Combustion in Compression Ignition Engine

Working Principle: 4-stroke

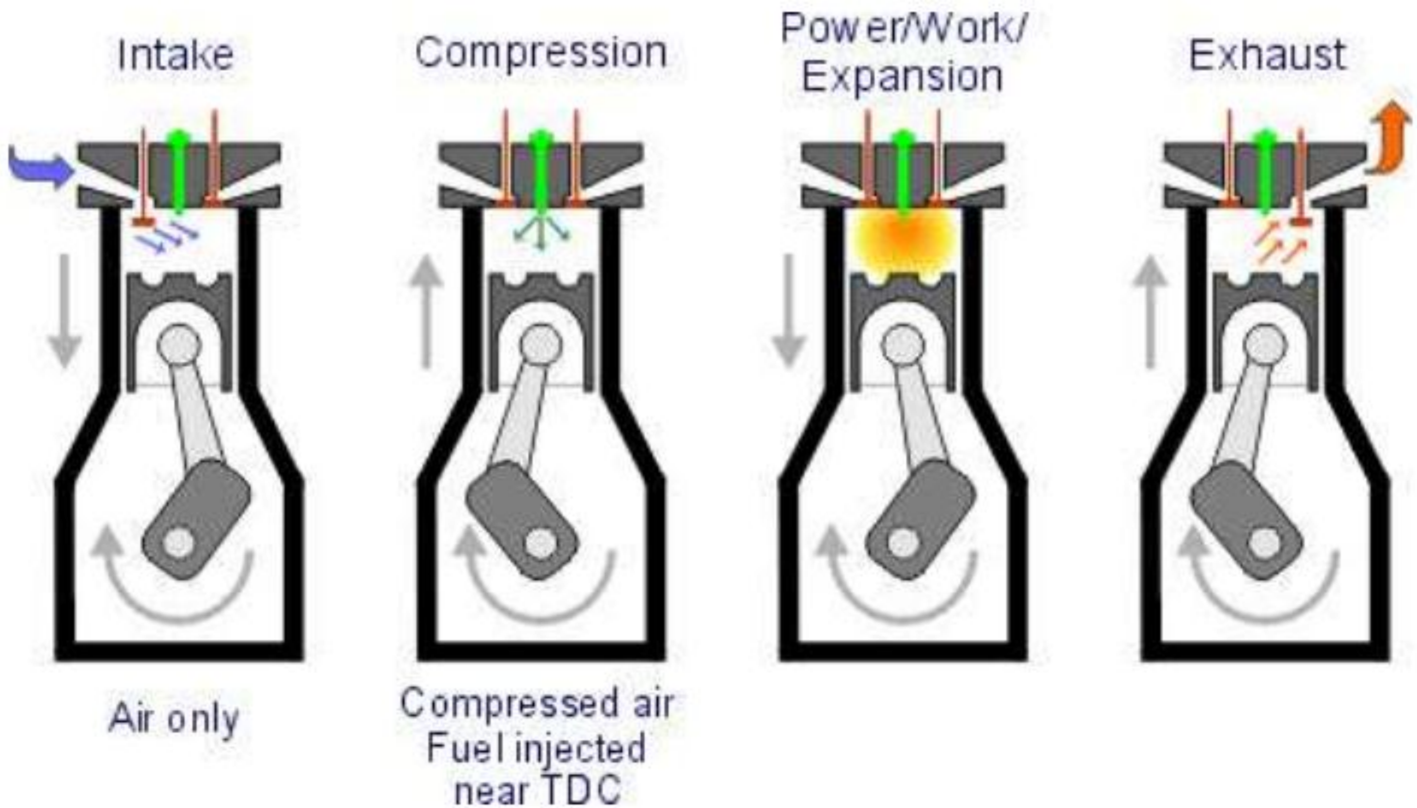
1. **Induction**
   Pure air is drawn into the cylinder

2. **Compression**
   The air is compressed to high temperature and pressure

3. **Power Stroke**
   Around TDC fuel is injected, which self-ignites and burns, further increasing pressure and there by forcing the piston down.

4. **Exhaust**
   The hot gas is released to the surrounding

Working Principle: 4-stroke



The importance of CI engines is due to:

- ❑Its higher thermal efficiency than SI engines.
- ❑CI engines fuels being less expensive than SI engine fuels.

Due to these factors the running cost of CI engine s much less than SI engines and make them attractive for all industrial and transport applications.

Why Passenger cars did not use CI engines?????

Because of the CI engine are ***heavier*** weight, noise , vibration, smoke and odour than the SI engines.

- ➢The compression ratio of SI (6:1 to 11:1) but in CI (12:1 to 22:1) this factor affect on the parts of engine be heavier and increase engine weight.
- ➢The smoke and odour are the result of the nature of diesel combustion phenomena, i.e., incomplete combustion of a heterogeneous mixture, and droplet combustion.

Combustion in CI engine:

- **In SI engine,**

  a homogeneous carbureted mixture of petrol vapor and air, in nearly stoichiometric or chemically correct ratio, is compressed in the compression stroke through a small compression ratio (6:1 to 11:1) and the mixture is ignited at one place before the end of the compression stroke by means of an electric spark. After ignition a single definite flame front progresses through the air fuel mixture, and entire mixture being in the combustible range.

- **In CI engine,**

  air alone is compressed through a large compression ratio (12:1 to 22:1) during the compression stroke raising highly its temperature and pressure. In this highly compressed and highly heated air in the combustion chamber one or more jets of fuel are injected in the liquid state, compressed to high pressure of 110 to 200 bar by means of a fuel pump. Each minute droplet as it enters the hot air (temperature 450-550 ^{o}C and pressure 30-40 bar) is quickly surrounded by an envelope of its own vapor.

As the fuel vapor and air in contact reach a certain temperature and the local air fuel ratio is within combustible range, ignition takes place. Once ignition has taken place and a flame established, the heat required for further evaporation will be supplied from that released by combustion.

- **In CI engine the fuel is not injected at once, but is spread over a definite period of time corresponding to 20-40 degrees of crank travel.**

  - The initial fuel droplets meet air whose temperature is only little above their self ignition temperature and they ignite after the ignition delay.

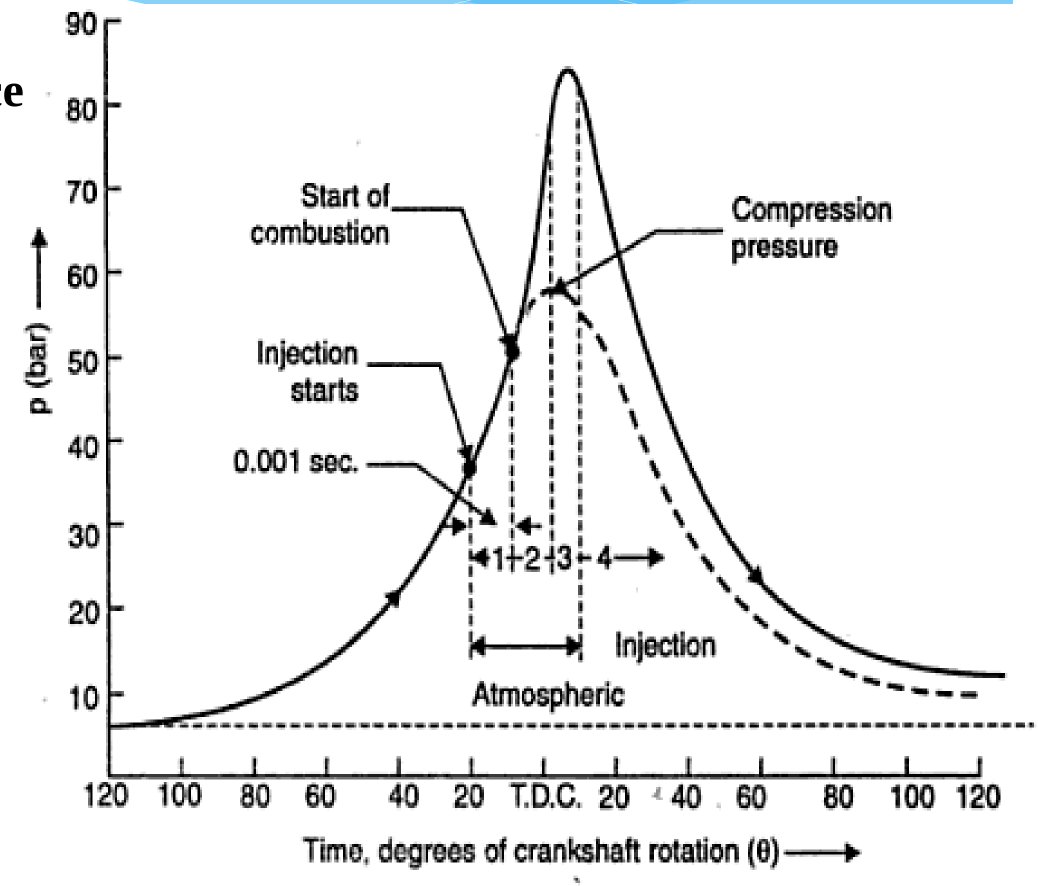
  - The subsequent fuel droplets find air already heated to a much higher temperature by the burning of initial droplets and light up much more quickly but their subsequent progress is handicapped because of less quantity of oxygen available.

Stages of Combustion:-

In CI engine combustion as taking place in three distinct stages:-

1. **Ignition delay period.**
2. **Rapid or uncontrolled combustion.**
3. **Controlled combustion.**

The third stage is followed by after burning, which may be the fourth stage.



Combustion phenomenon of C.I. engine.

First stage.

- Ignition delay period during which some fuel has been admitted but has not yet been ignited.
- The ignition delay is counted from the start of injection to the point where the p-θ curve separates from the pure air compression curve.

Second stage.

- Rapid or uncontrolled combustion following ignition. In this second stage the pressure rise is because during the delay period the fuel droplet have had time to spread themselves over a wide area and they have fresh air all around them.
- This stage is counted from the end of delay period to the point of maximum pressure on indicator diagram.
- about ***one-third*** of the heat is evolved during this stage.

Third stage.

- Controlled combustion, at the end of second stage the temperature and pressure are so high than the fuel droplets injected during the last stage burn almost as they enter and any further pressure rise can be controlled by purely mechanical means.
- The heat evolved by the end of controlled combustion is about ***70 to 80 percent of the total heat*** of the fuel supplied during cycle.

Fourth stage.

- After burning, theoretically it is expected that combustion process shall end after the third stage.
- Because of poor distribution of the fuel particles, combustion continues during part of the remainder of the expansion stroke.
- The duration of after burning may correspond to 70-80 degree of crank travel from tdc and the total heat evolved by the end of entire combustion process is 95 to 97% and 3 to 5% of heat goes as unburned fuel in exhaust.

Delay Period or Ignition Lag:-

➢The delay period exerts a very great influence on both engine design and performance .

➢The delay period can be divided into two parts:

- ✓**Physical delay.** Is the time between the beginning of injection and the attainment of chemical relation conditions. Here the fuel is atomized, vaporized, mixed with air and raised in temperature.

- ✓**Chemically delay.** Is the second part of delay period at which reaction start slowly and then accelerate until ignition take place.

❖Chemical delay is longer than the physical delay.
❖In SI engine the ignition lag is basically equivalent to the chemical delay only because the charge consist of homogeneous mixture of vapor fuel and air.

The effect of delay period in CI engine:-

➢The delay period affect the rate of pressure rise , knocking and engine startability.

➢The longer the delay period the more rapid and higher is the pressure rise, more fuel will be in cylinder before the rate of burning come under control so it cause engine knock.

The factor affecting on Delay Period in CI engine:-

1. fuel
2. Injection pressure or size of droplet.
3. Injection advance angle.
4. Compression ratio.
5. Intake pressure.
6. Jacket water temperature.
7. Fuel temperature.
8. Intake temperature.
9. Speed.
10. Air to fuel ratio.
11. Engine size.
12. Type of combustion chamber.

1. Fuel properties:-

- *Self ignition temperature.* Is the most important property of fuel which affect delay period .
  - ✓ The lower self ignition temperature mean a wider margin between it and the temperature of compressed air and here lower delay period.
  - ✓ The higher *cetane number* mean a lower delay period, and smoother engine operation because the cetane number depend on the chemical composition of the fuel.

- The other fuel properties which affect on delay period:

  i) Volatility, ii) latent heat, iii) viscosity, and surface tension.
  - ✓ *Volatility and latent heat* affect on time taken to form an envelope of vapor.
  - ✓ *Viscosity and surface tension* influence the fineness of atomization.

2. Injection pressure or size of droplet:-

- The rate of burning depends on the relative movement of the burning droplets to the surrounding air charge.

- The time taken to establish and ignite a film of vapor surrounding a liquid droplet is practically independent of the size of the droplet. So that, the rate of burning and pressure rise following ignition will dependent upon the exposed surface face area of the vaporizing liquid droplets.

- It is possible, to control the droplet size by the injection needle spring closing load. Generally the greater the injector spring load, the smaller and finer droplet size.

- As the size of droplet depend on the injection pressure, it can be said that lower the injection pressure the lower the rate of pressure rise during the uncontrolled phase and smoother the engine running.

3. Injection advance angle:-

- The delay period increase with increase in injection advance angle, because of the temperature and pressure are lower when the injection begins.

- When the injection advance angles are small , the delay period reduces and operation of engine is smoother but power is reduced because large amount of fuel burns during expansion stroke.

- The optimum angle of injection be 12 to 20 degree before tdc, to cause peak pressure to occur 10 to 15 degree after tdc.

4. Compression ratio:-

- Increase in compression ratio reduce the delay period as it raises both temperature and density.

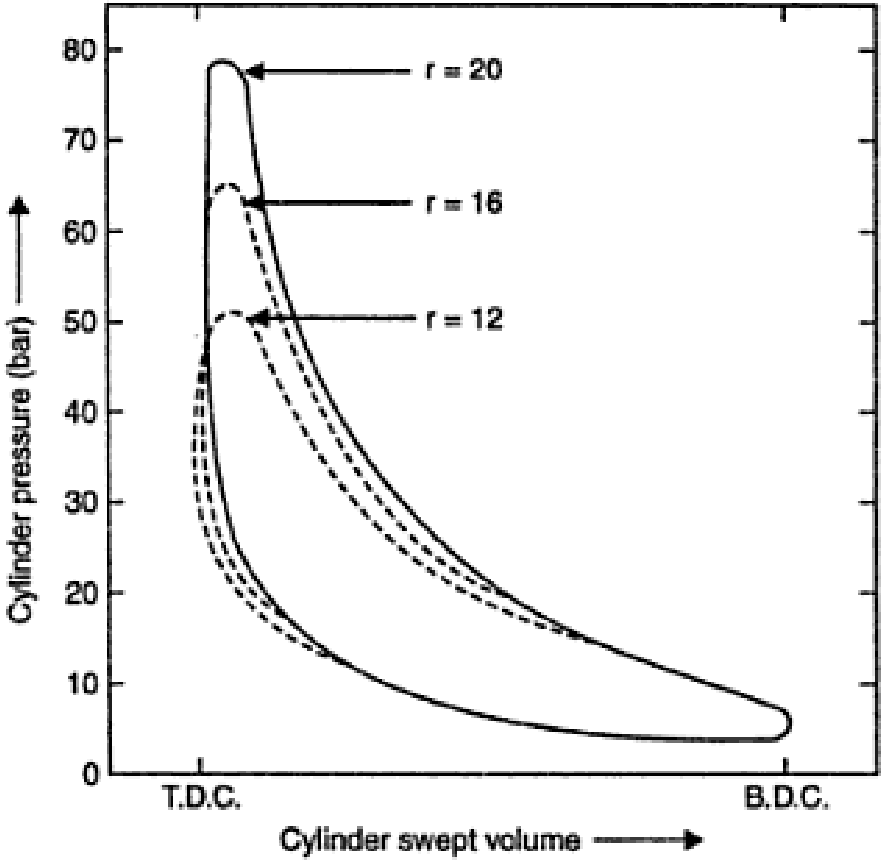
- Increase in compression ratio lead to:

  - ✓ The cylinder compression pressure and temperature increase, the ignition time lag between the point of injection to the instant when ignition first commences reduces.

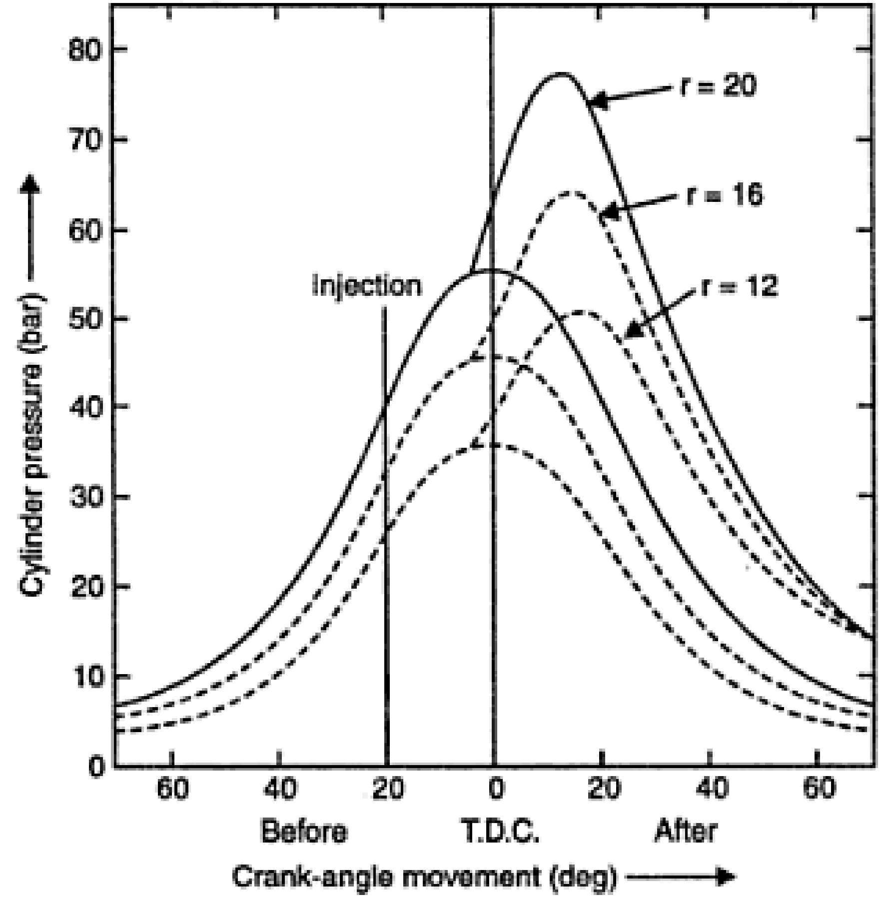
  - ✓ The density and turbulence of the charge increase, and increase rate of burning and increase the rate of pressure rise and the magnitude of peak cylinder pressure reduced.

  - ✓ Thermal efficiency and specific fuel consumption are improved.

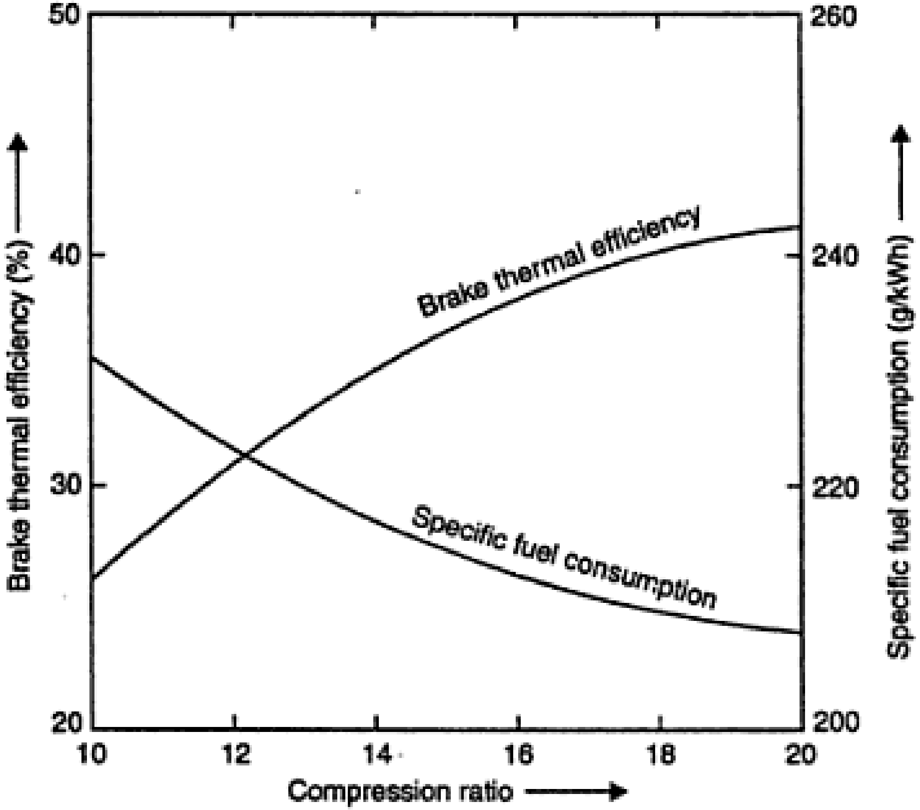
  - ✓ The mechanical efficiency and volumetric efficiency are reduced.



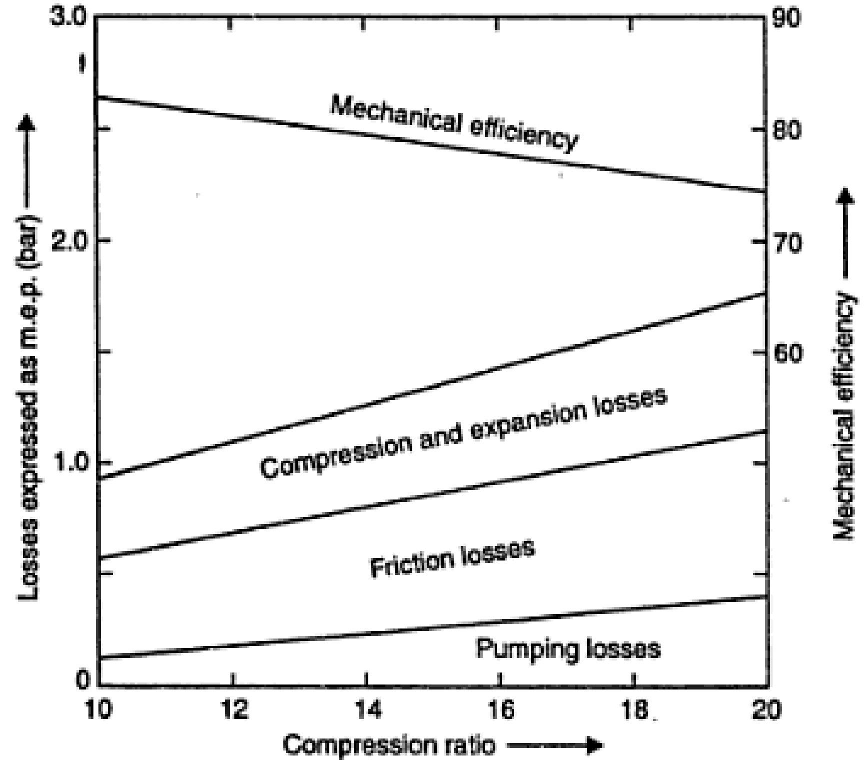
Effect of compression ratio on the characteristic pressure—volume diagrams for a diesel engine.



Effect of compression ratio on the characteristic pressure –crank-angle movement diagrams for a diesel engine.



. Effect of compression ratio on the thermal efficiency and specific fuel consumption.



Effect of compression ratio on the pumping, friction, compression and expansion losses and the resultant mechanical efficiency.

5. Intake temperature:-

- Increasing the intake temperature would result in increase in the compressed air temperature, which would reduce the delay period. But also it reduce the density of air and hence the volumetric efficiency and power output.
- Preheating the air by 100 ^{o}C reduces the delay angle by 2^{o}.

6. Jacket water temperature:-

- Increase in jacket water temperature also increase compressed air temperature so it reduce delay period.

7. Fuel temperature:-

- Increase in fuel temperature would reduce both physical and chemical delay period.

8. Intake pressure or supercharger:-

- Increasing the intake pressure or supercharger reduces the auto ignition temperature and reduce the delay period.

9. speed:-

- At constant speed, delay time is proportional to delay angle.
- At variable speed, delay period decrease in term of milliseconds but increase in term of crank angle.

10. Air – fuel ratio:-

- Increase in air fuel ratio the combustion temperature are lowered and cylinder wall temperature are reduced and the delay period increases.

11. Engine size:-

- The engine size has little effect on the delay period in milliseconds. As large engines operate at low rpm because of inertia stress limitations, the delay period in term of crank angle is smaller .

12. Type of combustion chamber :-

- In general, a pre-combustion chamber gives shorter delay period to open type combustion chamber.

Diesel Knock:-

- If the delay period is long a large amount of fuel will be injected and accumulated in the chamber, at the ignition of this large amount of fuel may cause high rate of pressure rise and high maximum pressure which may cause knock in diesel engine.

- The comparison between the detonation in SI engine and knock in CI engine:
  - *In SI engine,* the detonation occurs near the end of combustion.
    In CI engine, the detonation occurs near the beginning of combustion.

  - *In SI engine,* the detonation of a homogeneous charge causing very high rate of pressure rise.
    In CI engine, the fuel and air are imperfectly mixed and the rate of pressure rise is normally lower than in the detonation in SI engine.
  - *In SI engine,* it is easy to distinguish between detonation and non detonation operation as the human ear easy find the distinction.
    In CI engine, it is difficult because all CI engine have a sufficiently high rate of pressure rise per degree of crank angle to cause audible noise.

Methods of Controlling Diesel Knock (Reducing Delay Period) :-

- The diesel knock can be controlled by reducing delay period.

- The delay period is reduced by the following:

  - ✓ High charge temperature.
  - ✓ High fuel temperature.
  - ✓ Increase the cetane number, by adding chemical dopes, called ignition accelerators.
  - ✓ A fuel with a short induction period, by arranging the injector so only a small amount of fuel is injected at first.

The Combustion Chambers of Compression Ignition Engine

The CI Engine Combustion Chambers:-

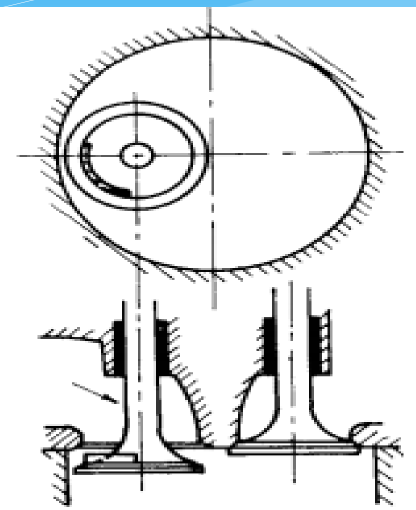
- The important of design the combustion chamber:
  - ✓ In SI engine, the fuel and air are mixed outside the combustion chamber.
  - ✓ In CI engine, the mixing of fuel and air take place inside the combustion chamber where the fuel is injected near the end of compression stroke during a period of 20 to 35 degrees of crank angle.

- The most important function of CI engine combustion chamber , is to provide proper mixing of fuel and air in a short time by made air swirl.
- Methods for made air swirl in CI engine:-
  - ✓ By directing the flow of air during its entry to the cylinder, called induction swirl used in *open combustion chamber*.
  - ✓ By forcing the air through a tangential passage into a separate swirl chamber during the compression stroke, called compression swirl used in *swirl chamber*.
  - ✓ By use of the initial pressure rise due to partial combustion to create swirl turbulence, called combustion induced swirl used in *pre combustion chamber* and *air cell chamber*.

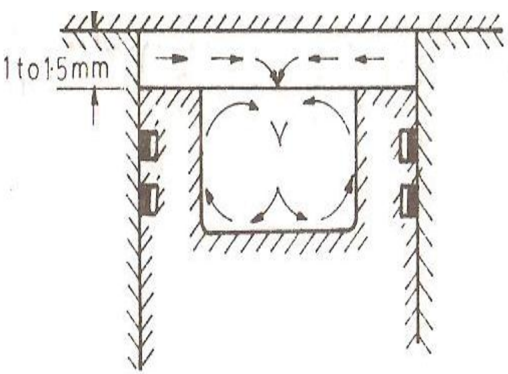
The Classification of CI Engine Combustion Chambers:-

- **CI engine Combustion Chamber**
  - **Open Chamber or Induction Swirl**
  - **Divided Chamber or Turbulent Chamber**
    - **Swirl Chamber (Compression Swirl)**
    - **Pre combustion Chamber**
    - **Air Cell Chamber**

❑ Open Combustion Chamber or Induction Swirl:-

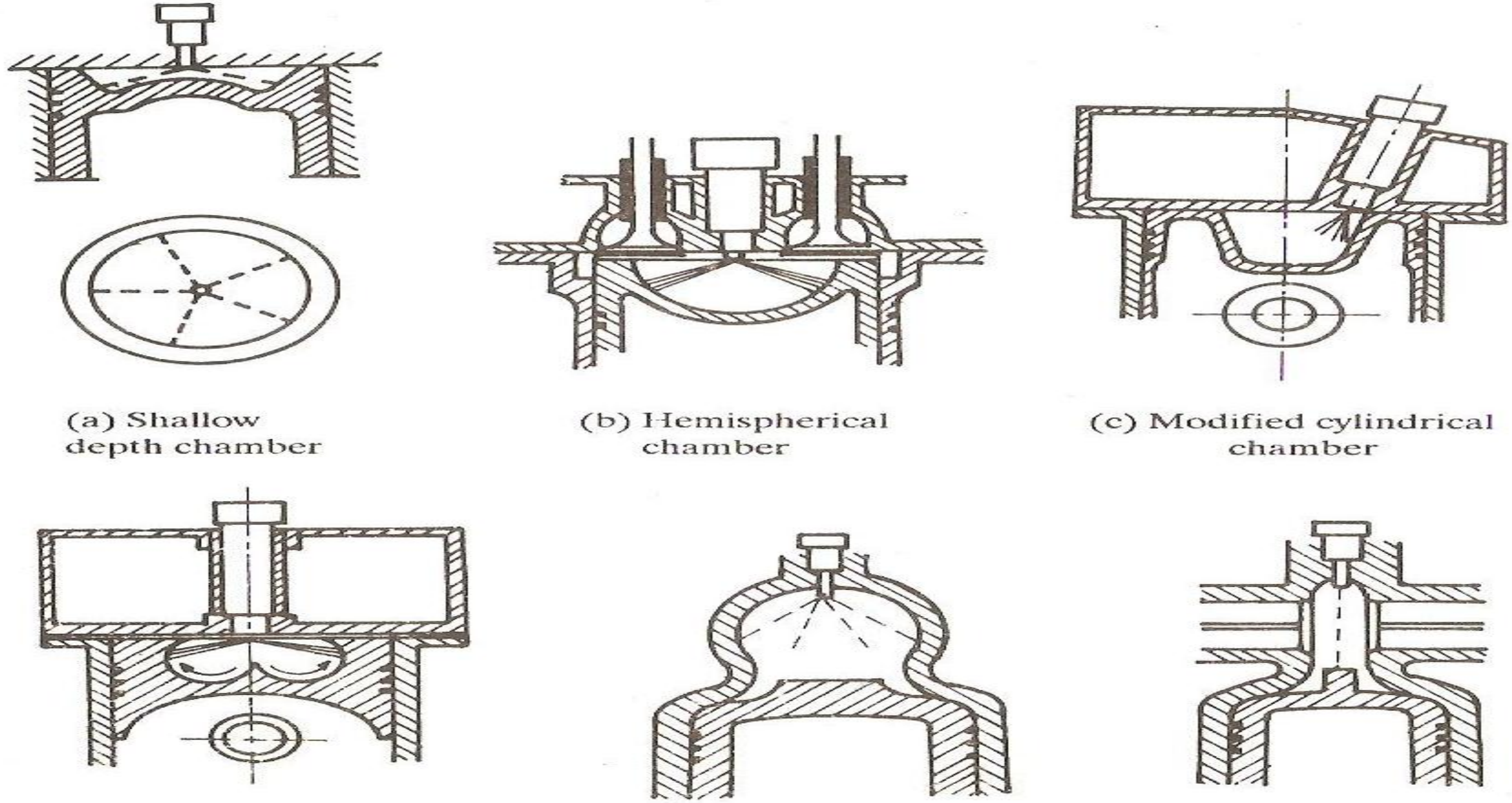


- In four stroke engines, induction swirl can be obtained by:
  - ✓ Careful formation of the air intake passage.
  - ✓ Making or shorting a portion of circumference of the inlet valve. The angle of mask is from 90 to 140 degree of circumference.



- In four stroke engines, induction swirl can be obtained by:
  - ✓ The secondary air movement called *squish*.
  - ✓ Squish is the flow of air radially inwards towards the combustion recess by squeezing it out from between the piston and the cylinder head as they approach each other at end of the stroke.

- **The Various Design of Open Combustion Chamber :-**
  - ✓ Here, the combustion space is essentially a single cavity with little restriction and there are no large differences in pressure between different parts of the chamber during the combustion process.



(a) Shallow depth chamber

(b) Hemispherical chamber

(c) Modified cylindrical chamber

(d) Torodial chamber

(e) NACA design displacer on piston

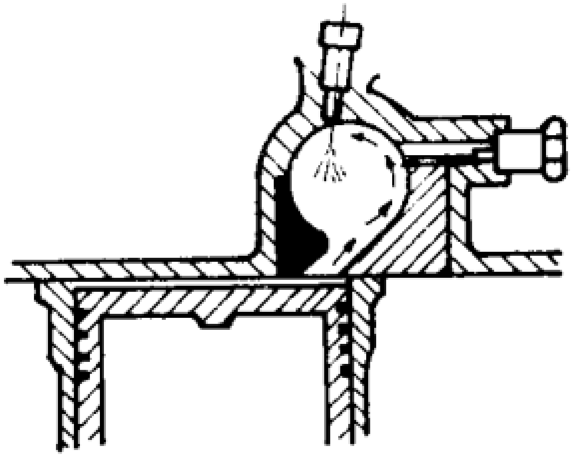
- **The Advantages of Induction Swirl:-**
  1. Easier starting (due to low intensity of swirl).
  2. High excess air (low temperature), low turbulence (less heat loss), therefore indicated thermal efficiency is high.
  3. Production of swirl requires no additional work.
  4. Used with low speeds, therefore low quality of fuel can be used.

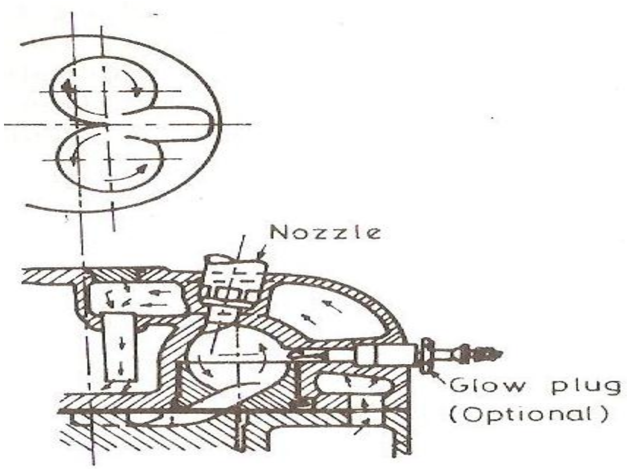
- **The Disadvantages of Induction Swirl:-**
  1. Shrouded valves, smaller valves, low volumetric efficiency.
  2. Weak swirl, low air utilization (60%), lower m.e.p. and large size (costly) engine.
  3. Weak swirl, multi orifice nozzle, high induction pressure, clogging of holes, high maintenance.
  4. Swirl not proportional to speed; efficiency not maintained at variable speed engine.
  5. Influence minimum quality of fuel. Complication at high loads and idling.

Compression Swirl Chambers:-

- *the divided chamber* is one in which the combustion space is divided into two or more distinct components, between which there are restrictions or throats small enough so that considerable pressure differences occur between them during the combustion process.

- Examples of compression swirl chamber:





Ricardo swirl chamber
Comet, MarkII

The Advantages of Compression Swirl:-

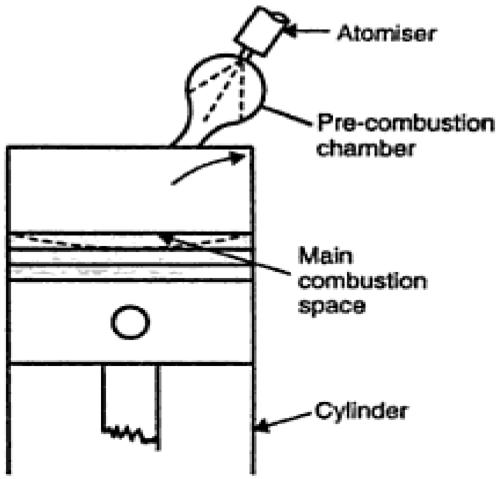
1. Large valves, high volumetric efficiency.
2. Single injector, pintle type (self cleaning), less maintenance.
3. Smooth engine operation.
4. Greater air utilization due to strong swirl. Smaller (cheaper) engine.
5. Swirl proportional to speed, suitable for variable speed operation.

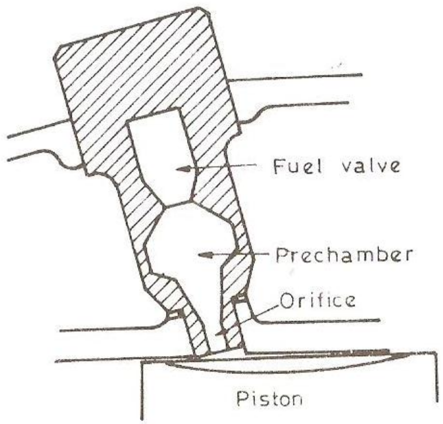
The Disadvantages of Compression Swirl:-

1. Cold starting trouble due to high loss due to strong swirl, mechanical efficiency lower.
2. Less excess air; lower indicated efficiency; 5 to 8% more fuel consumption; decreased exhaust valve life.
3. Cylinder more expensive in construction.
4. Work absorbed in producing swirl, mechanical efficiency lower.

Pre-combustion Chambers:-

- **the combustion chamber is separated in *two* chambers: *pre-combustion chamber* connected to the *main chamber* through a number of very *small holes*.**
  - ✓ The *pre-combustion chamber* or *anti-chamber* contains 20 to 30 percent of the clearance volume.
  - ✓ The fuel is injected into pre-combustion chamber.
  - ✓ The combustion is beginning in it and the result pressure rise forces the flaming droplets and air together with their combustion products to rush out at high velocity through a small holes to the main combustion chamber.
  - ✓ The total energy is released in the main combustion chamber (about 80% of energy).



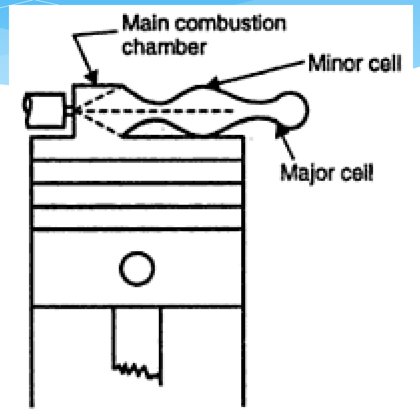


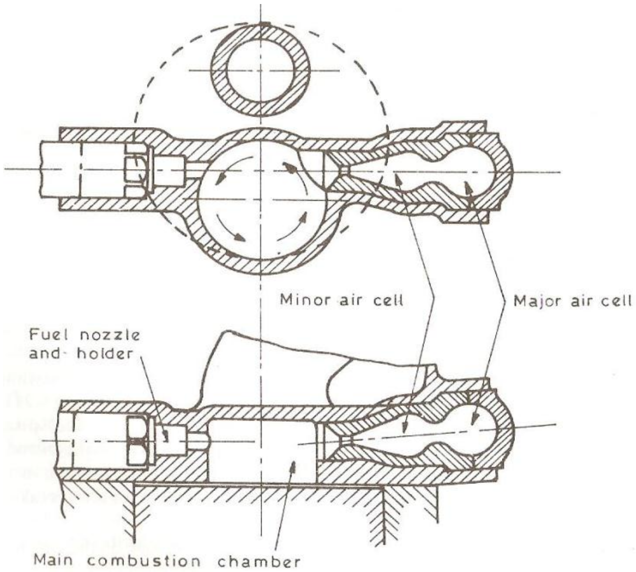
- **The Advantages of Pre-combustion :-**
  1. Due to short or practically no delay period for the fuel entering the main combustion space, tendency to knock is minimum, and as such running is smooth.
  2. The combustion in the third stage is rapid.
  3. As mixing of fuel and air is through due to violent projection of combustion products from pre-chamber, the fuel injection system design need not be critical.

- **The Disadvantages of Pre-combustion Swirl:-**
  1. The velocity of burning mixture is too high during the passage from pre-chambers, so the heat loss is very high. This causes reduction in the thermal efficiency, which can be offset by increasing the compression ratio.
  2. Cold starting will be difficult as the air loses heat to chamber walls during compression.

Air cell Chambers or Energy Cell Chamber:-

- The *air cell* consist of *two* parts, *major* and *minor,* which are separated from each other and from the main chamber by narrow orifices.
- The air cell contains about 10 to 15 percent of the clearance volume.
- The fuel injected in the main chamber space towards the open neck of the air cell.
- The first ignition probably starts near the neck of minor air cell chamber where pressure rises sharply, this results in outflow of air, burning gas, fuel to the main chamber, but due to restricted passage and start of expansion stroke the high pressure is not transmitted to the main chamber.



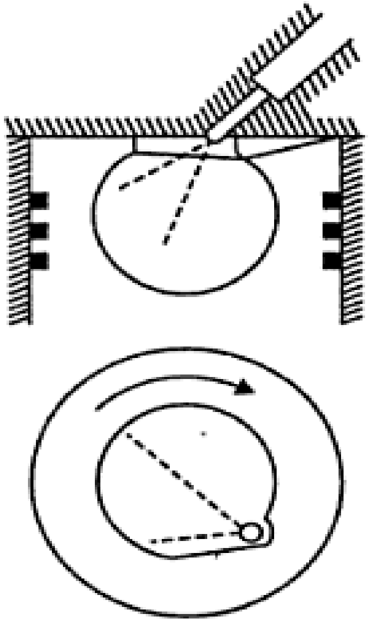


- **The Advantages of Air Cell-chamber :-**
  1. Low pressure in main chamber so it gives smooth running and easy starting.
  2. Used for comparatively small engines of medium duty.

- **The Disadvantages of Air Cell-chamber :-**
  1. Low efficiency and low power.
  2. This design not suitable for variable speed operation.

M. Combustion Chamber :-

- The M-combustion chamber is a special type of *open combustion chamber*, having combustion chamber in the *piston cavity*.
- The fuel injected *tangentially* from multi-holes nozzle on the surface of the chamber in the direction of the air swirl. Injected fuel forms a film about 0.15 mm thick on the surface of the chamber.
- The combustion is initiated by auto-ignition of small portion of fuel which is air-borne at the very beginning. The amount of this air is controlled by selecting a proper distance between the nozzle tip and the combustion chamber wall.
- The combustion characteristics are similar to those of Otto cycle combustion.



- **The Advantages of M-chamber :-**
  1. Low peak pressure.
  2. Low rate of pressure rise.
  3. Low smoke level.
  4. Ability to operated on a wide range of liquid fuels (multi- fuel capacity).

- **The Disadvantages of M-chamber :-**
  1. Low volumetric efficiency.
  2. Since fuel vaporization depends upon the surface temperature of the combustion chamber, cold starting requires certain aids.
  3. At starting and idling conditions hydrocarbon emissions may occurs.

comparison between open combustion chambers and divided combustion chambers.

S. No.	*Aspects*	*Open Combustion Chamber*	*Divided Combustion Chamber*
1.	*Fuel used*	Can consume fuels of good ignition quality, *i.e.* of shorter ignition delay or higher cetane number.	Can consume fuels of poor ignition quality *i.e.*, larger ignition delay. or lower cetane number.
2.	*Type of injection nozzle used*	Requires multiple hole injection nozzles for proper mixing of fuel and air, and also higher injection pressures.	It is able to use single hole injection nozzles and moderate injection pressures. It can tolerate greater degree of nozzle fouling.
3.	*Sensitivity to fuel spray characteristic*	Sensitive.	Insensitive.
4.	*Mixing of fuel and air*	Mixing of fuel and air is not so efficient and thus high fuel/air ratios are not feasible without smoke.	Ability to use higher fuel/air ratios without smoke, due to proper mixing and consequent high air utilization factor.
5.	*Cylinder construction*	Cylinder construction is simple.	More expensive cylinder construction.
6.	*Starting*	Easy cold starting.	Difficult cold starting because of greater heat loss through the throat.
7.	*Thermal efficiency*	Open combustion chambers are thermally more efficient.	Divided combustion chambers suffer from irreversibilities like throttling through the throat during the compression and expansion ; thus leading to pressure losses and available heat losses. Therefore, these engines are thermally less efficient comparatively.

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- **The Important Factors Which Should Be Taken Into Consideration In The Design Of C.I. Combustion Chamber :-**

1) High thermal efficiency.
2) Fuel requirement - ability to use less expensive fuel, ability of multi-fuel operation.
3) Ease of starting (heat loss to combustion chamber walls should be less).
4) Capacity of variable speed operation.
5) Smoothness of operation and avoidance of diesel knock (combustion noise).
6) Low exhaust emission.
7) Nozzle design (injection pressure maintenance problems).
8) High volumetric efficiency.
9) High Bmep (engine weigh per unit volume).

Cold Starting Of C.I. Engines

➢ The Cold Starting Of C.I. Engines:-

➢ The most important requirement of CI engine is its easy starting from cold, so that, the *compression ratios* higher than necessary are used.

➢ **The Cold Starting may become difficult in:-**

✓ Extreme cold climate like Himalayan region.
✓ When the cylinder liner is heavily worn.
✓ When the valve are leaky.

so that: some times it is necessary to some electrical aid for cold starting.

➢ **There is both a minimum and maximum speed for cold starting of CI engine**:

✓ ***At very low speed,*** the engine will not start *because of* high heat losses to the cold walls of cylinder during compression and grater time available for leakage past piston rings.
✓ ***At too high speed,*** the engine will not start *because of* too short time available for vaporization and preparation of mixture chemically for ignition.

- ✓ **The optimum speed for cold starting depends on:-**
  - ✓ surface volume ratio (which controls the heat loss to cylinder walls).
  - ✓ Intensity of air swirl (higher swirl make the cold starting difficult due to removal of stagnant gas film).
  - ✓ Physical condition of engine (leakage past piston and valves reduces temperature and pressure of compressed air).

- ➢ it is found that if engine of 1000 – 2000 CC per cycle, optimum starting speed is 200 – 300 rpm.

- ➢ **The open chamber direct injection engines are easiest to cold start due to:**

  - ✓ They have smallest surface to volume ratio.
  - ✓ They have lowest intensity of air swirl.

❑ The Cold Starting Aids:-

❑ Past starting aids:

- ✓ Injection of a small quantity of lubricating oil or fuel oil.
- ✓ Starting as petrol engine. (engine have spark plug and carburetor at starting compression ratio is reduced by providing an auxiliary chamber).
- ✓ Preheating the engine cylinder by warm water.
- ✓ Modifying valve timings for starting.

❑ Modern starting aids:

- ✓ Electric glow plugs in the combustion chamber.
- ✓ Manifold heaters which ignite a small feed of fuel.
- ✓ The injection into the intake. (by use ethyl-ether fuel with low ignition temperature liquid)