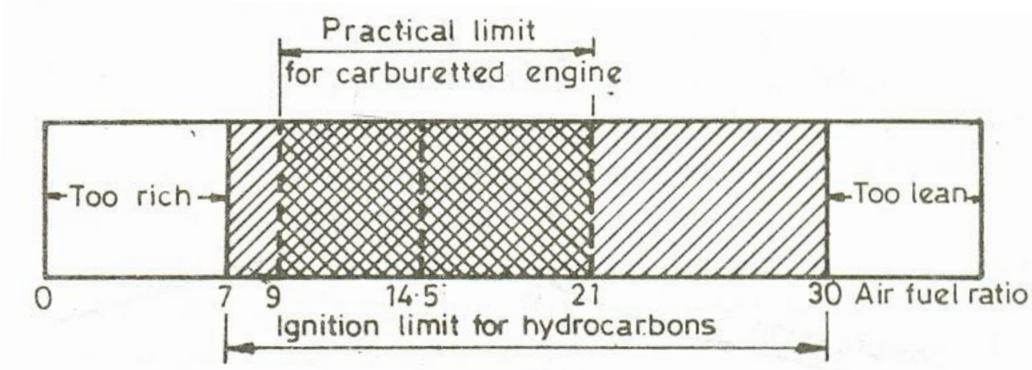
Working of SI Engine

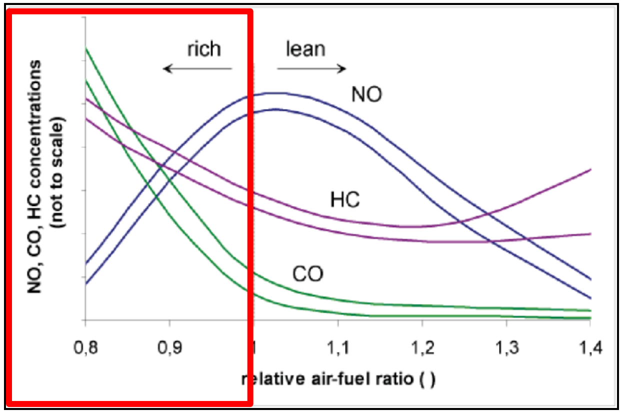


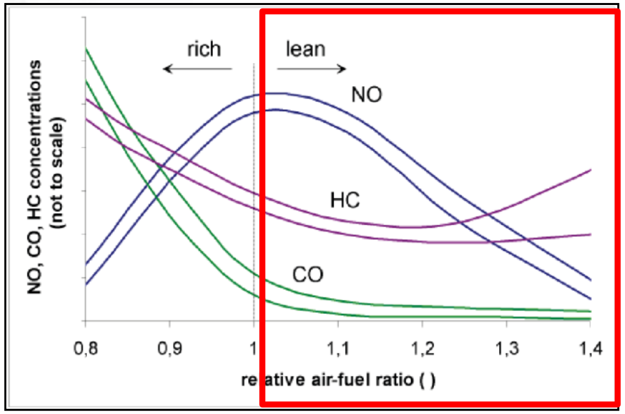


- In spark-ignition engine the fuel and air are mixed together in the intake system outside the engine cylinder.
- This air-fuel vapors is inducted through the intake valve into the cylinder.
- Where it mixed with residual gas, and then compression take place.
- Under normal operating conditions, combustion is initiated towards the end of the compression stroke at the spark plug by an electric discharge.
- A turbulent flame develops, propagates through this premixed fuel, air, burned gas mixture until it reaches the combustion chamber walls, and then extinguishes.
- In SI engine compression ratio is about 8 to 10.

Ignition Limits



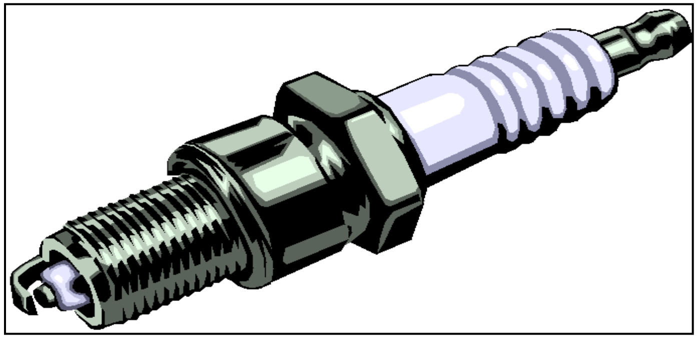


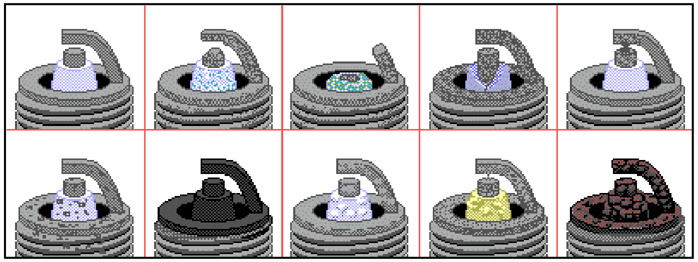


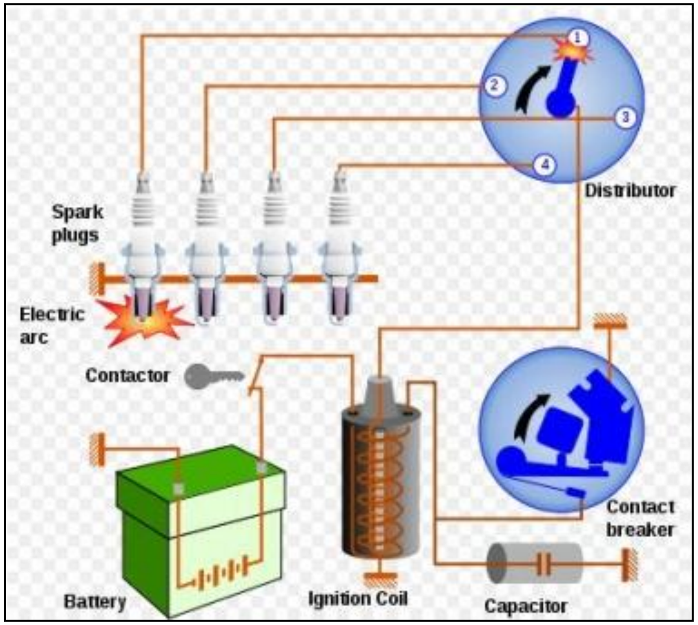
- ❖ Ignition of the charge is only possible within certain limits of air-fuel ratio.
- ❖ For hydrocarbon fuel the stoichiometric air-fuel ratio is about 15:1.
- ❖ Ignition limit for hydrocarbon fuel must lie between 7:1 to 30:1.
- ❖ The lower and upper ignition limits of the mixture depend upon mixture ratio and temperature.
- ❖ The ignition limits are wider at increased temperatures because of higher rates of reaction and higher thermal diffusivity coefficients of the mixture.

Spark Plug

- For a spark to jump across an air gap of 0.6 mm in an engine cylinder, having a compression ratio of 8:1, approx. 8 kV is required. Ignition system has to transform battery voltage of 12 V to 8-20 kV and, has to deliver the voltage to the right cylinder, at the right time.
- About 0.2 mJ of energy is required to ignite a stoichiometric mixture at normal engine operating conditions by means of a spark. Over 3 mJ is required for a rich or lean mixture. In general, ignition systems deliver 30 to 50 mJ of electrical energy to the spark.
- Fundamental requirements of the ignition source:
  - A high ignition voltage to break down in the spark-gap,
  - A low source impedance or steep voltage rise,
  - A high energy capacity to create a spark kernel of sufficient size,
  - Sufficient duration of the voltage pulse to ensure ignition,







Ignition System in SI Engines

When the mixture could be ignited:

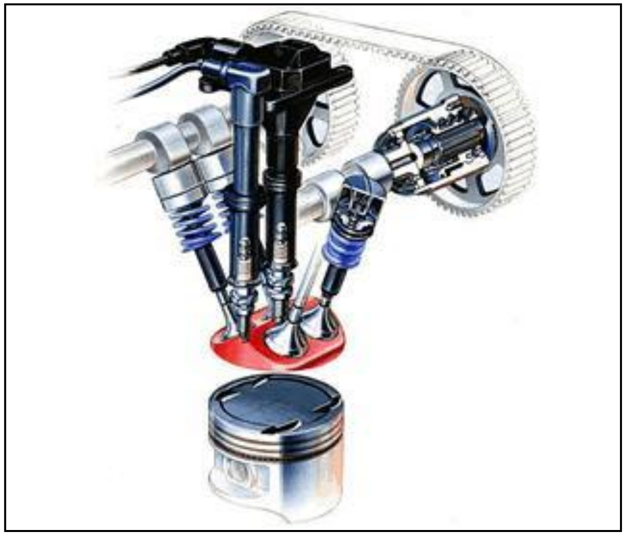
(a) Spark energy must be higher than the minimum energy of ignition of the mixture,

(b) Distance between electrodes is larger than the extinguishing distance for a given mixture,

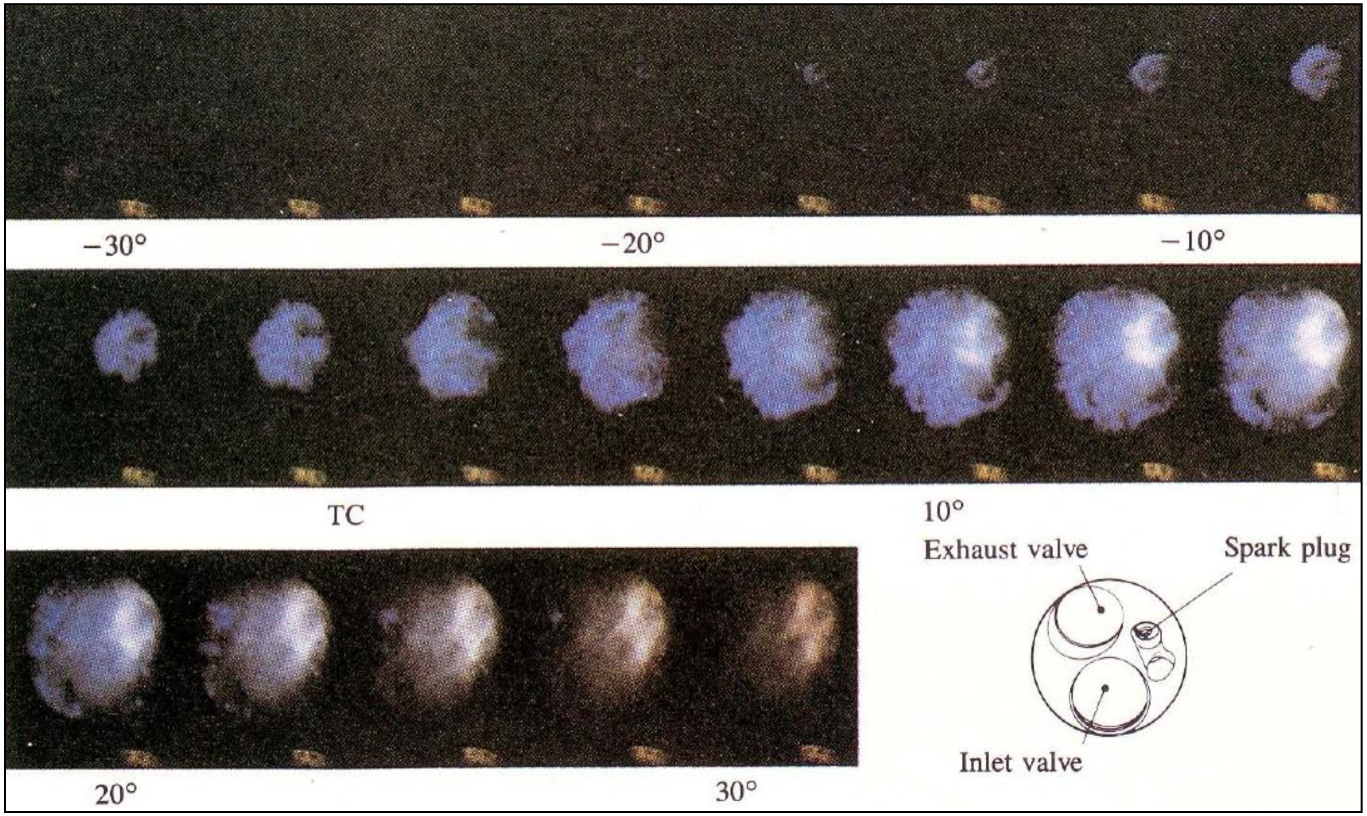
(c) Local gradient of velocity is smaller than the critical for a given mixture.

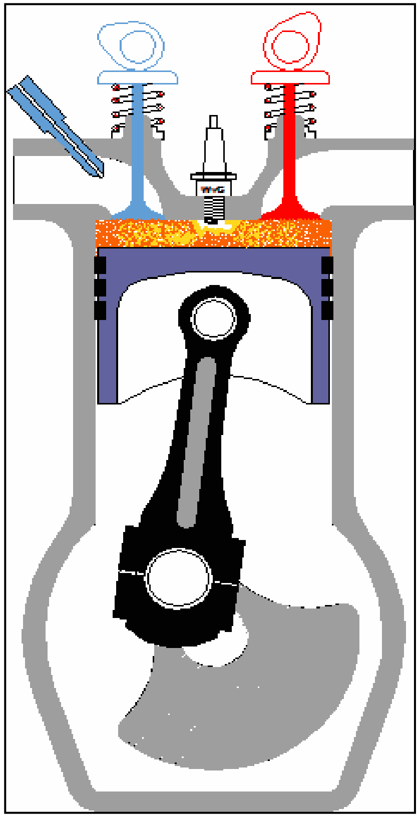
Improvement of spark ignition effectiveness

1. Energy of spark generated by spark-plug is in the range of 50-100 mJ. This is enough for ignition of stoichiometric mixture, but it could be not enough for the lean mixtures.
2. To improve the effectiveness of spark ignition of lean mixtures a few modifications of SI engines ignition systems have been proposed:
   - ❖ 2- spark-plug systems (twin-spark),
   - ❖ Increase of ignition energy by:
     - ➢ Increase of spark energy,
     - ➢ Laser ignition
   - ❖ Increase the distance between electrodes



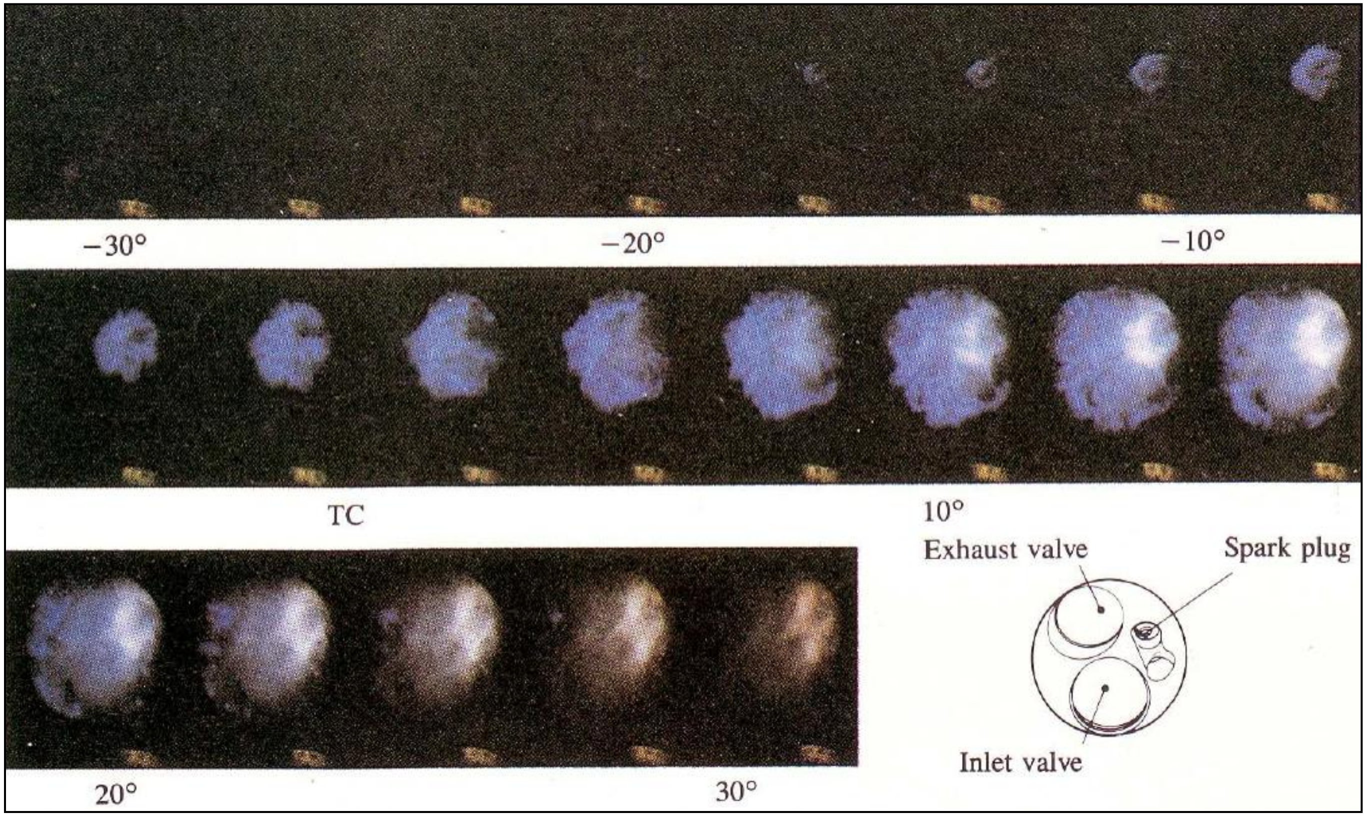
Spark and Flame Propagation

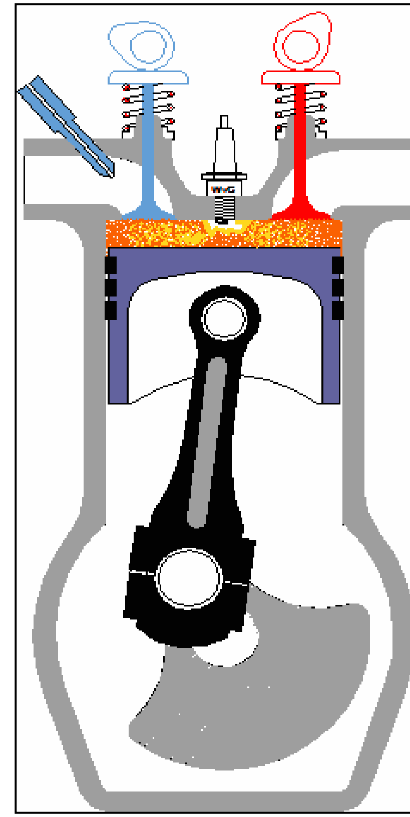




- Spark discharge is at -30˚ & flame is visible first at -24˚.
- Nearly circular flame propagates outward from the spark plug location. Irregular shape of turbulent flame front is apparent.
- Blue light is emitted most strongly from the flame front.
- At TC, flame diameter ≈2/3 of cylinder bore.

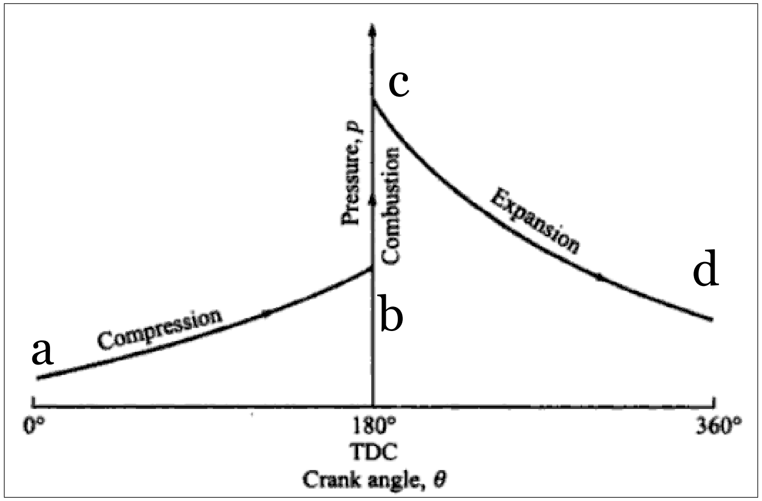
Spark and Flame Propagation

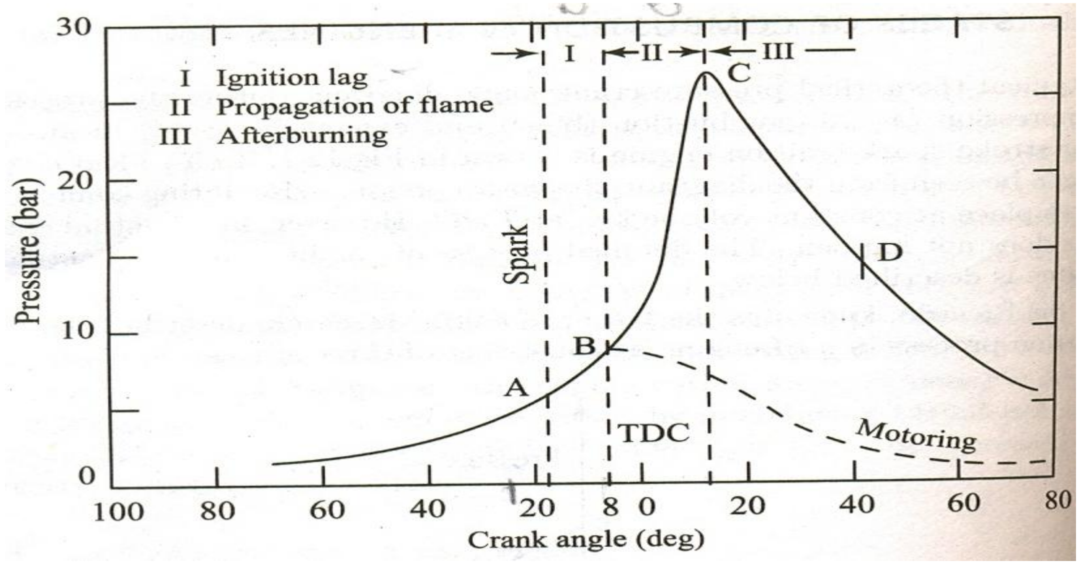




- ❖ Flame reaches the farthest cylinder wall at 15˚ ATC, but combustion continues for another 10˚.
- ❖ At about 10° ATC, additional radiation - initially white, turning to pinkish-orange – centered at the spark plug location is evident.
- ❖ These afterglow comes from the gases behind the flame as these are compressed to the highest temperatures attained in the cylinder (at about 15° ATC) while the rest of the charge burns.

Stages of Combustion in SI Engines





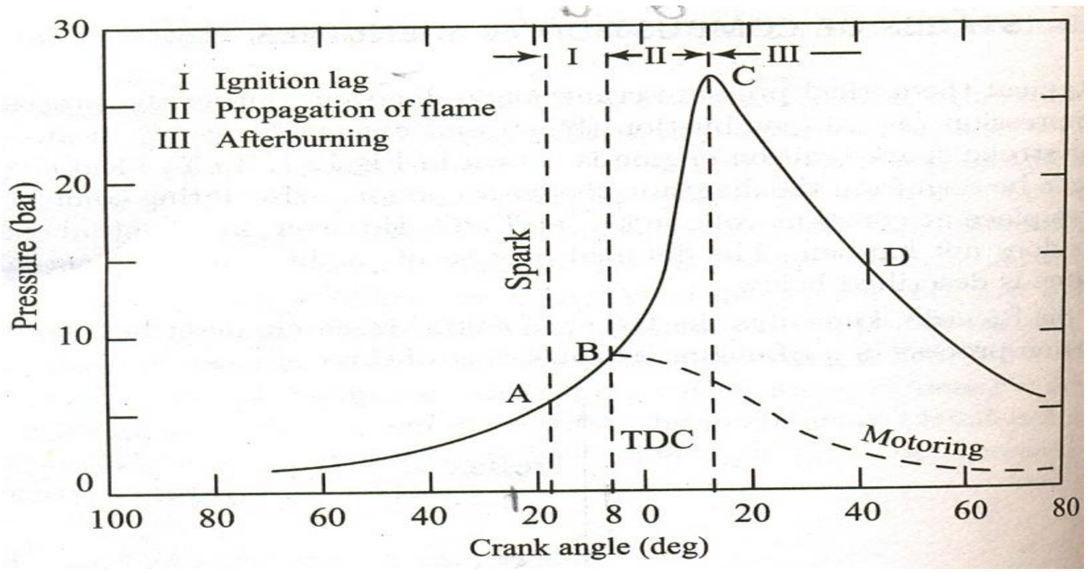
- Theoretical diagram of pressure crank angle diagram is shown. (a→b) is compression process, (b→c) is combustion process and (c→d) is an expansion process.
- In an ideal cycle it can be seen from the diagram, the entire pressure rise during combustion takes place at constant volume i.e., at TDC. However, in actual cycle this does not happen.

Ricardo's Theory of Combustion

Sir Ricardo, known as father of engine research describes the combustion process can be imagined as if it is developing in two stages:

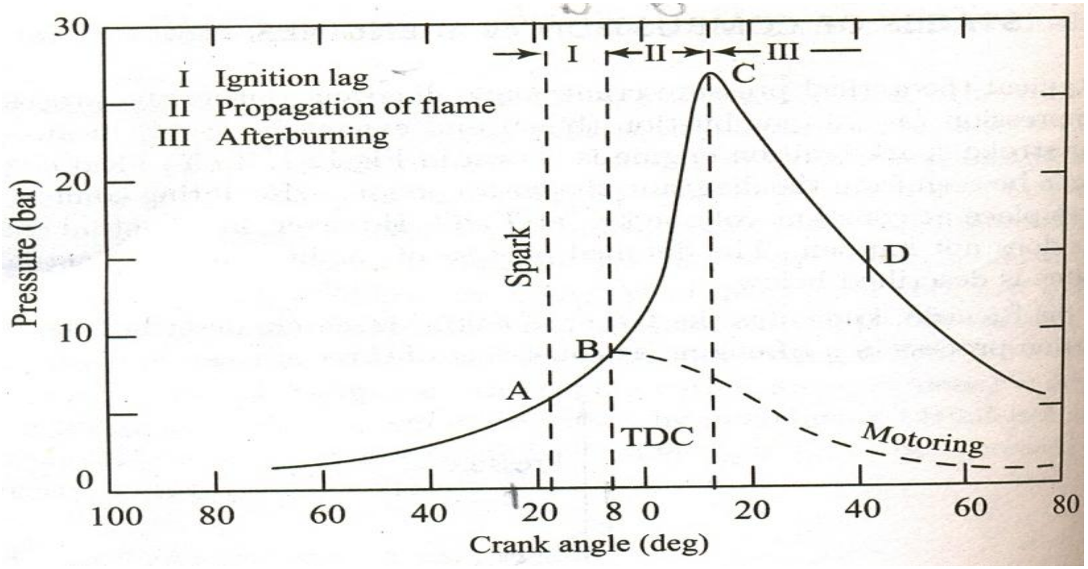
1. Growth and development of a self propagating nucleus flame (Ignition lag).
2. Spread of flame through the combustion chamber.

Stages of Combustion in SI Engines



- Detailed process of combustion in actual engine is different from the theoretical process. Sir Ricardo describes the combustion process in an actual SI engine as consisting of three stages:
- A shows the point of the passage of the spark (about 20° BTDC), B the point at which the first rise of the pressure can be seen (about 8° BTDC) and C the attainment of the peak pressure.
- AB represent the first stage (Ignition lag)
- BC represent the second stage (Propagation of flame)
- CD represent the third stage (Afterburning)

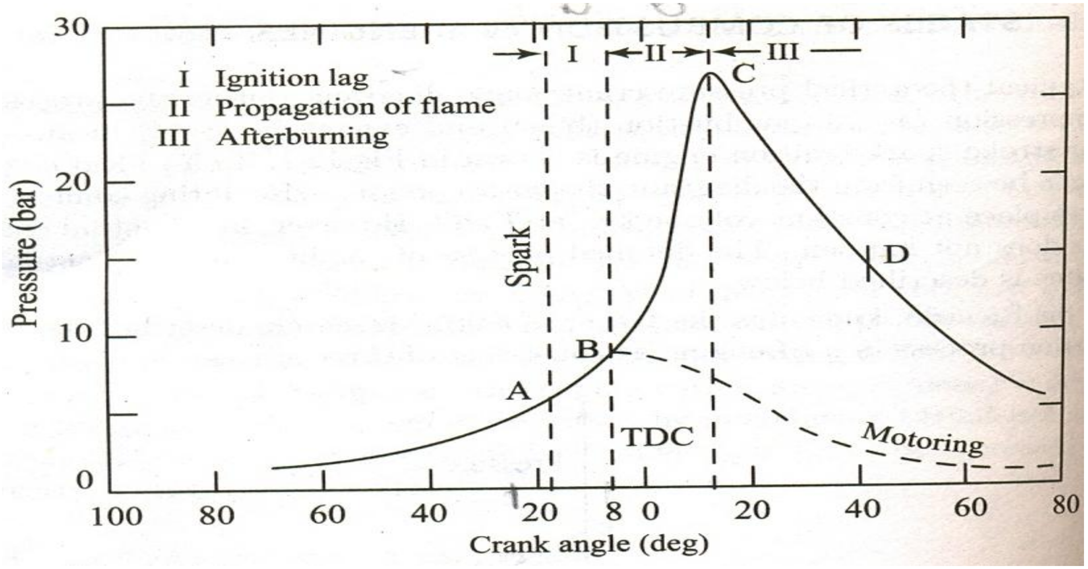
Stages of Combustion in SI Engines



Ignition Lag

- ❖ There is a certain time interval between instant of spark and instant where there is a noticeable rise in pressure due to combustion. This time lag is called **Ignition Lag**.
- ❖ Ignition lag is the time interval in the process of chemical reaction during which molecules get heated up to self ignition temperature , get ignited and produce a self propagating nucleus of flame.
- ❖ Ignition lag is very small and lies between 0.0015 to 0.002 seconds. An ignition lag of 0.002 seconds corresponds to 35 deg crank rotation when the engine is running at 3000 RPM.
- ❖ This is a chemical process depending upon the nature of fuel, temperature and pressure, proportions of exhaust gas and rate of oxidation or burning.

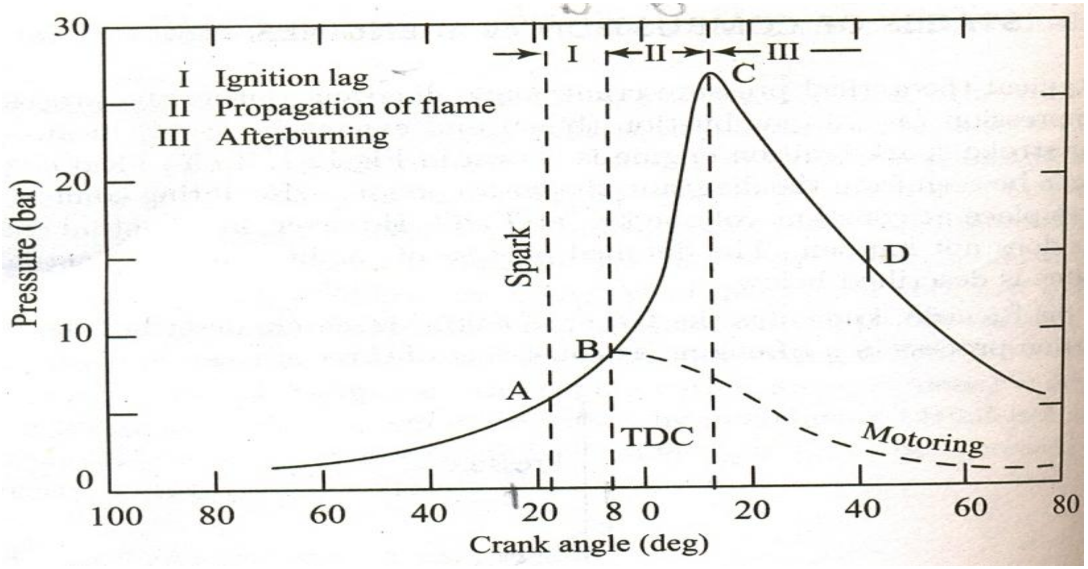
Stages of Combustion in SI Engines



Propagation of flame

- Once the flame is formed, it should be self sustained and must be able to propagate through the mixture. This is possible when the rate of heat generation by burning is greater than heat lost by flame to surrounding.
- The starting point of the second stage is where first measurable rise of the pressure can be seen on the indicator diagram.
- This stage is also called as main stage as about 87% energy evolved in this stage.

Stages of Combustion in SI Engines

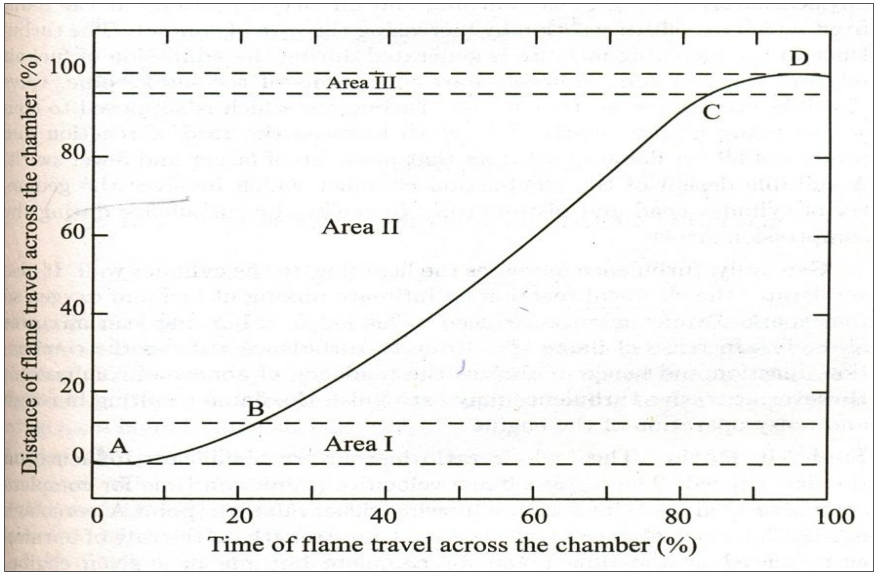


Afterburning

- Combustion does not terminate at this point and afterburning continues for a long time near the walls and behind the turbulent flame front.
- The combustion rate in this stage reduces due to surface of the flame front becoming smaller and reduction in turbulence.
- About 10% or more heat is evolved in after-burning stage.

Flame Front Propagation

- **A-B:** The flame front progresses relatively slowly due to a low transposition rate and low turbulence.
- **B-C:** The flame front leaves the quiescent zone and proceeds into more turbulent area. It consumes a greater mass of mixture and it progresses more rapidly and at a constant rate.
- **C-D:** The volume of unburned charge is very much less towards the end of flame travel so transposition rate again becomes negligible which reduces the flame speed.
- Rate of flame propagation affects the combustion process in SI engines. Higher combustion efficiency and fuel economy can be achieved by higher flame propagation velocities. Unfortunately flame velocities for most of fuel range between 10 to 30 m/second.



The factors which affect the flame propagations are;

- ✓ Air fuel ratio
- ✓ Compression ratio
- ✓ Load on engine
- ✓ Turbulence and engine speed
- ✓ Other factors

Effect of Engine Variables on Ignition Lag

- First phase of combustion is called ignition lag.
- This time is normally about 0.0015 second and crank angle is 10 to 20 degrees.

Nature of Fuel

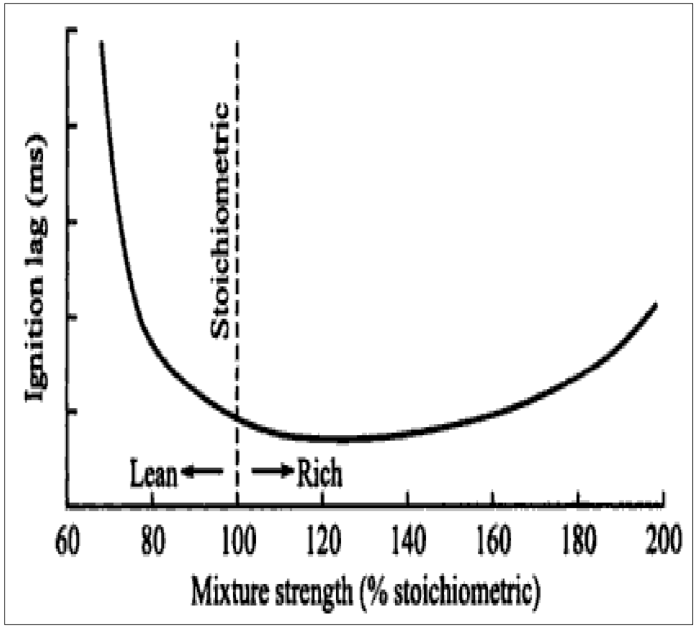
- The ignition lag depends on the chemical nature of the fuel.
- The higher the self-ignition temperature of the fuel, the longer the ignition lag.

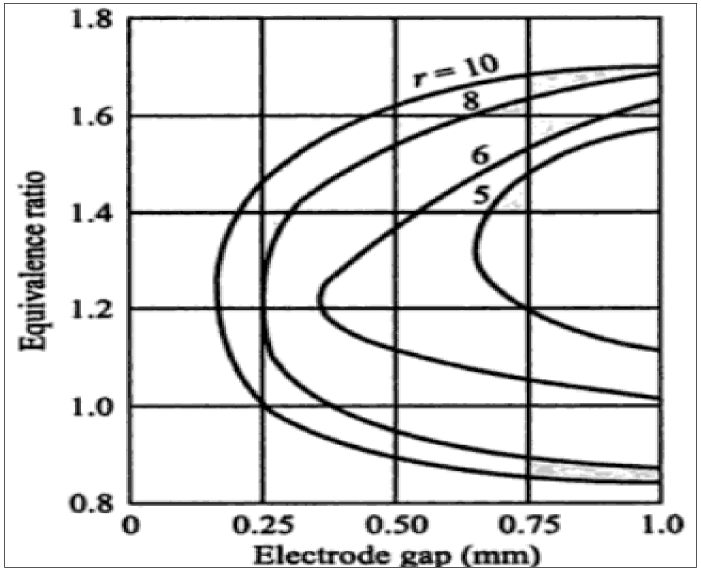
Mixture ratio

- The ignition lag is smallest for the mixture ratio which gives the maximum temperature. This ratio is somewhat richer than the stoichiometric ratio.

Electrode gap

- If gap is too small quenching of flame nucleus may occur but if it too large spark intensity reduced . Lower the compression ratio higher the electrode gap required.





Effect of Engine Variables on Ignition Lag

Initial temperature and pressure

- Increasing the intake temperature and pressure, increasing the compression ratio and retarding the spark, these all reduce the ignition lag.

Turbulence

- Excessive turbulence of the mixture in the area of spark plug is harmful.
- Since it increases the heat transfer from the combustion zone and leads to unstable development of the nucleus of flame.

Factors Influencing The Flame Speed

Turbulence

- Turbulence increases the heat flow to the cylindrical wall. It also accelerates the chemical reaction by intimate mixing of fuel and oxygen so that spark advance may be reduced.
- This helps in burning lean mixture also. The increase of flame speed due to turbulence reduces the combustion duration and hence minimizes the tendency of abnormal combustion.
- However, excessive turbulence may extinguish the flame resulting in rough and noisy operation of the engine.

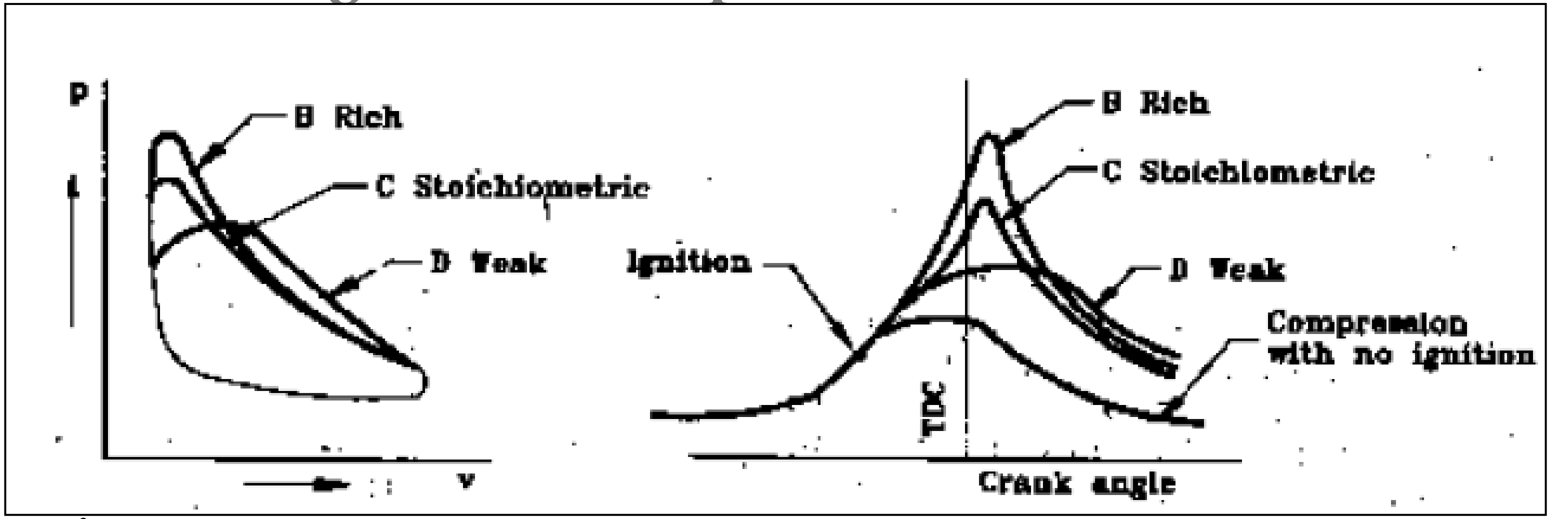
Temperature and Pressure

- Flame speed increases with an increase in intake temperature and pressure.
- A higher initial pressure and temperature may help to form a better homogeneous mixture which helps in increasing the flame speed. This is possible because of an overall increase in the density of the charge.

Engine Speed

- The flame speed increases almost linearly with engine speed.
- Since the increase in engine speed increases the turbulence inside the cylinder.

Factors Influencing The Flame Speed



Fuel-Air Ratio

- The Fuel-air ratio has a very significant influence on the flame speed. The highest flame velocities (minimum time for complete combustion) are obtained with somewhat richer mixture (point A) as shown in fig.
- When the mixture is made leaner or richer the flame speed decreases.
- Less thermal energy is released in the case of lean mixtures resulting in lower flame temperature.
- Very rich mixtures lead to incomplete combustion which results in the release of less thermal energy.

Engine Output

- The cycle pressure increases when the engine output is increased. With the increased throttle opening the cylinder gets filled to a higher density. This results in increased flame speed.

Factors Influencing The Flame Speed

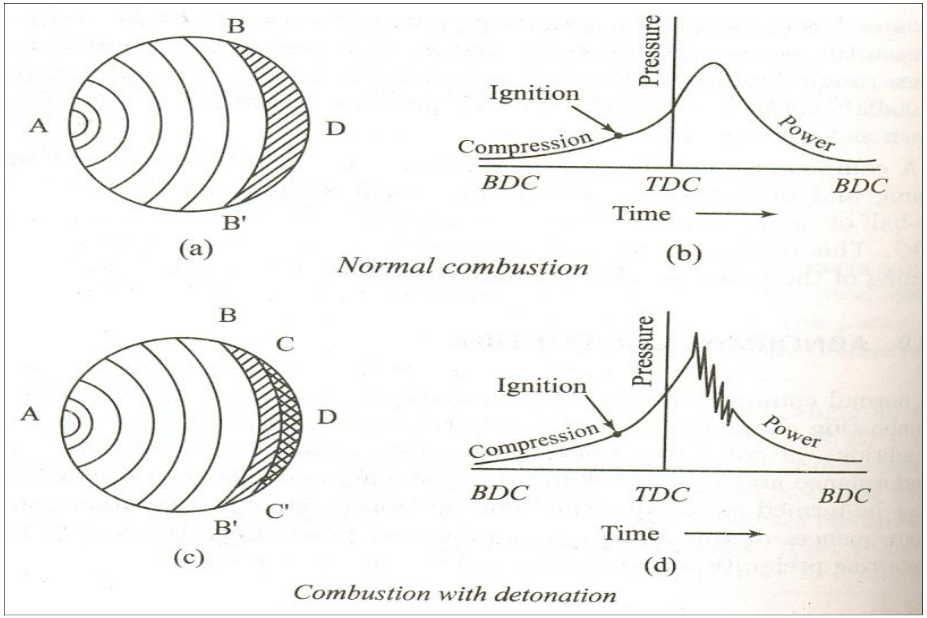
Compression Ratio

- A higher compression ratio increases the pressure and temperature of the working mixture which reduces the initial preparation phase of combustion and hence less ignition advance is needed.
- Thus engines having higher compression ratios have higher flame speeds.

Engine Size

- The size of the engine does not have much effect on the rate of flame propagation.
- In large engines the time required for complete combustion is more because the flame has to travel a longer distance.
- This requires increased crank angle duration during the combustion. This is one of the reasons why large sized engines are designed to operate at low speeds.

The Phenomenon of Knock in SI Engines



- ❖ Fig (a) shows the cross-section of the combustion chamber with flame advancing from the spark plug location A without knock.
- ❖ Fig. (c) shows the combustion process with knock.
- ❖ In the normal combustion the flame travels across the combustion chamber from A towards D.
- ❖ The advancing flame front compresses the end charge BB'D farthest from the spark plug, thus raising its temperature.
- ❖ The temperature is also increased due to heat transfer from the hot advancing flame front.

Phenomenon of Knock in SI Engines

- ❖ The temperature of the end charge had not reached its self-ignition temperature, the charge would not auto-ignite and the flame will advance further and consume the charge BB'D. This is the normal combustion process.
- ❖ If the end charge BB'D reaches its auto-ignition temperature and remains for some time equal to the time of pre flame reactions the charge will auto-ignite, leading to knocking combustion.
- ❖ When flame has reached the position BB', the charge ahead of it has reached critical auto-ignition temperature. During the pre flame reaction period if the flame front could move from BB' to only CC' then the charge ahead of CC' would auto-ignite.
- ❖ Because of the auto-ignition, another flame front starts traveling in the opposite direction to the main frame front.
- ❖ When the two flame fronts collide, a severe pressure pulse is generated.
- ❖ The gas in the chamber is subjected to compression and rarefaction along the pressure pulse until pressure equilibrium is restored.
- ❖ This disturbance can force the walls of the combustion chamber to vibrate as the same frequency as the gas.
- ❖ This phenomenon is called knocking in SI engines.

Effect of Engine Variables on Knock

Time factor

- Increasing the flame speed or reducing the exposure of unburned charge to auto-ignition will reduce knocking.
- Increase in turbulence increase the flame speed and reduce time for auto-ignition of unburned charge
- Increase in engine speed increase the turbulence and reduce knocking.
- In larger engine flame require more time to travel across combustion chamber therefore it has greater tendency of knocking.
- Combustion chambers are made as spherical as possible to minimize length of flame travel.
- Spark plug is centrally located in in combustion chamber to reduce flame travel.

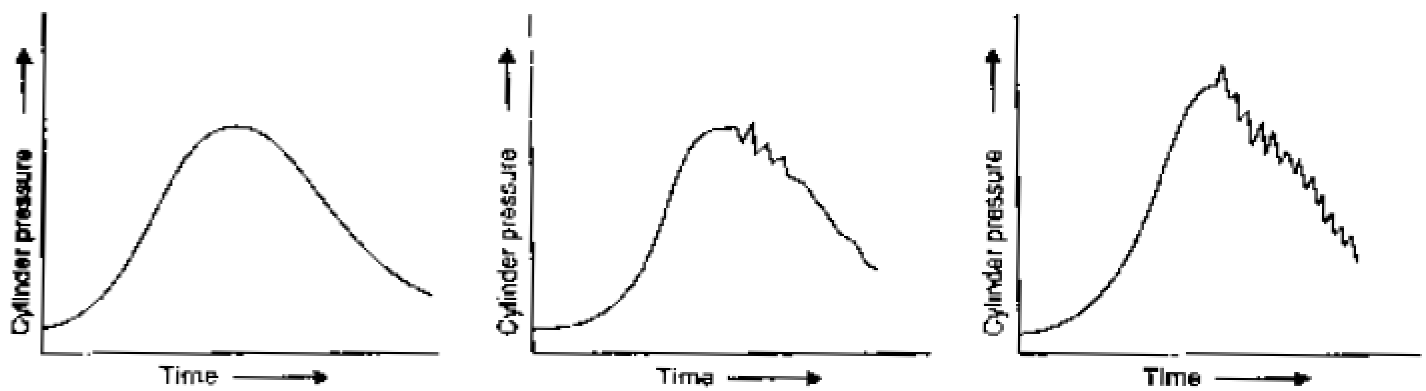
Composition factor

- Fuel-air ratio and octane number play important role to reduce knock.
- Reaction rate and flame temperature are affected by fuel air ratio. Maximum tendency of knock takes place for fuel-air ratio which give minimum reaction time.
- Higher octane number fuels have lower tendency for knocking.

Effect of Engine Variables on Knock

Density factors

- Reducing the density of charge tends to reduce knocking.
- Increase in compression ratio will increase the density of charge which increases knocking tendency of engine.
- Reducing the amount of charge induced by throttling or by reducing supercharging will reduce density.
- Increase in inlet temperature of mixture makes compression temperature higher which increase tendency to knock.
- End gas should not be compressed against spark plug and exhaust wall as they are the hottest parts.
- Decrease in output of engine will decrease the temperature of cylinder.



(i) Normal combustion with *no knock*   (ii) Combustion with *slight knock*   (iii) Combustion with *heavy knock*

Effects of Detonation

Noise and Roughness

- When the intensity of the knock increases a loud pulsating noise is produced due to the development of a pressure wave which vibrates back and forth across the cylinder.
- The presence of vibratory motion causes crankshaft vibrations and engine runs rough.

Mechanical Damage

- In most cases of knocking a local and very rapid pressure rise is observed with subsequent waves of large amplitude.
- Which results in to increasing the rate of wear and erosion of crown.
- The cylinder head and valves may also be pitted.
- Detonation is very dangerous in engines having high noise level.
- In small engines the knocking noise is easily detected and the corrective measures can be taken.
- In large heavy duty engines, it is difficult to detect knocking noise so corrective measures cannot be taken.
- If severe detonation may persist for a long time which may result in complete wreckage of piston.

Carbon Deposit

- Increase in carbon deposit.

Effects of Detonation

Increase in Heat Transfer

The increase in heat transfer is due to two reasons:

- The minor reason is that the maximum temperature in a detonating engine is about 150°C higher than in a non-detonating engine, due to rapid completion of combustion.
- The major reason is the scouring away of protective layer of inactive stagnant gas on the cylinder walls due to pressure waves.
- The inactive layer of gas normally reduces the heat transfer by protecting the combustion chamber walls and piston crown from direct contact with flame.

Decreases power output and efficiency

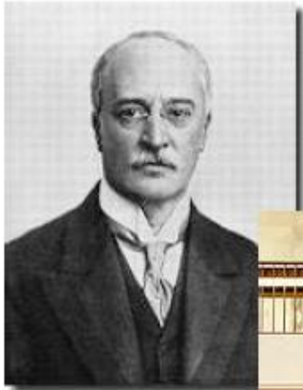
- Increase in heat transfer decrease power output and efficiency.

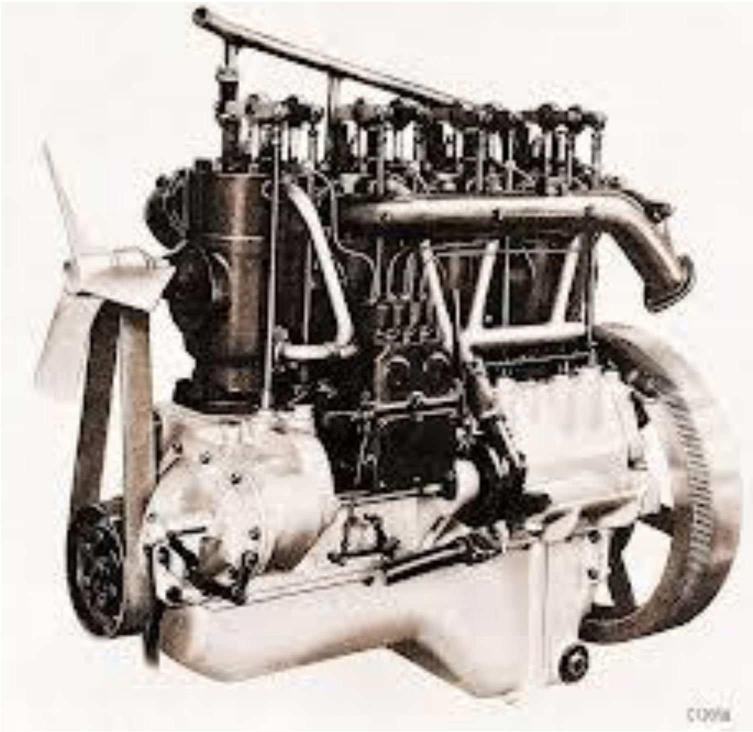
Pre-Ignition

- Increase in local heat transfer cause local overheating especially of sparking plug which may reach a temperature high enough to ignite the charge before the passage of spark. It causes pre-ignition.

COMBUSTION IN DIESEL ENGINE

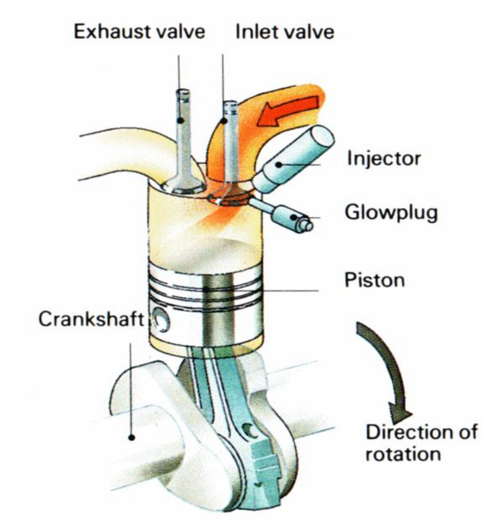
History of Diesel Engine



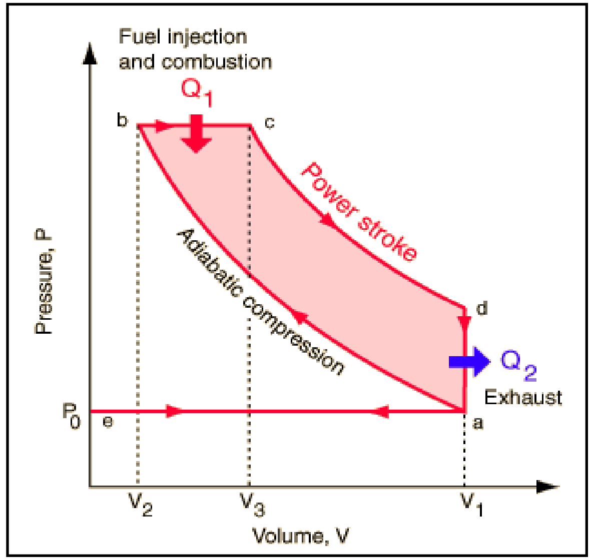


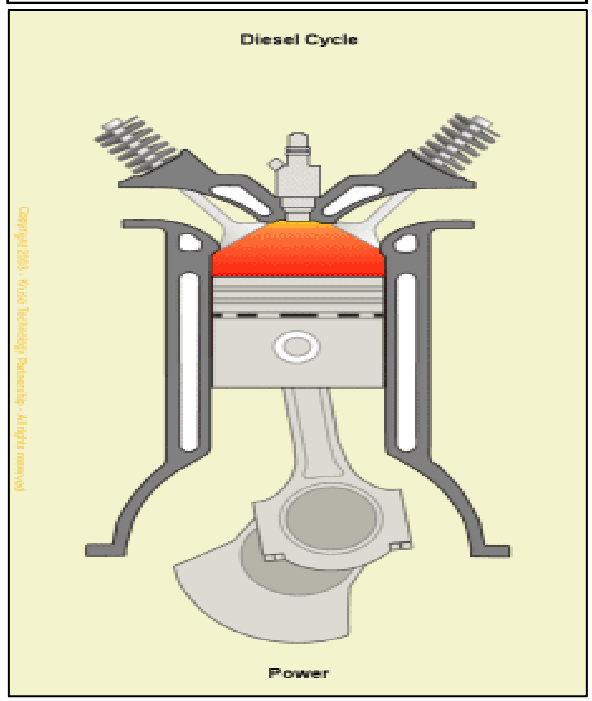
- Rudolf Diesel developed the idea for the diesel engine and obtained the German patent for it in 1892.
- His goal was to create an engine with high efficiency.
- Gasoline engines had been invented in 1876 and especially at that time, were not very efficient.
- Both the gasoline and diesel engine utilize the process of internal combustion for power.
- Diesel engines uses the heat of compressed air to ignite the fuel (intakes air, compresses it, then injects fuel).

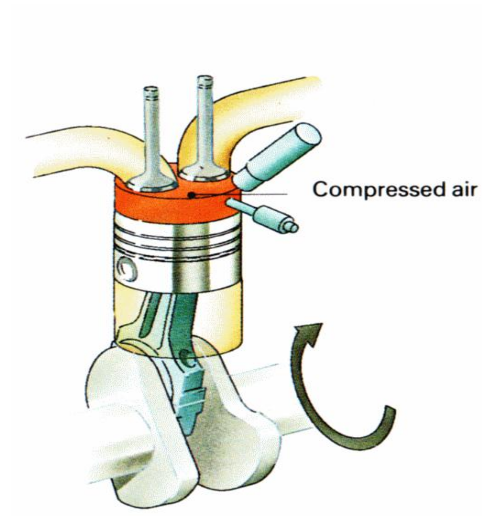
Diesel Cycle



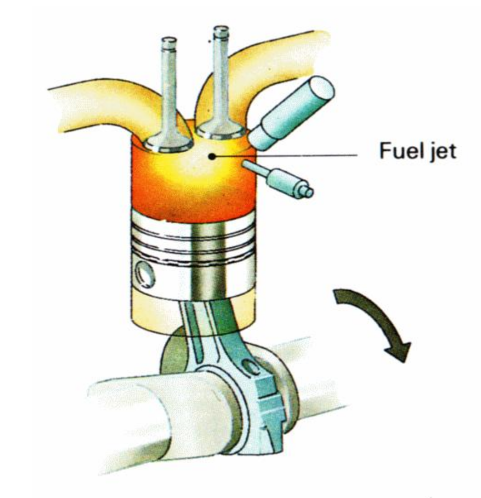
1. Induction stroke



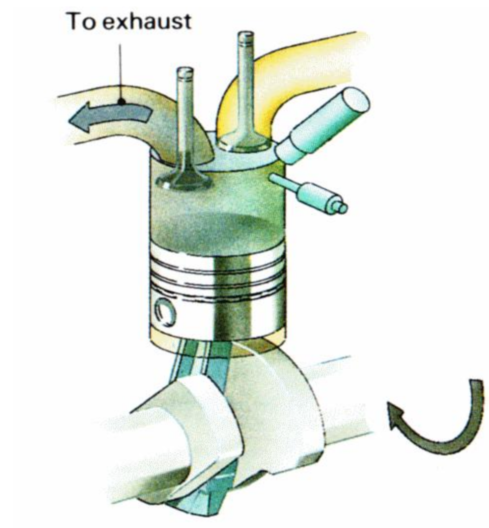




2. Compression stroke



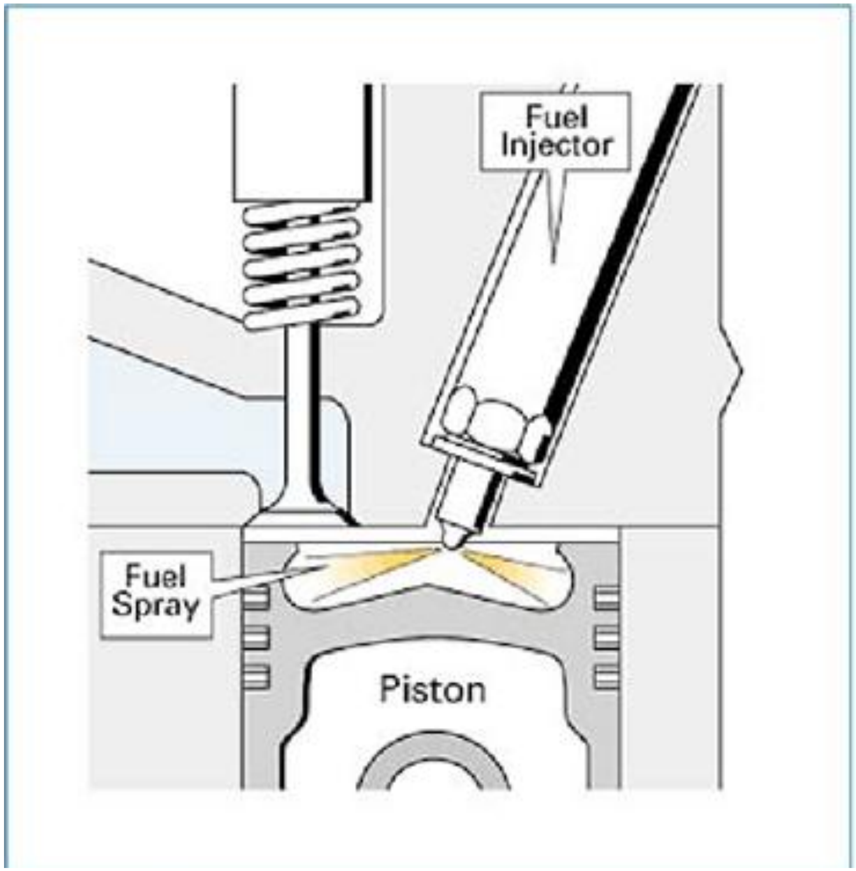
3. Injection stroke
(working stroke)

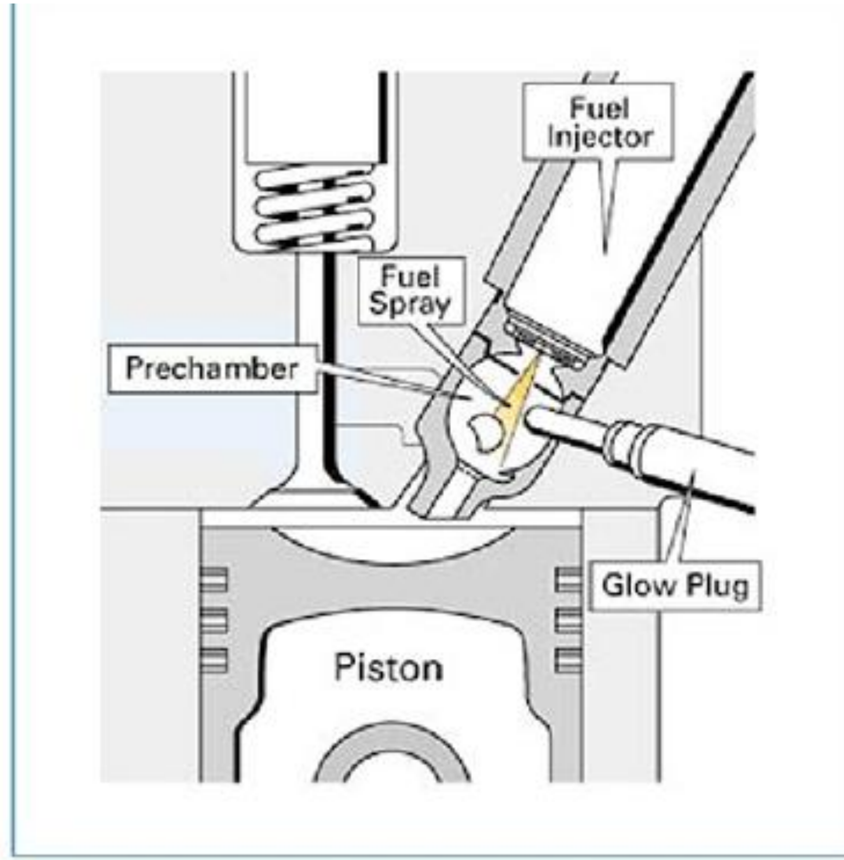


4. Exhaust stroke

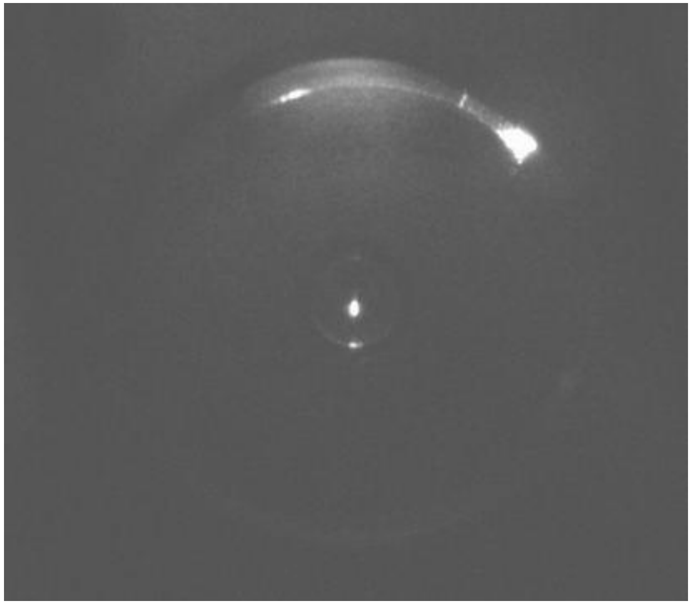
Types of CI Engines

- **Direct-injection** – have a single open combustion chamber into which fuel is injected directly
- **Indirect-injection** – chamber is divided into two regions and the fuel is injected into the "pre-chamber" which is connected to the main chamber via a nozzle, or one or more orifices.

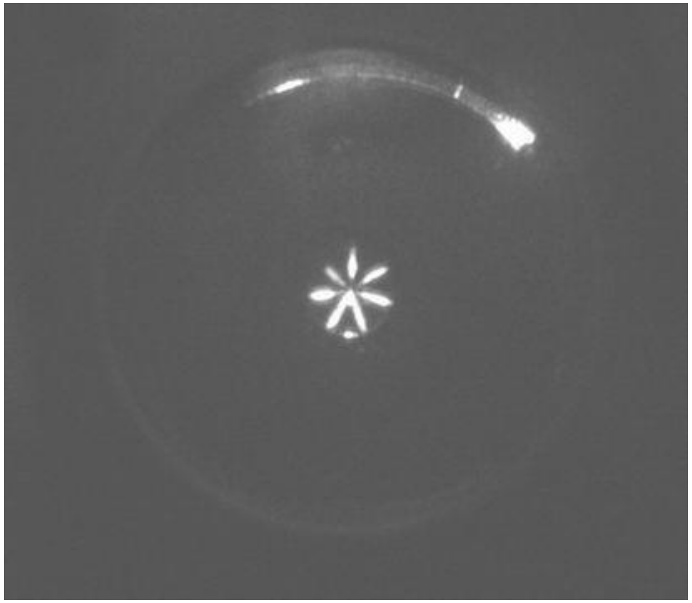




Flame Formation



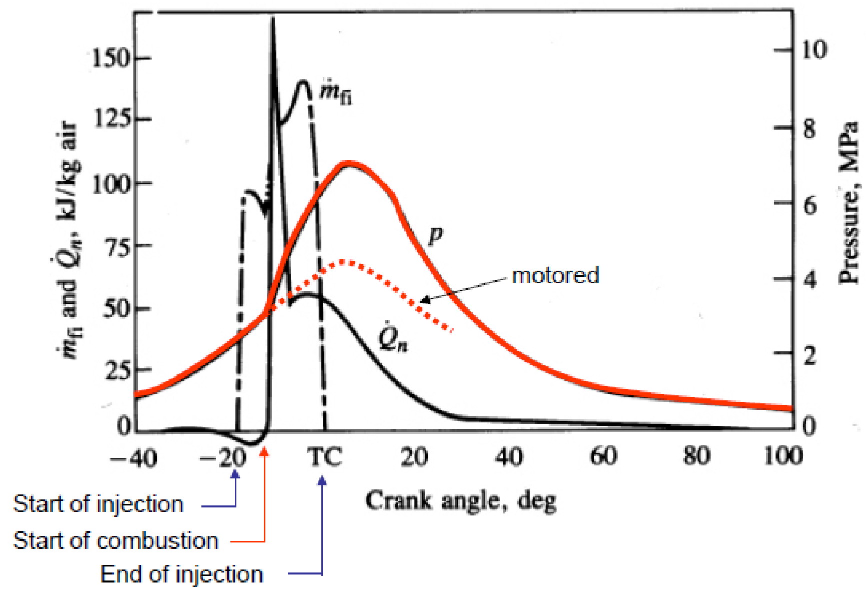
Pilot Injection



Main Injection

Processes in Diesel Engine

- In a CI engine the fuel is sprayed directly into the cylinder and the vaporized part of the fuel mixes with air and ignites spontaneously.
- This graph shows the fuel injection flow rate, net heat release rate and cylinder pressure for a direct injection CI engine.

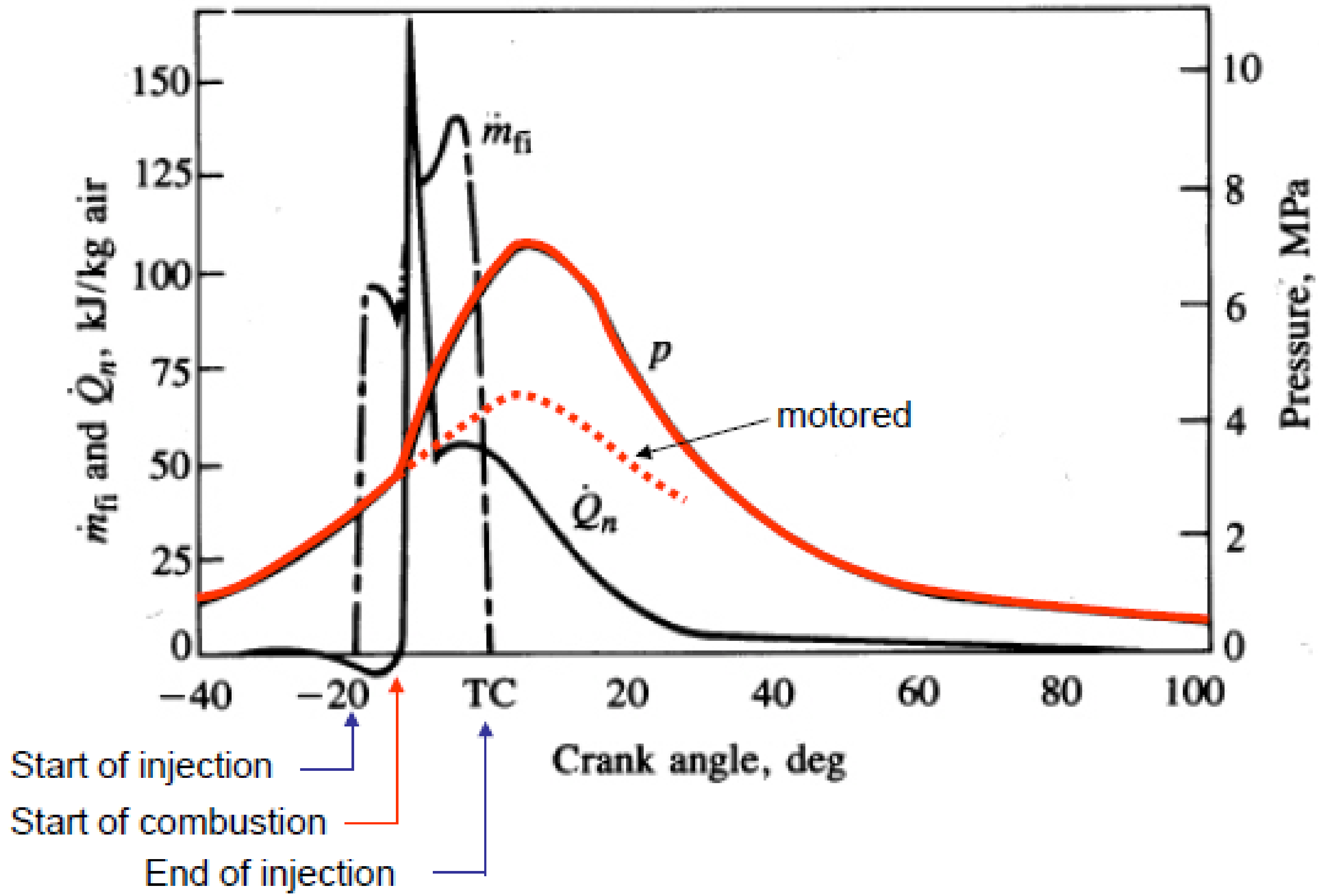


Physical Processes

1. Fuel is injected into the combustion chamber
2. The oil jet is atomized to droplets
3. Droplets undergo evaporation
4. Vapors are mixed with hot air and combustible mixture is formed.

Chemical Processes

1. Low-temperature oxidation of hydrocarbons and alkylperoxy radicals formation
2. Cold flames
3. Blue flames
4. Hot flames


150
125
100
75
50
25
0
$\dot{m}_{fi}$ and $\dot{Q}_n$, kJ/kg air
10
8
6
4
2
0
Pressure, MPa
$\dot{m}_{fi}$
p
motored
$\dot{Q}_n$
−40
−20
TC
20
40
60
80
100
Crank angle, deg
Start of injection
Start of combustion
End of injection

Stages of CI Combustion

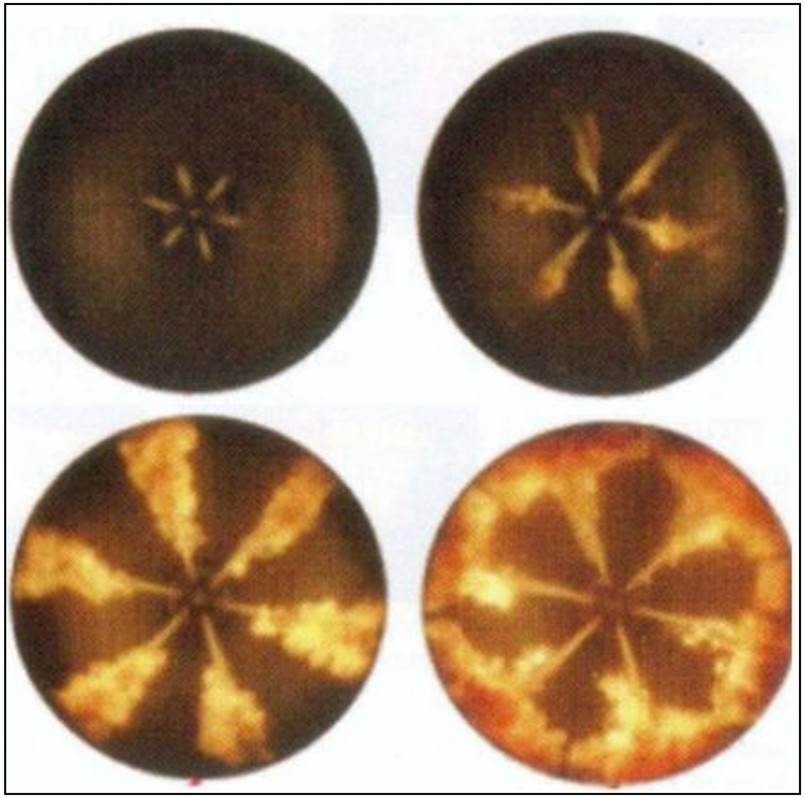
CI combustion can be divided into following four stages;

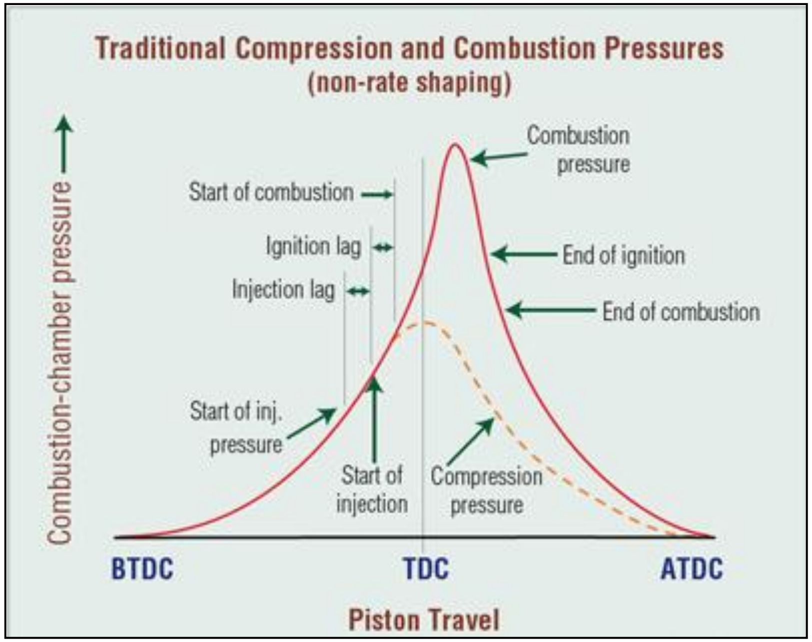
(a) Ignition Delay Period (Pre-flame combustion)

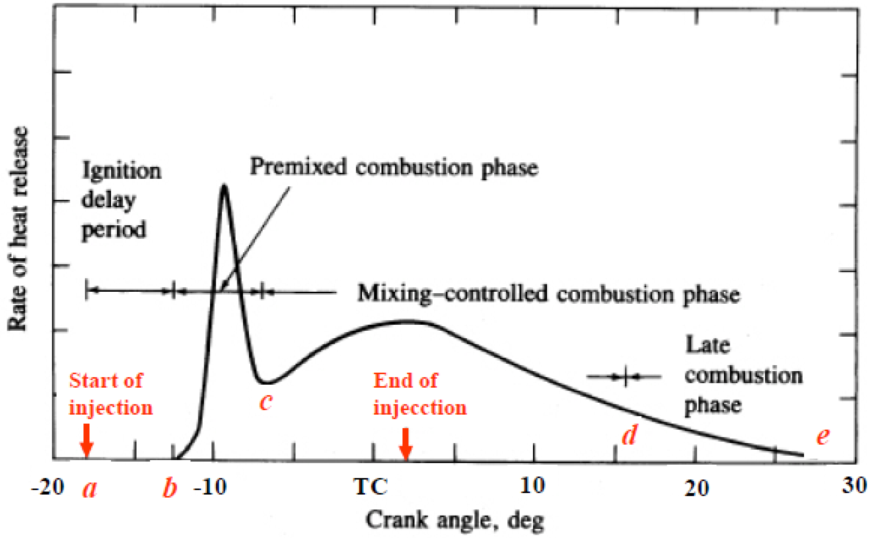
(b) Uncontrolled combustion (Premixed Combustion)

(c) Mixing Controlled combustion

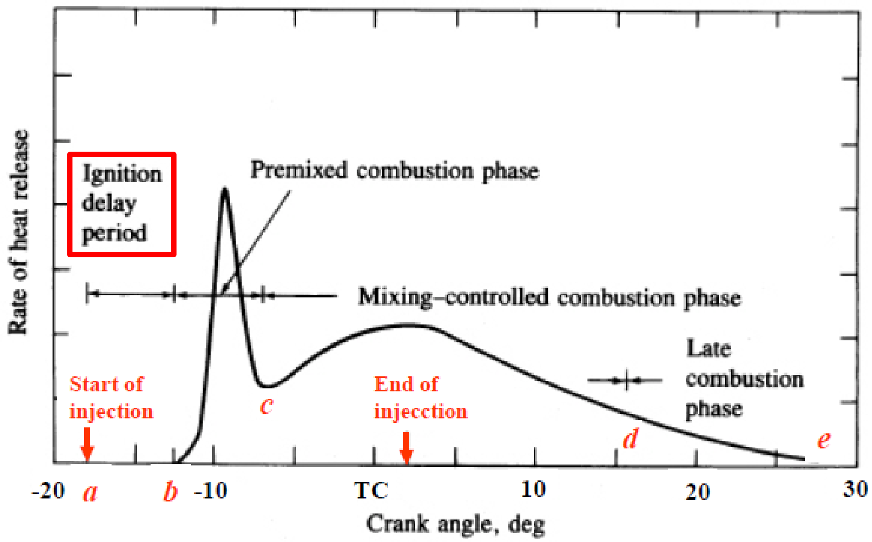
(d) After burning (Late Combustion)







Stages of CI Combustion



Ignition delay *(ab)*

- ❖ The time required to start the actual combustion after starting the fuel injection is known as "Delay period" and the crank angle required for this is known as " Delay period angle"
- ❖ The air-fuel mixture in the combustion chamber before starting the combustion is very heterogeneous and concentration of fuel may vary from 0 to 100%. The first ignition (flame) generally occurs in the region of chemically correct A:F mixture because it requires minimum reaction time.
- ❖ Once the ignition takes place, the flame formed propagates through the mixture of air and vaporized fuel ignites the adjacent part of charge or it may initiate the auto-ignition in the part of A:F mixture away from the flame front by transferring the heat by radiation.

Ignition Delay

Physical Delay

- Physical processes include fuel spray atomization, evaporation and mixing of fuel vapor with air.
- Good atomization requires high fuel pressure, small injector hole diameter, optimum fuel viscosity, high cylinder pressure (large divergence angle).
- Rate of vaporization of the fuel droplets depends on droplet diameter, velocity, fuel volatility, pressure and temperature of the air.

Chemical Delay

- Chemical processes similar to auto ignition phenomenon in premixed fuel-air, but more complex since heterogeneous reactions (reactions occurring on the liquid fuel drop surface) also occur.

Factors Affecting Ignition Delay

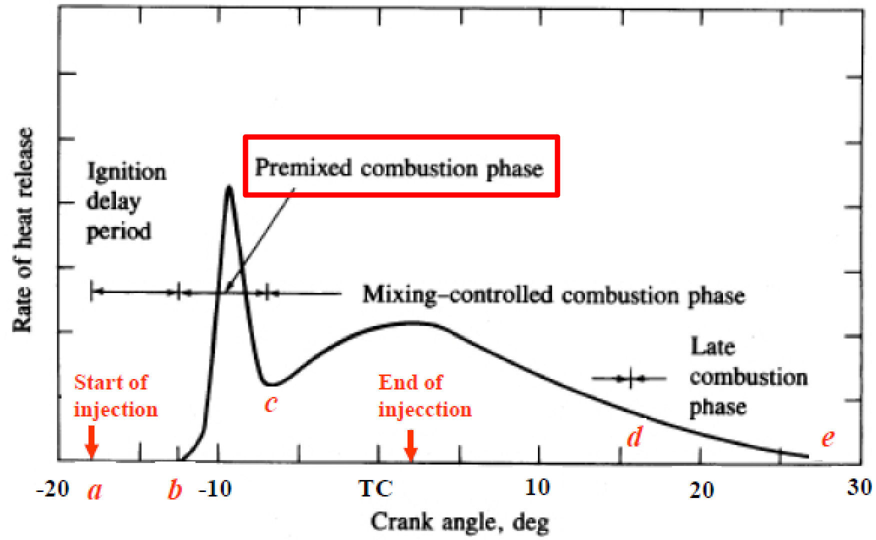
- **Injection timing** – At normal engine conditions the minimum delay occurs with the start of injection at about 10-15 BTDC. Earlier or later injection timing results in a lower air temperature and pressure during the delay period → increase in the ignition delay time.
- **Load** – For a CI engine the air is not throttled so the load is varied by changing the amount of fuel injected. Increasing the load (BMEP) increases the residual gas and wall temperature which results in a higher charge temperature at injection → decrease in the ignition delay.

Factors Affecting Ignition Delay

- **Intake air temperature and pressure** – An increase in either will result in a decrease in the ignition delay due to better atomization and fuel mixing.
- **Compression Ratio** --An increase in the compression ratio also decreases ignition delay.
- **Fuel Quality** -- The properties of the fuel affect the ignition delay. The ignition quality of a fuel is defined by its cetane number (CN). For low cetane fuels the ignition delay is long and for high cetane fuels the ignition delay is short .

SN	Variable	Effect on delay period	Reason
1.	Cetane number of fuel	Reduces	Reduces self-ignition temperature
2.	Injection pressure	Reduces	Greater surface volume ratio, less physical delay
3.	Injection advance angle	Increases	Pressures and temperatures lower when injection begins
4.	Compression ratio	Reduces	Increases air temperature and pressure and reduces auto-ignition temperatures.
5.	Intake temperature	Reduces	Increases air temperature
6.	Intake Pressure	Reduces	Increase in density reduces auto-ignition temperature
7.	Speed of engine	Reduces in milli-seconds but increases in crank angle	Less loss of heat more crank angle in a given time
8.	Load(fuel-air-ratio)	Decreases	Operating temperature increases

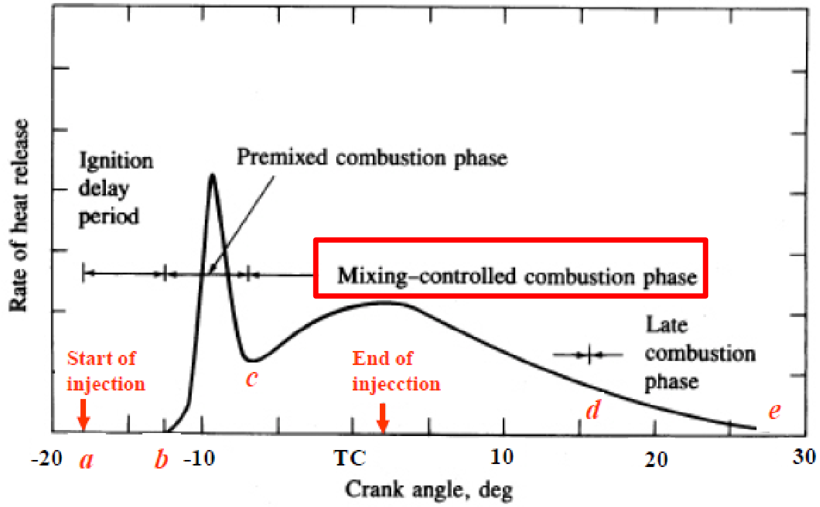
Stages of CI Combustion



Premixed combustion phase *(bc)*

- *Combustion of the fuel which has mixed* with the air to within the flammability limits (air at high-temperature and high- pressure) during the ignition delay period occurs rapidly in a few crank angles.
- A considerable amount of fuel is accumulated in the combustion chamber during the delay period.
- This accumulated fuel burns very rapidly causing a steep rise in the cylinder pressure. The rate of pressure rise increases with the increase in delay period because the amount of fuel taking part in this combustion increases with an increase in delay period.
- This phase of combustion causing rapid pressure rise in the cylinder is known as “Period of uncontrolled combustion”.

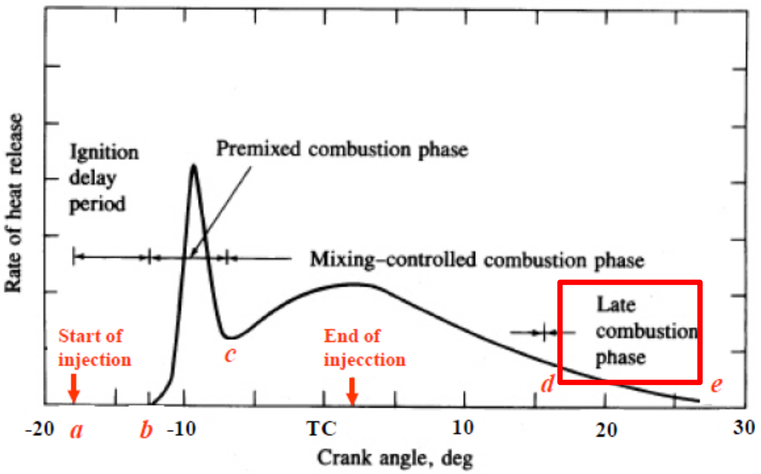
Stages of CI Combustion



Mixing controlled combustion phase *(cd)*

- *After premixed gas consumed, the* burning rate is controlled by the rate at which mixture becomes available for burning. The burning rate is controlled primarily by the fuel-air mixing process.
- The fuel injected after the process of uncontrolled combustion burns at the same rate at which it is injected because, the vaporization of fuel, mixing with the air and burning takes place at almost instantaneously as the fuel leaves the nozzle.
- This is because , the temperature and pressure inside the cylinder are sufficiently high and sufficient turbulence is created due to previous burning, thus the delay period for the fuel injected after the process of uncontrolled combustion is almost zero. This period of combustion is known as "Controlled combustion".

Stages of CI Combustion

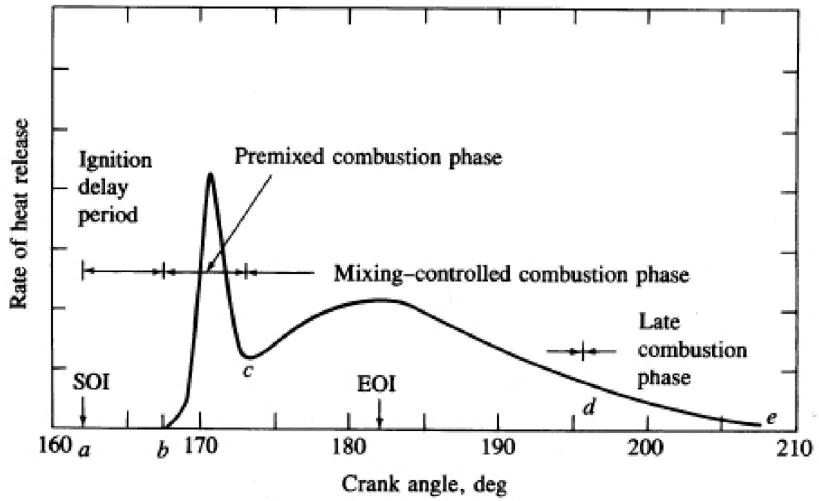


Late combustion phase *(de)*

- *Heat release may proceed at a lower rate well* into the expansion stroke (no additional fuel injected during this phase). Combustion of any unburned liquid fuel and soot is responsible for this.
- The Thermal decomposition of the part of fuel takes place during uncontrolled and controlled combustion.
- The decomposed fuel molecules contain enough number of hydrocarbons and carbon particles which have lower reaction rate.
- Some carbon and hydrocarbons, decomposed from fuel are left in the combustion products because the rate of decomposition during uncontrolled and controlled combustion I more than the rate of reaction of these molecules during that period.
- These unburned hydrocarbons and carbon generally burn after stopping the fuel injection or during the expansion stroke. This process of combustion of decomposed carbon atoms is known as "After Burning".

Cetane Number and its Significance

- The method used to determine the ignition quality in terms of CN is similar to that used for determining the antiknock quality of fuels via the ON.
- The cetane number scale is defined by blends of two pure hydrocarbon reference fuels: isocetane and cetane.
- For *low cetane fuels the ignition delay is long and most of the fuel is* injected before auto ignition and rapid combustion, under extreme cases this produces an audible knocking sound referred to as “diesel knock”.
- For *high cetane fuels the ignition delay is short and very little fuel is injected* before auto ignition, the heat release rate is controlled by the rate of fuel injection and fuel-air mixing – smoother engine operation.



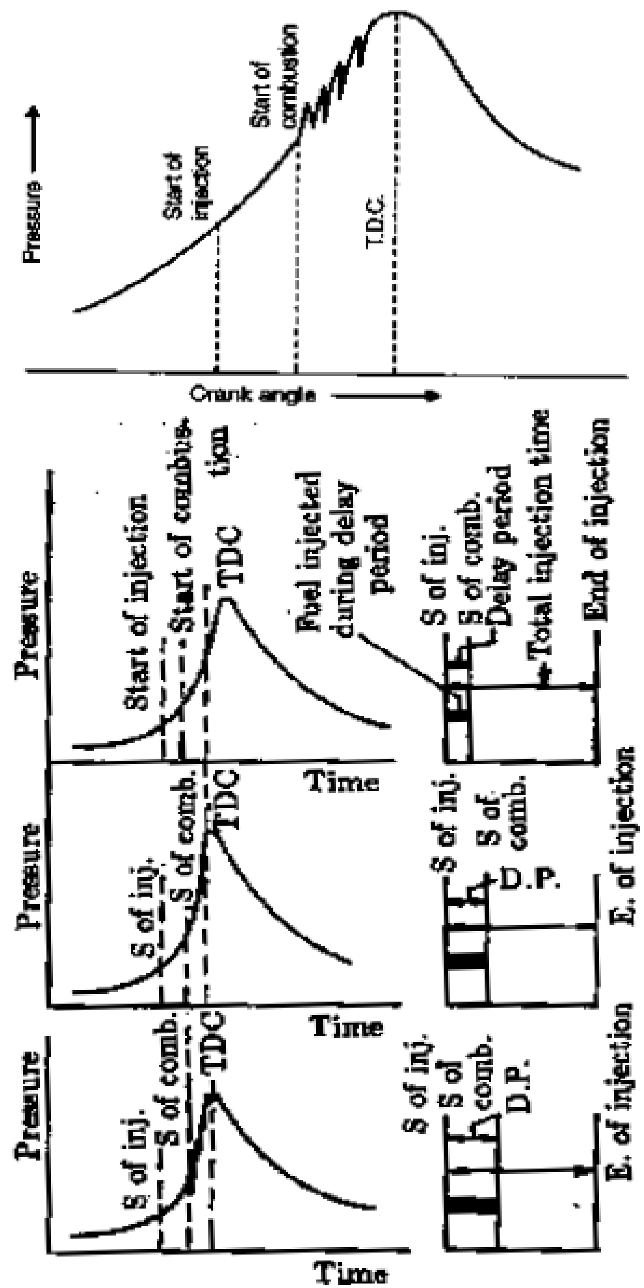
Detonation in CI engines

- If the rate of fuel supply is very large than the rate of fuel burned then the accumulated fuel in the combustion chamber is considerably large and the burning of fuel in some pocket suddenly starts as a bomb.

- A very high pressure wave is generated and pressurizes the mixture to that pressure and temperature which is much higher than the self ignition temperature.

- That part of mixture also suddenly ignites creating another pressure wave and this is continued till all the fuel in the combustion chamber burns.

- This creates highly pulsating combustion and is known as Detonation.



Factors Affecting the Detonation in C.I. Engines

- The factors which are responsible for the delay period also responsible for the detonation.
- If the injection of fuel is too far advanced, the rate of pressure rise during auto-ignition is very high and causes detonation.
- Inferior fuels (having lower cetane number)promote diesel knock but this can be avoided by using better types of fuel(higher cetane number)
- Fuel injection parameters (better penetration and distribution) better combustion chamber design(split type) influences detonation tendency.
- Initial condition of the air (higher temperature or higher pressure in case of supercharged engine) influences detonation tendency.
- The fuel having longer delay period and higher self ignition temperature lead to detonation.
- Following factors can effectively control the detonation in CI combustion;
  - Using a better fuel
  - Controlling the rate of fuel supply
  - Knock reducing fuel injector

Factors which reduce Knock in S.I. and C.I. engines

(1) In S.I. engines, the knocking occurs near the end of combustion where as in C.I. engine, this occurs at the beginning of combustion.

(2) The knocking in S.I. engine takes place in an homogeneous mixture, therefore, the rate of pressure rise is high. In C.I. engines, the mixture is heterogeneous and hence rate of pressure is lower.

(3)The knocking in S.I. engines is because of auto-ignition of the last part of the charge. To avoid this, the fuel must have long delay period and high self ignition temperature.

(4) To avoid knock in C.I. engine, the delay period should be as small as possible and fuel self –ignition temperature should be as low as possible.

S. No	Factors affecting Knock	S.I. engines	C.I. engines
1.	Self ignition temperature	High	Low
2.	Delay period of fuel	Long	Short
3.	Compression Ratio	Low	High
4.	Inlet temperature	Low	High
5.	Inlet Pressure	Low	High
6.	Speed	High	Low
7.	Cylinder size	Small	Large
8.	Combustion chamber wall Temp	Low	High

Comparison of SI and CI Combustion

SL NO	COMUSTION IN SI ENGINE	COMBUSTION IN CI ENGINE
1	Homogeneous mixture of petrol vapour and air is compressed (CR 6:1 to 11:1) at the end of compression stroke and is ignited at one place by spark plug.	Air alone is compressed through large Compression ratio (12:1 to 22:1)and fuel is injected at high pressure of 110 to 200 bar using fuel injector pump.
2	Single definite flame front progresses through air fuel mixture and entire mixture will be in combustible range	Fuel is not injected at once, but spread over a period of time. Initial droplets meet air whose temperature is above self ignition temperature and ignite after ignition delay.
3	For effective combustion, turbulence is required. Turbulence which is required in SI engine implies disordered air motion with no general direction of flow to break up the surface of flame front and to distribute the shreds of flame thought-out in externally prepared homogeneous combustible mixture.	For effective combustion, swirl is required. Swirl which is required in CI engine implies an orderly movement of whole body of air with a particular direction of flow, to bring a continuous supply of fresh air to each burning droplets and sweep away the products of combustion which otherwise suffocate it.
4	In SI Engine ignition occurs at one point with a slow rise in pressure	In the CI engine, the ignition occurs at many points simultaneously with consequent rapid rise in pressure. There is no definite flame front.
5	In SI engine physical delay is almost zero and chemical delay controls combustion	In CI engine physical delay controls combustion.
6	In SI engine , A/F ratio remains close to stoichiometric value from no load to full load	In CI engine , irrespective of load, at any speed, an approximately constant supply of air enters the cylinder. With change in load, quantity of fuel is changed to vary A/F ratio. The overall A/F can Range from 18:1 to 80:1.