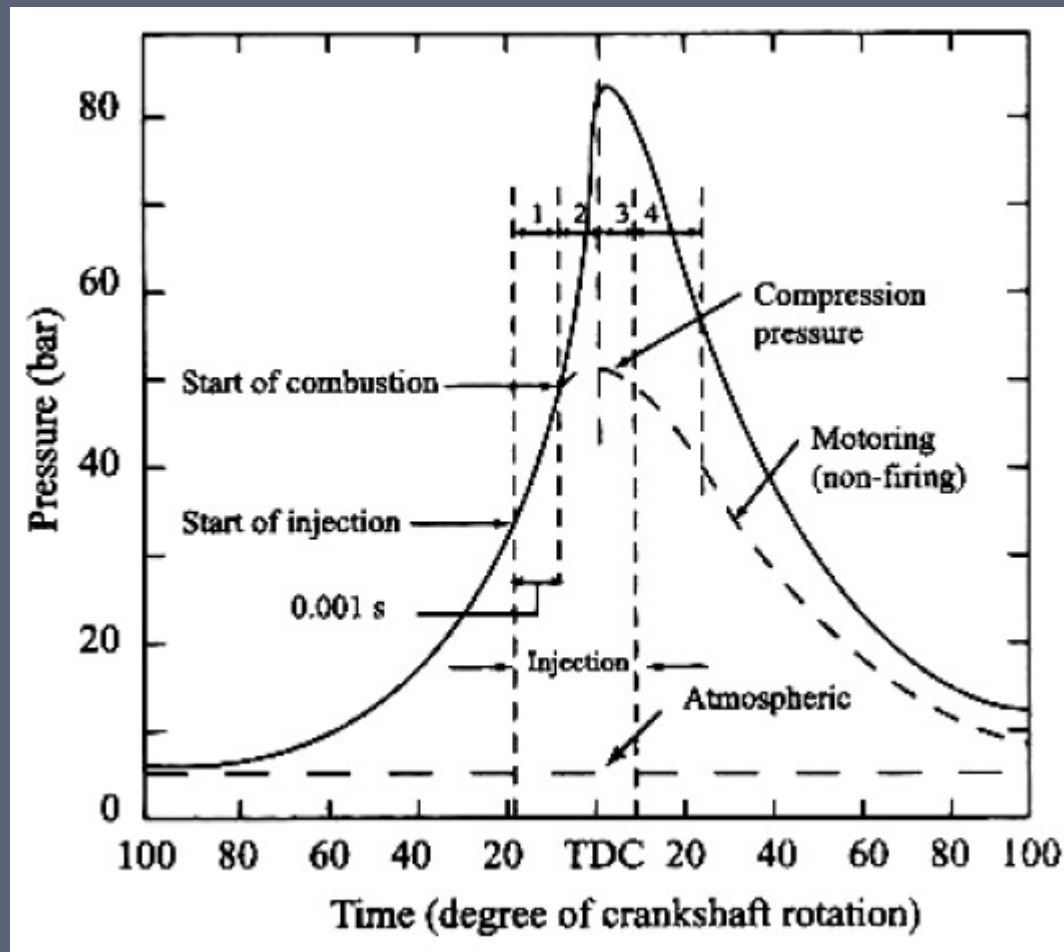


- **Combustion in CI Engines**

- Combustion in CI engines differ from SI engine due to the basic fact that CI engine combustion is unassisted combustion occurring on its' own.
- In CI engine the fuel is injected into combustion space after the compression of air is completed.
- Due to excessively high temperature and pressure of air the fuel when injected in atomised form gets burnt on its' own and burning of fuel is continued till the fuel is injected.
- Theoretically this injection of fuel and its' burning should occur simultaneously up to the cut-off point, but this does not occur in actual CI engine. Different significant phases of combustion are explained as under.

- Stages of Combustion in CI Engines



- 1) Ignition Delay Period

- Physical delay
- Chemical Delay

- 2) Uncontrolled Combustion

- 3) Controlled Combustion

- 4) After Burning

- **Stages of Combustion in CI Engines**

- (i) **Ignition Delay Period**

- Injection of fuel in atomized form is initiated into the combustion space containing compressed air.
 - Fuel upon injection does not get burnt immediately instead some time is required for preparation before start of combustion.
 - Fuel droplet injected into high temperature air first gets transformed into vapour (gaseous form) .
 - Subsequently, if temperature inside is greater than self ignition temperature at respective pressure then ignition gets set.
 - Thus, the delay in start of ignition may be said to occur due to 'physical delay' i.e. time consumed in transformation from liquid droplet into gaseous form, and 'chemical delay' i.e. time consumed in preparation for setting up of chemical reaction (combustion).

- Stages of Combustion in CI Engines

- (i) Ignition Delay Period

- The duration of ignition delay depends upon **fuel characteristic, compression ratio (i.e. pressure and temperature after compression), fuel injection, ambient air temperature, speed of engine, and geometry of combustion chamber** etc.
 - Ignition delay is inevitable stage and in order to accommodate it, the fuel injection is advanced by about 20° before TDC. Ignition delay is shown by $a - b$ in Fig., showing pressure rise during combustion.
 - Fuel injection begins at 'a' and ignition begins at 'b'. Theoretically, this ignition delay should be as small as possible.

- Stages of Combustion in CI Engines

- (ii) Uncontrolled Combustion

- During the ignition delay period also the injection of fuel is continued as it has begun at point 'a' and shall continue upto the point of cut-off.
- For the duration in which preparation for ignition is made, the continuous fuel injection results in accumulation of fuel in combustion space.
- The moment when ignition just begins, if the sustainable flame front is established then this accumulated fuel also gets burnt rapidly.
- This burning of accumulated fuel occurs in such a manner that combustion process becomes uncontrolled resulting into steep pressure rise as shown from 'b' to 'c'.
- *The uncontrolled burning* continues till the collected fuel gets burnt.
- During this 'uncontrolled combustion' phase if the pressure rise is very abrupt then combustion is termed as 'abnormal combustion' and may even lead to damage of engine parts in extreme conditions.

- Stages of Combustion in CI Engines

- (ii) Uncontrolled Combustion

- Thus, it is obvious that 'uncontrolled combustion' depends upon the 'ignition delay' period as during ignition delay itself the accumulation of unburnt fuel occurs and its' burning results in steep pressure rise.
 - Hence in order to have minimum uncontrolled combustion the ignition delay should be as small as possible.
 - During this uncontrolled combustion phase about one-third of total fuel heat is released.

- Stages of Combustion in CI Engines

- (iii) Controlled Combustion

- After the 'uncontrolled combustion' is over then the rate of burning matches with rate of fuel injection and the combustion is termed as 'controlled combustion'.
 - Controlled combustion is shown between 'c' to 'd' and *during this phase maximum of heat gets evolved in controlled manner.*
 - *In controlled* combustion phase rate of combustion can be directly regulated by the rate of fuel injection i.e. through fuel injector.
 - Controlled combustion phase has smooth pressure variation and maximum temperature is attained during this period.
 - It is seen that about two-third of total fuel heat is released during this phase.

- Stages of Combustion in CI Engines

- (iv) After Burning

- After controlled combustion, the residual if any gets burnt and the combustion is termed as 'after burning'.
 - This after burning may be there due to fuel particles residing in remote position in combustion space where flame front could not reach.
 - 'After burning' is spread over $60 - 70^\circ$ of crank angle rotation and occurs even during expansion stroke.

- **Combustion in CI Engines**

- **Abnormal Combustion**

- Thus, it is seen that the complete combustion in CI engines may be comprising of four distinct phases i.e. 'ignition delay' followed by 'uncontrolled combustion,' 'controlled combustion' and 'after burning'.
 - Combustion generally becomes abnormal combustion in CI engines when the ignition delay is too large resulting into large uncontrolled combustion and zig-zag pressure rise.
 - Abnormal combustion in CI engines may also be termed as 'knocking' in engines and can be felt by excessive vibrations, excessive noise, excessive heat release, pitting of cylinder head and piston head etc.
 - In order to control the knocking some additives are put in CI engine fuel so as to reduce its' self ignition temperature and accelerate ignition process.
 - Also, the combustion chambers are properly designed so as to have reduced physical and chemical delay.

- **Factors affecting Delay Period in CI Engines**

- **Compression Ratio**

Increase in CR increases the temperature of air. Autoignition temperature decreases with increased density. Both these reduce the delay period(DP).

- **Engine Power Output**

With an Increase in engine power, the operating temperature increases. A/F ratio decreases and delay period decreases

- **Engine Speed**

Delay period decreases with increasing engine speed, as the temperature and pressure of compressed air rises at high engine speeds.

- **Injection Timing**

The temperature and pressure of air at the beginning of injection are lower for higher injection advance. The DP increases with increase in injection advance or longer injection timing. The optimum angle of injection is 20° BTDC

- **Atomization of fuel**

Higher fuel injection pressures increase the degree of atomization. The fineness of atomization reduces the DP due to higher A/V ratio of the spray droplets.

- **Factors affecting Delay Period in CI Engines**

- **Injection Pressure**

Increase injection pressure reduces the auto ignition temperature and hence decreases DP.

- **Intake Temperature**

High intake temperature increase the air temperature after compression , which reduces DP.

- **Engine Size**

Large engines operate at lower speeds, thus increasing the DP in terms of crank angle.

- **Cetane No.**

Fuels with high cetane no. Have lower DP.

- **F/A ratio**

With increasing F/A ratio, operating temperature increases and thus DP decreases.

- **Injection Duration**

Increase in injection duration, results in higher quantity of fuel injected which reduces DP.

- Comparison of Knocking in SI and CI Engines

Parameter	SI Engines	CI Engines
Timing	Occurs at the end of combustion	Occurs at the beginning of combustion
Major Cause	Auto ignition of end charge	Ignition of accumulated fresh charge
Pre-Ignition	Possible as the fuel air mixture is compressed	Not possible as only air is compressed

- Parameters which reduce knocking in SI and CI Engines

S.No.	Parameter	SI Engines	CI Engines
1	Self Ignition Temperature of fuel	High	Low
2	Ignition Delay	Long	Short
3	Inlet Temperature	Low	High
4	Inlet Pressure	Low	High
5	Compression Ratio	Low	High
6	Speed	Low	High
7	Combustion Chamber Wall Temperature	Low	High
8	Cylinder Size	Small	Large

COMBUSTION CHAMBER FOR CI ENGINES

Combustion Chamber Characteristics

- The proper design of a combustion chamber is very important.
- In a CI engine the fuel is injected during a period of some 20 to 35 degrees of crank angle.
- In this short period of time an efficient preparation of the fuel-air charge is required, which means:
 - An even distribution of the injected fuel throughout the combustion space, for which it requires a directed flow or swirl of the air.
 - A thorough mixing of the fuel with the air to ensure complete combustion with the minimum excess air, for which it requires an air swirl or squish of high intensity.

COMBUSTION CHAMBER FOR CI ENGINES

Combustion Chamber Characteristics

An efficient smooth combustion depends upon:

- A sufficiently high temperature to initiate ignition; it is controlled by the selection of the proper compression ratio.
- A small delay period or ignition lag.
- A moderate rate of pressure rise during the second stage of combustion.
- A controlled, even burning during the third stage; it is governed by the rate of injection.
- A minimum of afterburning.
- Minimum heat losses to the walls. These losses can be controlled by reducing the surface- to-volume ratio.

The main characteristics of an injection system that link it with a given combustion chamber are atomization, penetration, fuel distribution, and the shape of the fuel spray.

Classification of CI Engine Combustion Chambers

- (a) direct-injection (DI) engines, which have a single open combustion chamber into which fuel is injected directly;
- (b) indirect-injection (IDI) engines, where the chamber is divided into two regions and the fuel is injected into the pre-chamber which is situated above the piston crown and is connected to the main chamber via a nozzle or one or more orifices.

DIRECT INJECTION (DI) ENGINES OR OPEN COMBUSTION CHAMBER ENGINES

An open chamber has the entire compression volume in which the combustion takes place in one chamber formed between the piston and the cylinder head.

The shape of the combustion chamber may create swirl or turbulence to assist fuel and air.

- Swirl denotes a rotary motion of the gases in the chamber more or less about the chamber axis.
- Turbulence denotes a haphazard motion of the gases.

In this combustion chamber, the mixing of fuel and air depends entirely on the spray characteristics and on air motion, and it is not essentially affected by the combustion process. In this type of engine, the spray characteristics must be carefully arranged to obtain rapid mixing.

Fuel is injected at high injection pressure and mixing is usually assisted by a swirl, induced by directing the inlet air tangentially, or by a squish which is the air motion caused by a small clearance space over part of the piston.