Combustion In CI engines,

In the CI engines, fuel is injected into the cylinders late in compression stroke through one or more injectors into highly compressed air in the combustion chamber. After injection, the fuel must go through a series of events to assure the proper combustion process:

1. **Atomization.** Fuel drops break into very small droplets, the original drop size emitted by the injector, the quicker and more efficient will be this atomization process.

2. **Vaporization.** The small droplets of liquid fuel evaporate to vapor. This occurs very quickly due to the hot air temperatures created by the high compression of CI engines.

- High air temperature needed for this vaporization process.
- About 90% of the fuel injected into the cylinder can be vaporized within 1 ms after injection.

3. **Mixing.** After vaporization, the fuel vapor must mix with air to form a mixture within the *AFR* range which is combustible.

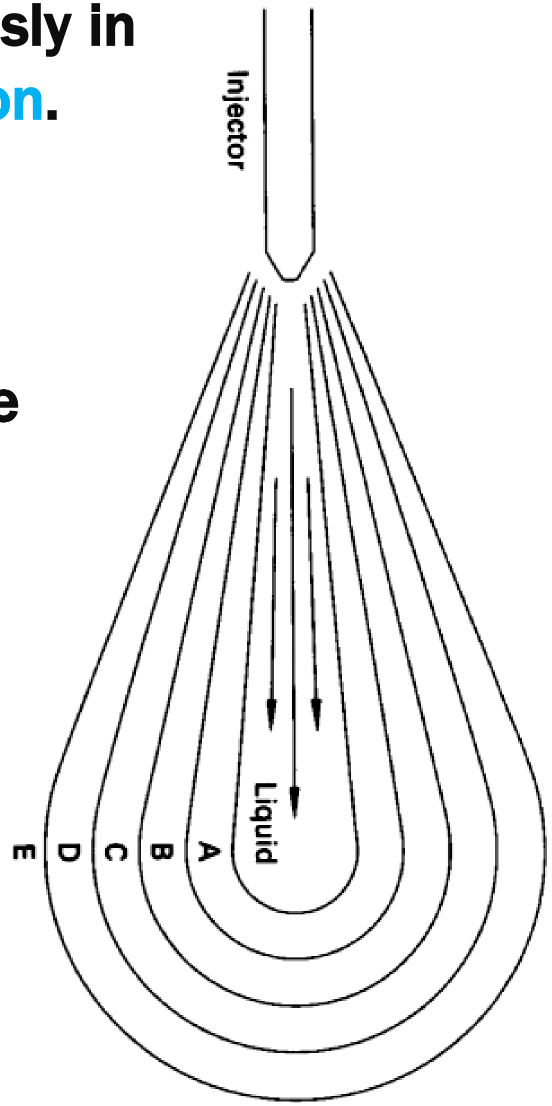
Combustion can occur within the equivalence ratio limits of $\phi = 1.8$ *(rich) and* $\phi = 0.8$ *(lean).*

Combustion in a CI engine is quite different from that of an SI engine.

While combustion in an SI engine is essentially a flame front moving through a homogeneous mixture.

Combustion in a CI engine is an unsteady process occurring simultaneously in many spots in a very non-homogeneous mixture controlled by fuel injection.

The Non-homogeneous distribution of *AFR* that develops around the injected fuel jet.



The figure shows fuel jet of a CI showing air-fuel vapor zones around the inner liquid core zone.

The liquid core is surrounded by successive zones of vapor which are:

i. (A) too rich to burn; ii. (B) rich combustible; iii. (C) stoichiometric;

iv. (D) Lean Combustible; v. (E) Too lean to burn

Self ignition starts mainly in zone B

- Self-Ignition. At about 8° bTDC, 6 - 8° after the start of injection, the air-fuel mixture starts to self-ignite.

Combustion Stages in C.I. Engines

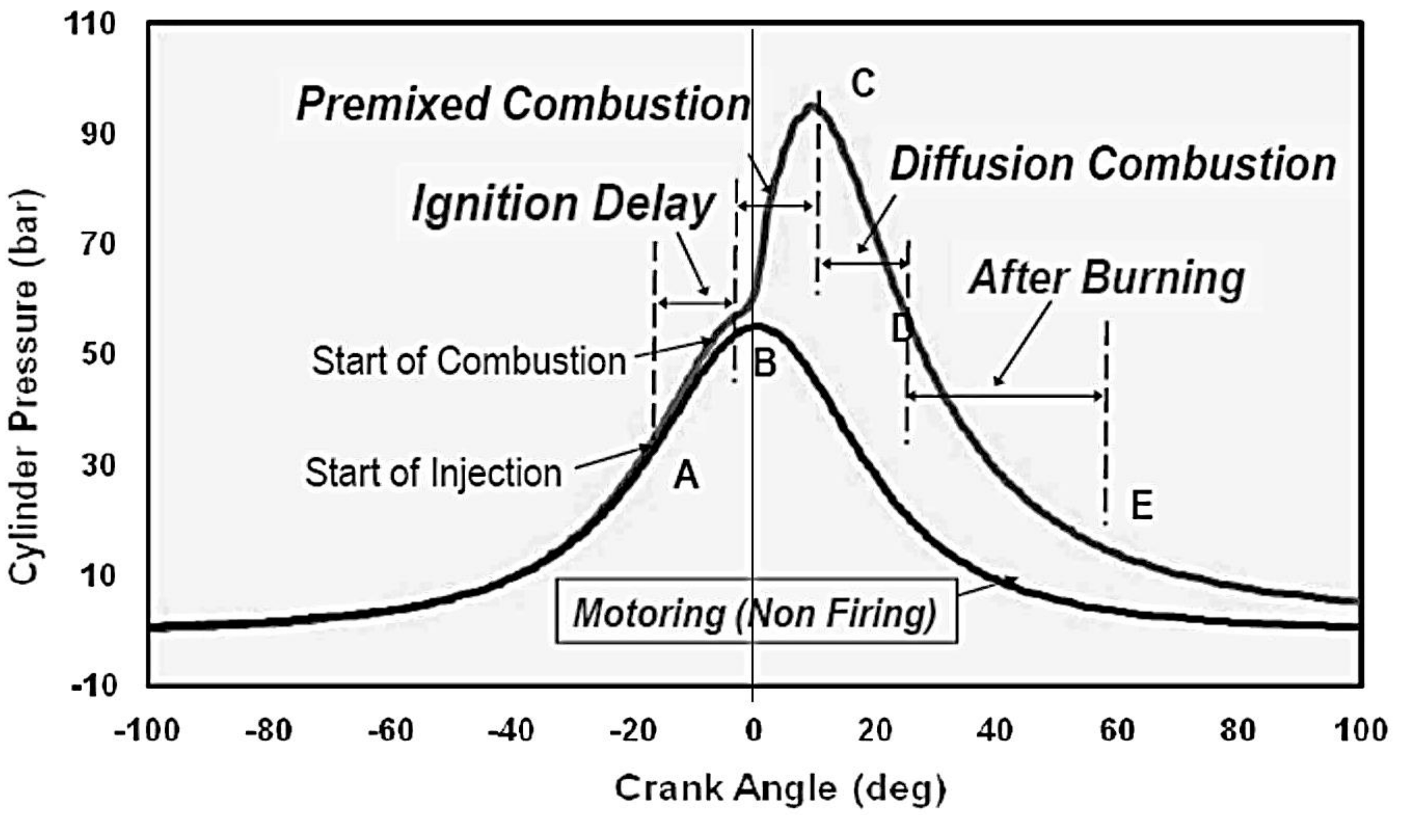
- Actual combustion is preceded by secondary reactions, including breakdown of large hydrocarbon molecules into smaller species and some oxidation.

❑ Combustion starts from self-ignition simultaneously at many locations in the slightly rich zone of the fuel jet, where the equivalence ratio is = 1 to 1.5 (zone B in the previous Fig.).

❑ When combustion starts, multiple flame fronts spreading from the many self-ignition sites quickly consume all the gas mixture which is in a correct combustible air-fuel ratio, ***even where self ignition wouldn't occur***.

❑The combustion in a CI engine is taking place in four stages

- Ignition delay period
- Rapid combustion
- Controlled combustion
- After-burning

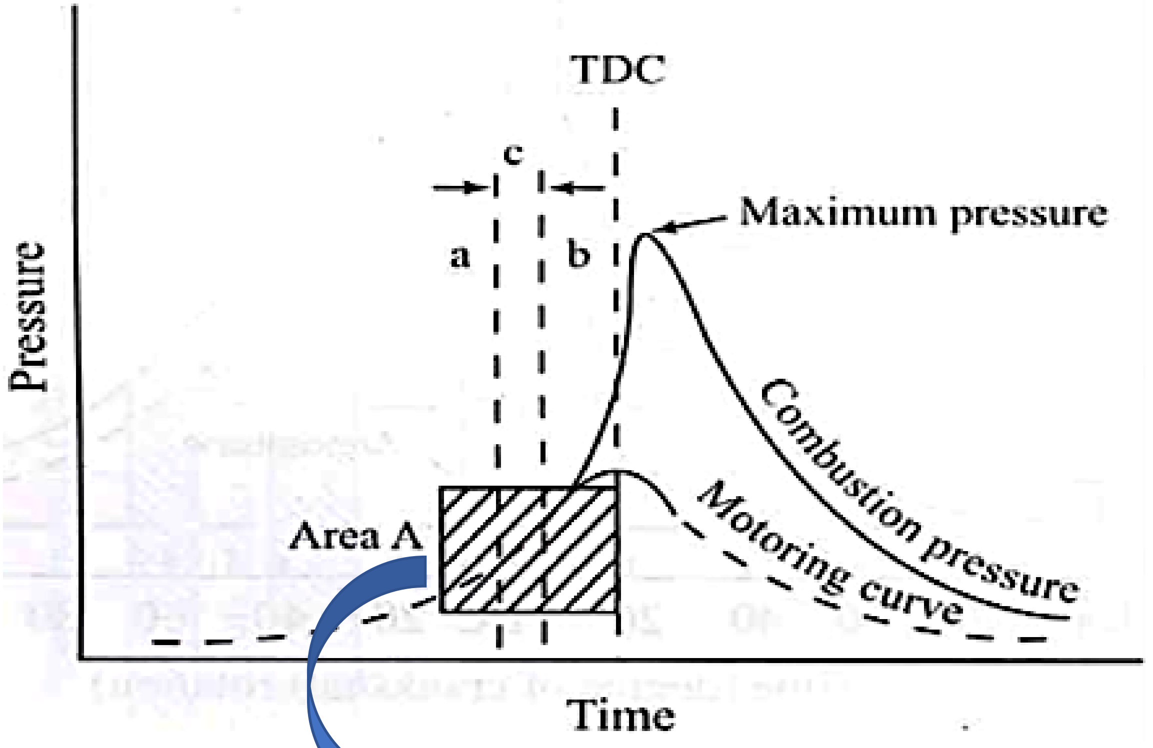


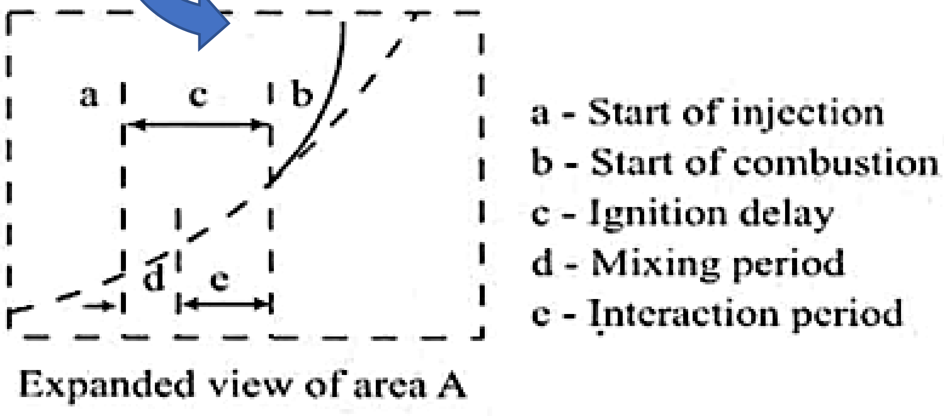
1. Ignition delay (a-b) : period is counted from the start of injection to towards the actual burning. The liquid fuel atomizes into small drops. The fuel vaporizes and mixes with the high-temperature high-pressure air.

- Point a represents the time of injection
- Point b represents the time at which the pressure curve (caused by combustion) first separates from the compression process.

The ignition delay period is divided into two parts:

1. Physical Delay (d): The physical delay is the time between the beginning of injection and the attainment of chemical reaction conditions. During this period he fuel is **atomized, vaporized, Mixed with air.**





2. Chemical Delay (e) : Period from beginning of chemical reactions to auto-ignition. During the chemical delay, reactions start slowly and then accelerated ignition taking place. Generally, the chemical delay is larger than the physical delay.

Factors Affecting Delay Period (DP)

1. Compression Ratio: DP decreases with increase of CR.

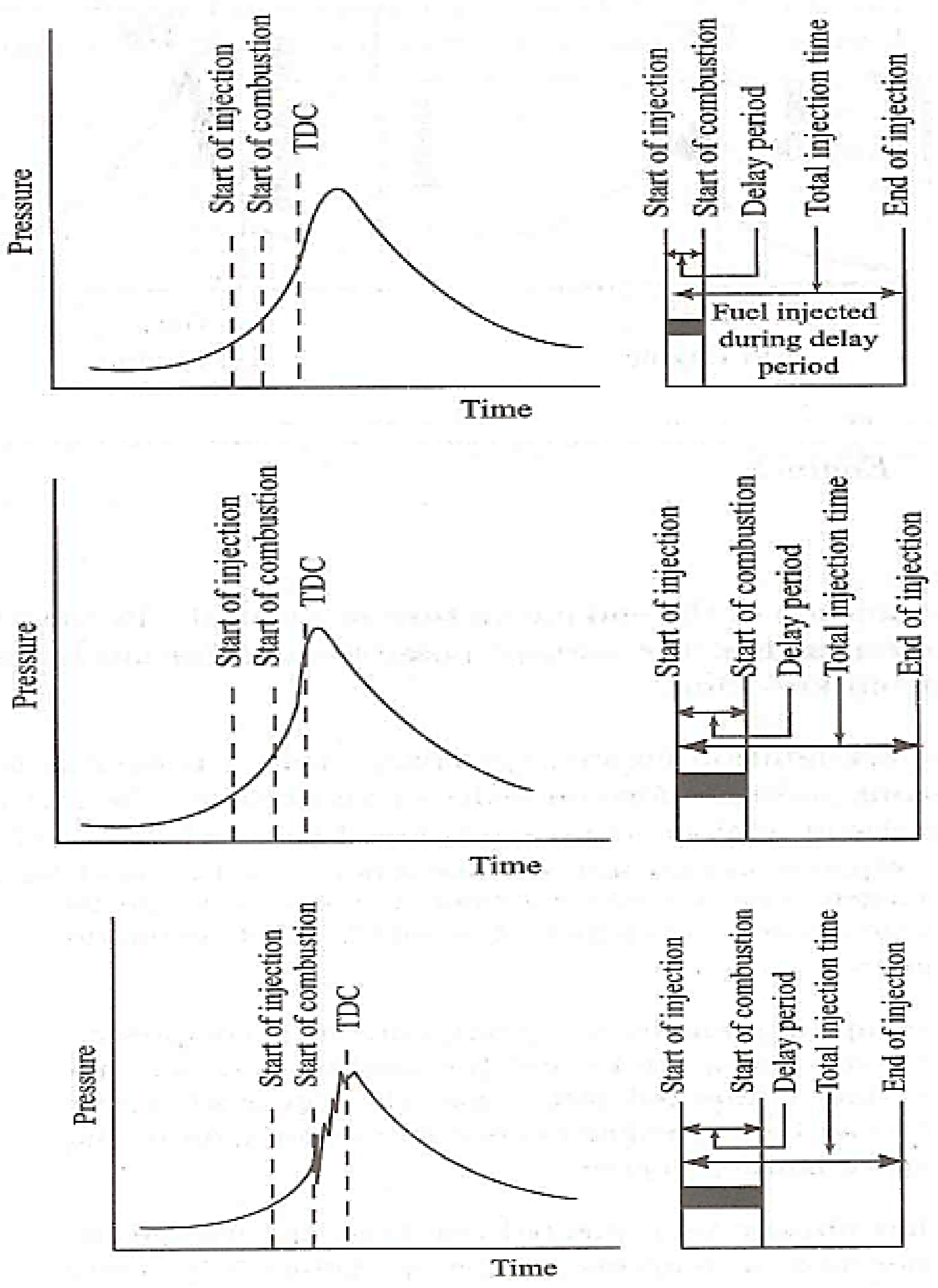
2. Engine Speed: DP decreases with increase of engine speed.

3. Power Output: DP decreases with increase of power output.

4. Fuel Atomization: DP decreases with fineness of atomization.

5. Fuel Quality: DP decreases with higher cetane number.

6. Intake Temp. & Pressure: DP decreases with increase of Temperature and pressure.



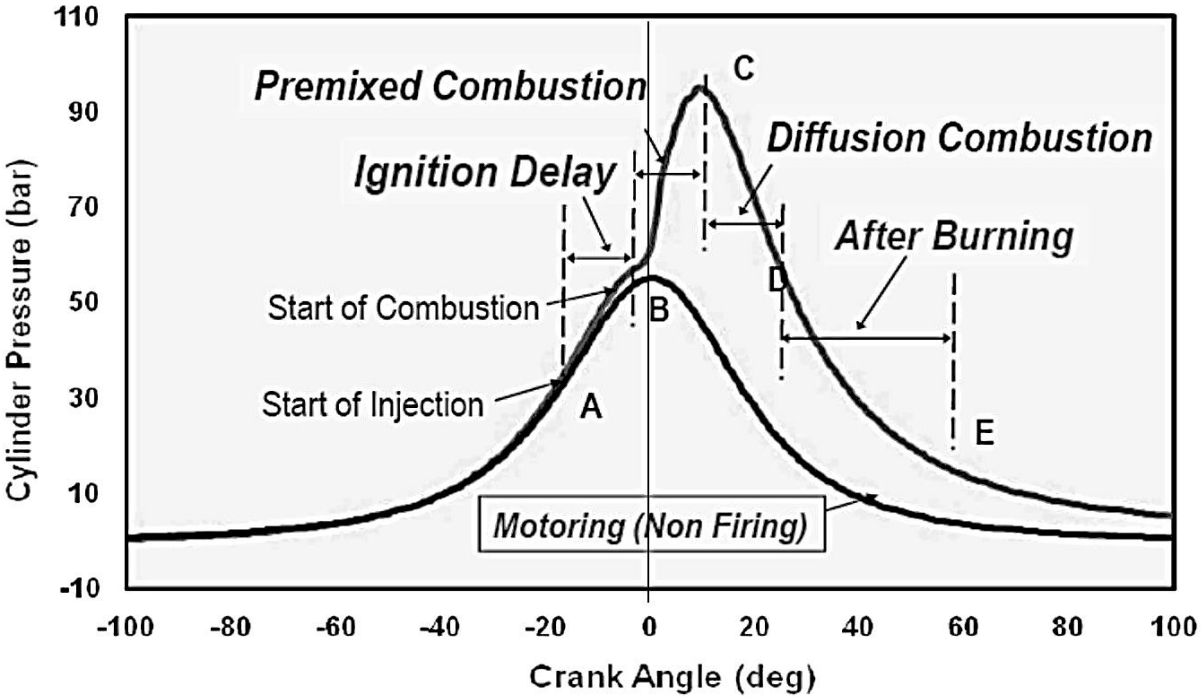
2. Period of Rapid Combustion: The period of rapid combustion is that phase in which the pressure rise is rapid.

The period of rapid combustion is counted from the beginning of the combustion to the point of maximum pressure on the indicator diagram.

This is also known as **uncontrolled combustion phase, because it is difficult to control the amount** of burning/ injection during the process of burning.

Most of the fuel would have formed combustible mixture with air and pre-flame reactions completed, so that the layers of fuel vapors burn as fast as they can find fresh oxygen to continue the combustion process.

In this phase the combustion of pre-ignited fuel occurs which was raised to self-ignition temperature after vaporization. The rate of heat release is maximum in this period.



3. Period of Controlled Combustion: It is assumed to be end when maximum temperature is reached inside the combustion chamber.

After premixed gas consumed, the burning rate is controlled by the rate at which mixture becomes available for burning. The rate of burning is controlled in this phase primarily by the fuel-air mixing process.

4. Period of After-Burning: Combustion does not stop after complete the injection process. The unburnt and partially burnt fuel particles left in the combustion chamber start burning as soon as they come into contact with the oxygen.

This process continues for a certain duration called the after-burning period. This burning may continue in expansion stroke up to 70 to 80% of crank travel from TDC.

Usually this period starts from the point of maximum cycle temperature and continues over apart of the expansion stroke.