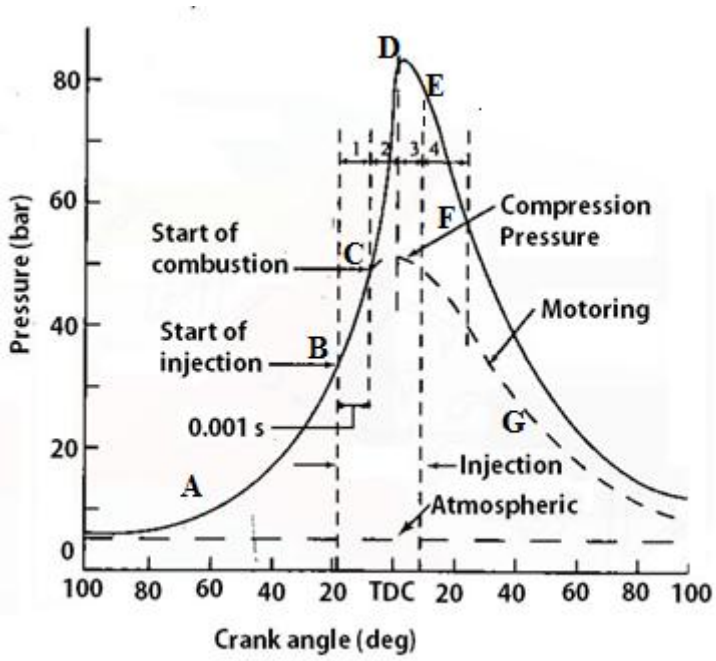
STAGES OF COMBUSTION IN CI (or) DIESEL ENGINE

The combustion in CI engine occurs in four stages namely

- Ignition delay or delay period.
- Uncontrolled combustion.
- Controlled combustion.
- After burning.



- ✓ Pressure Vs crank angle of a CI engine in a simplified from is shown in the figure.
- ✓ **The curve ABCG** represents compression and expansion of the air charge in the engine cylinder when the engine is being motored, without fuel injection.
- ✓ The **curve ABCDEF** shows the pressure trace of an actual engine

DELAY PERIOD

In an actual engine, fuel injection beings at the point B during the compression stroke. The injected fuel does not ignite immediately. It takes some time to ignite. Ignition sets in at the point C. During the crank travel B to C pressure in the combustion chamber does not rise above the compression curve. The period corresponding to the crank angle B to C is called delay period or ignition delay (about 0.001 seconds). During ignition delay, the following events take place. The injected spray enters the combustion chamber and slowly (at about 55 m/min) bores hole in the air mass, while the fuel particles are stripped away. Some of these particles are vapourized. Thus, the main body of the spray

is surrounded by vapour liquid particle air envelope. In small combustion chambers, the spray body may impinge on the walls. Some of the impinged fuel may bounce off the surface, while the rest may glide on the walls. Vapourization of fuel particles tends to lower the compression pressure and temperature slightly. At the same time, the energy released in the preflame reactions tends to raise the pressure. Now in the outer envelope of the spray, ignition nuclei are formed. Mostly, the nuclei are cool flame reactions, on the verge of auto-ignition. By oxidation or cracking reactions, luminescent carbon particles are formed.

UNCONTROLLED COMBUSTION

At the end of the delay period i.e. at the point C, fuel starts burning. At this point, a good amount of fuel would have already entered and got accumulated inside the combustion chamber. This fuel charge is surrounded by hot air. The fuel is finely divided and evaporated. Majority of the fuel burns with an explosion like effect. This instantaneous combustion is called uncontrolled combustion. This combustion causes a rapid pressure rise.

During uncontrolled combustion the following take place. Flame appears at one or more locations and spreads turbulently, with glowing luminosity. Flame of low luminosity marks regions of vapourized fuel and air (premixed flame. Flames of higher luminosity mark regions of liquid droplets and air (diffusion flame). The initial spreading of non-luminous and luminous flame arises from auto ignition and flame propagation. This is the knock reaction with a high rate of energy release and correspondingly high rate of pressure rise.

Combustion during crank travel C to D is called uncontrolled combustion. This is because no control over this combustion is possible by the engine operator. Since this combustion is more or less instantaneous, it is also called rapid combustion.

If more fuel is present in the cylinder at the end of delay period, and undergoes rapid combustion when ignition sets in, the rate of pressure rise and the peak pressure attained will be greater. During this combustion the piston is around TDC, and is almost stand still. Too rapid a pressure rise and severe pressure impulse at this position of the piston will result in combustion noise called Diesel Knock.

The severity of the knock reactions is in proportion to the mass enflamed. The regions of premixed flame are probably hotter (and older) than the regions where liquid droplets are present. As such, the knock reaction may be propagated mainly in the low luminosity state of the flame.

The rate at which the uncontrolled combustion takes place will depend upon the following

- ✓ The quantity of fuel in the combustion chamber at the point C. This quantity depends upon the rate at which fuel is injected during delay period and the duration of ignition delay.
- ✓ The condition of fuel that has got accumulated in the combustion chamber at the point C.

The rate of combustion during the crank travel C to D and the resulting rate of pressure rise determine the quietness and smoothness of operation of the engine.

CONTROLLED COMBUSTION

During controlled combustion, following thing happen. The flame spreads rapidly (but less than 135 m/min), as a turbulent, heterogeneous or diffusion flame with a gradually decreasing rate of energy release. Even in this stage, small auto ignition regions may be present. The diffusion flame is characterized by its high luminosity. Bright, white carbon flame with a peak temperature of 2500o C is noticed. In this stage, radiation plays a significant part in engine heat transfer.

During the period D to E, combustion is gradual. Further by controlling the rate of fuel injection, complete control is possible over the rate of burning. Therefore, the rate of pressure rise is controllable. Hence, this stage of combustion is called Gradual combustion or Controlled combustion. The period corresponding to the crank travel D to E is called the period of controlled combustion.

The rate of burning during the period of controlled combustion depends on the following:

- ✓ Rate of fuel injection during the period of controlled combustion.
- ✓ The fineness of atomization of the injected fuel.
- ✓ The uniformity of distribution of the injected fuel in the combustion chamber.
- ✓ Amount and distribution of the oxygen left in the combustion space for reaction of the injected fuel.

At the point E, injection of fuel ends, the period of controlled combustion ends at this point. When the load on the engine is greater, the period of controlled combustion is also greater.

During controlled combustion, the pressure in the cylinder may increase or remain constant or decrease. Usually during this period, the combustion is more or less at constant pressure (on a PV diagram) because the downward movement of the piston (i.e. increase in volume) compensates for the effect of heat release and the consequent pressure rise.

AFTER BURNING

At the last stage, i.e. between E and F the fuel that is left in the combustion space when the fuel injection stops is burnt. This stage of combustion is called after burning (burning on the expansion stroke). In the indicator diagram, after burning will not be visible. This is because the downward movement of the piston causes the pressure to drop inspired of the heat that is released by the burning of the last portion of the charge.

Increasing excess air, or air motion will shorten after burning i.e. reduce the quantity of fuel that may undergo after burning.