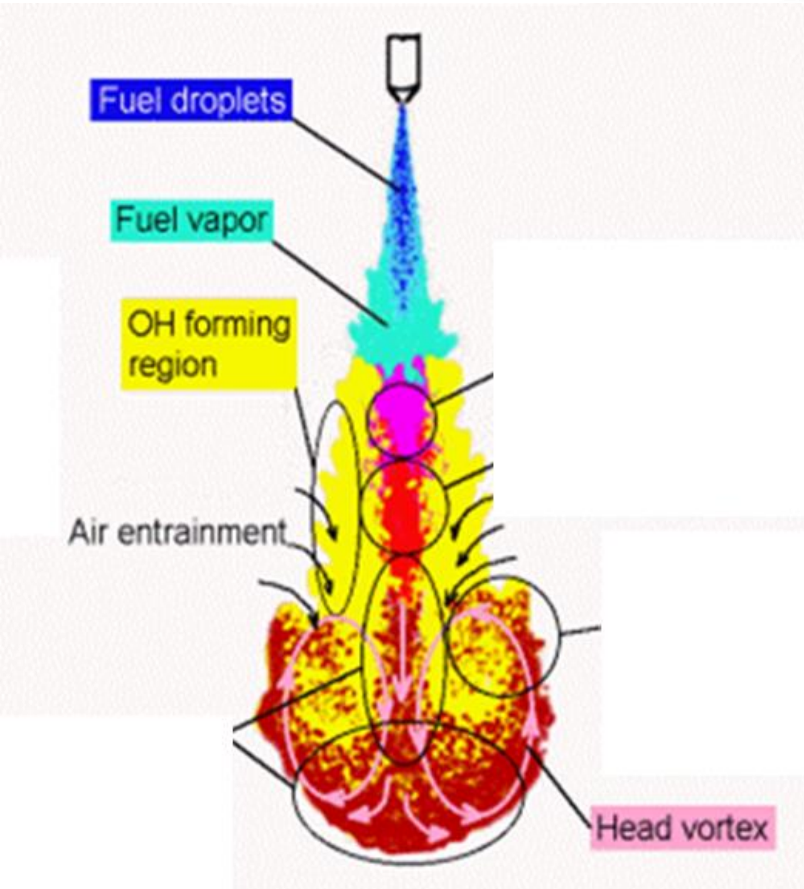
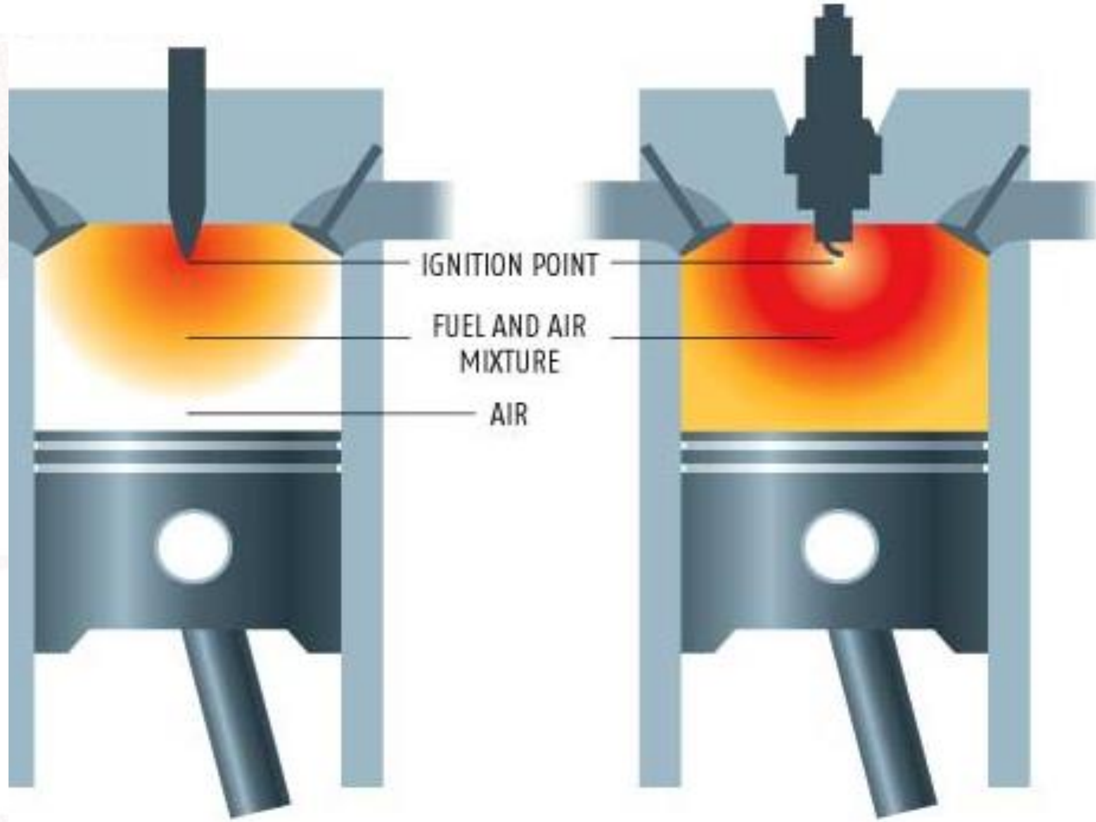
Combustion in C.I.Engine

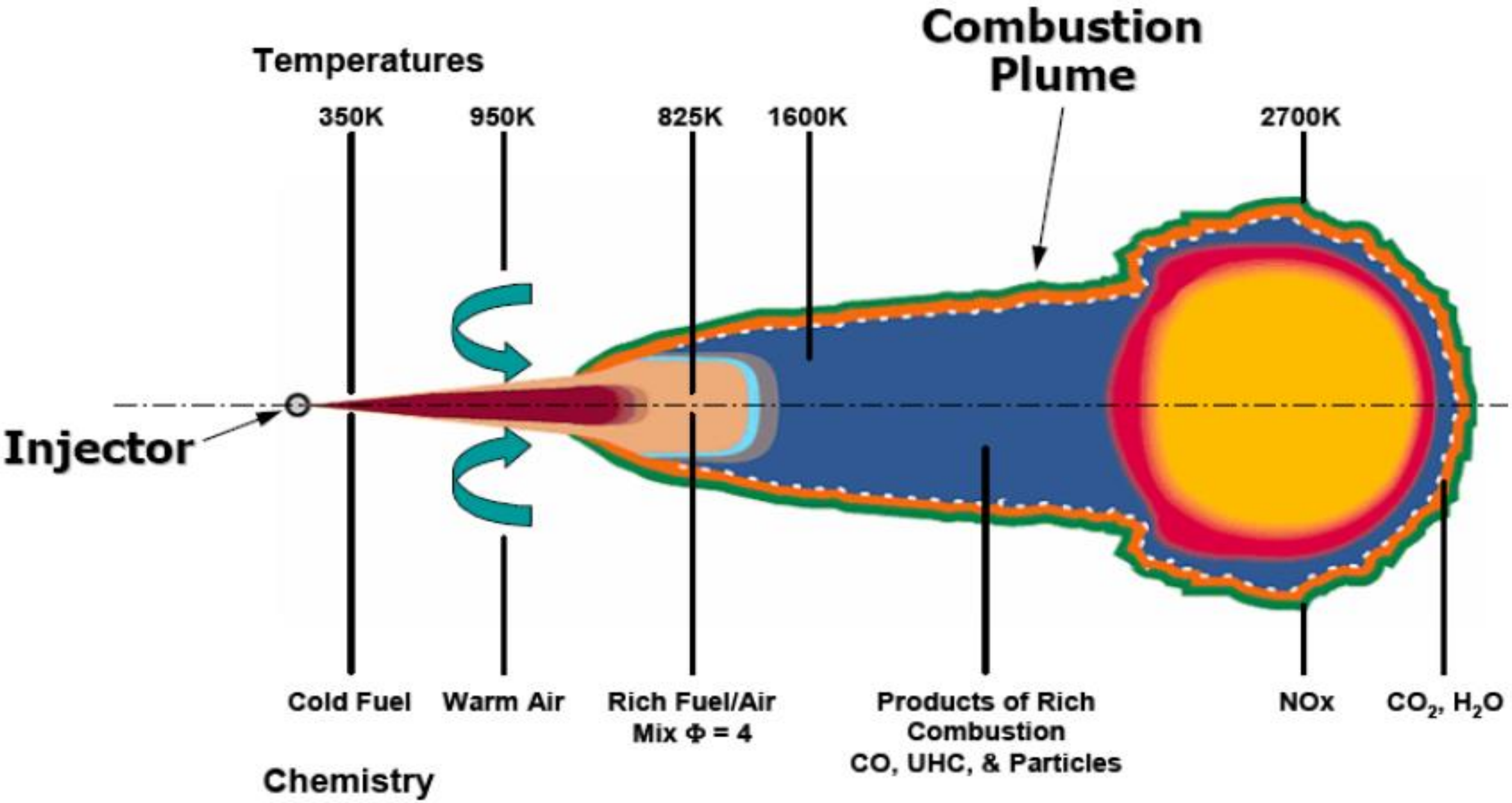




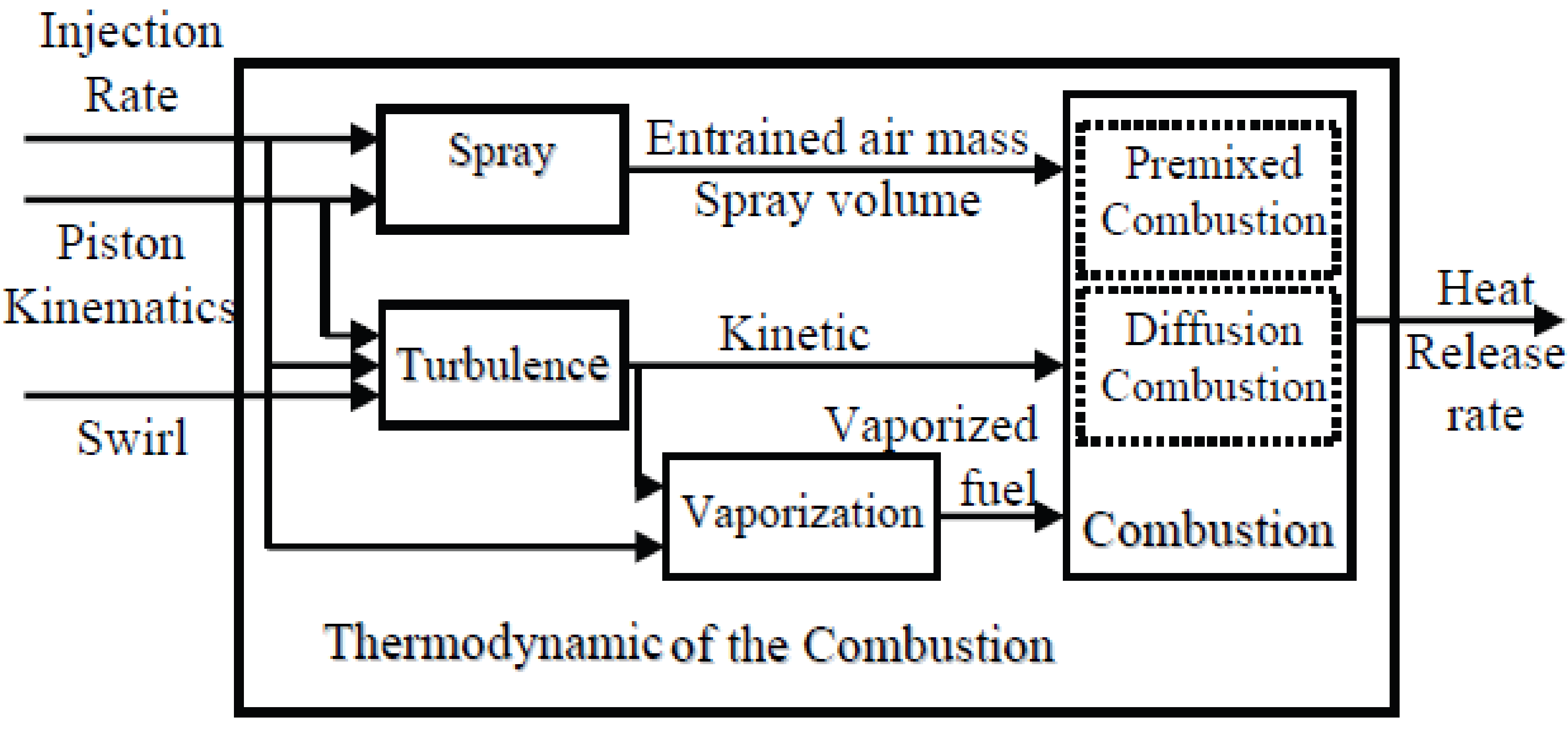
CI Engine

SI Engine

Schematic of a diesel spray & flame with temperatures and chemistry



Modeling of Events in CI Combustion

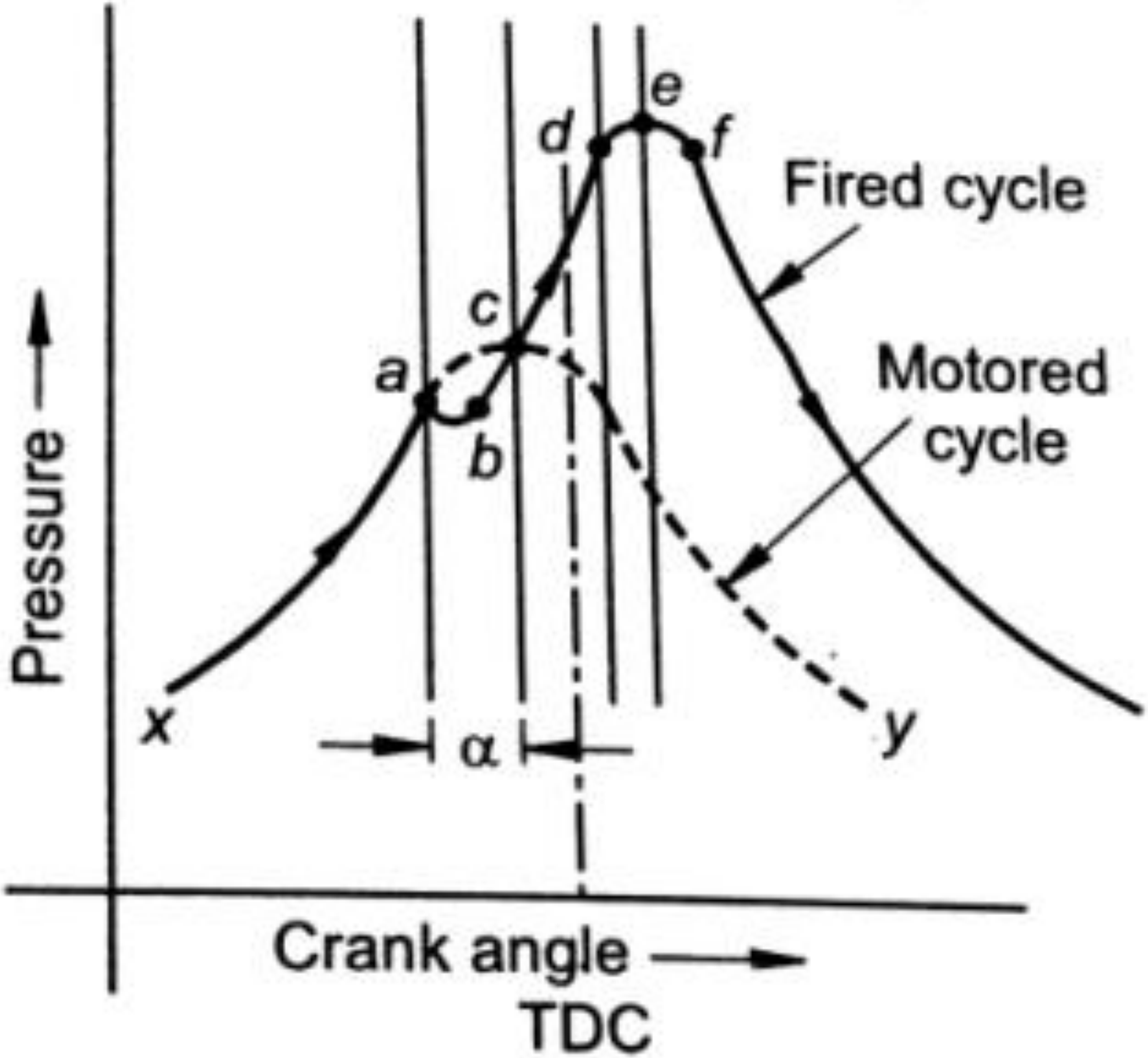


Introduction

1 the **fuel only burns after vaporization**, therefore, **the fuel mass** injected into the **combustion chamber** must be **broken into a large number of small particles** to **expose maximum surface area for evaporation.**

2 the **heat required for the vaporization of fuel** is taken from the **compressed air** as the **temperature of the air at the end of compression is sufficiently high**, but **this heat alone is not sufficient** to completely **vaporize the fuel** and **part of the fuel still** remains in **liquid condition** after **starting of actual combustion unlike in S.I.Engine.**

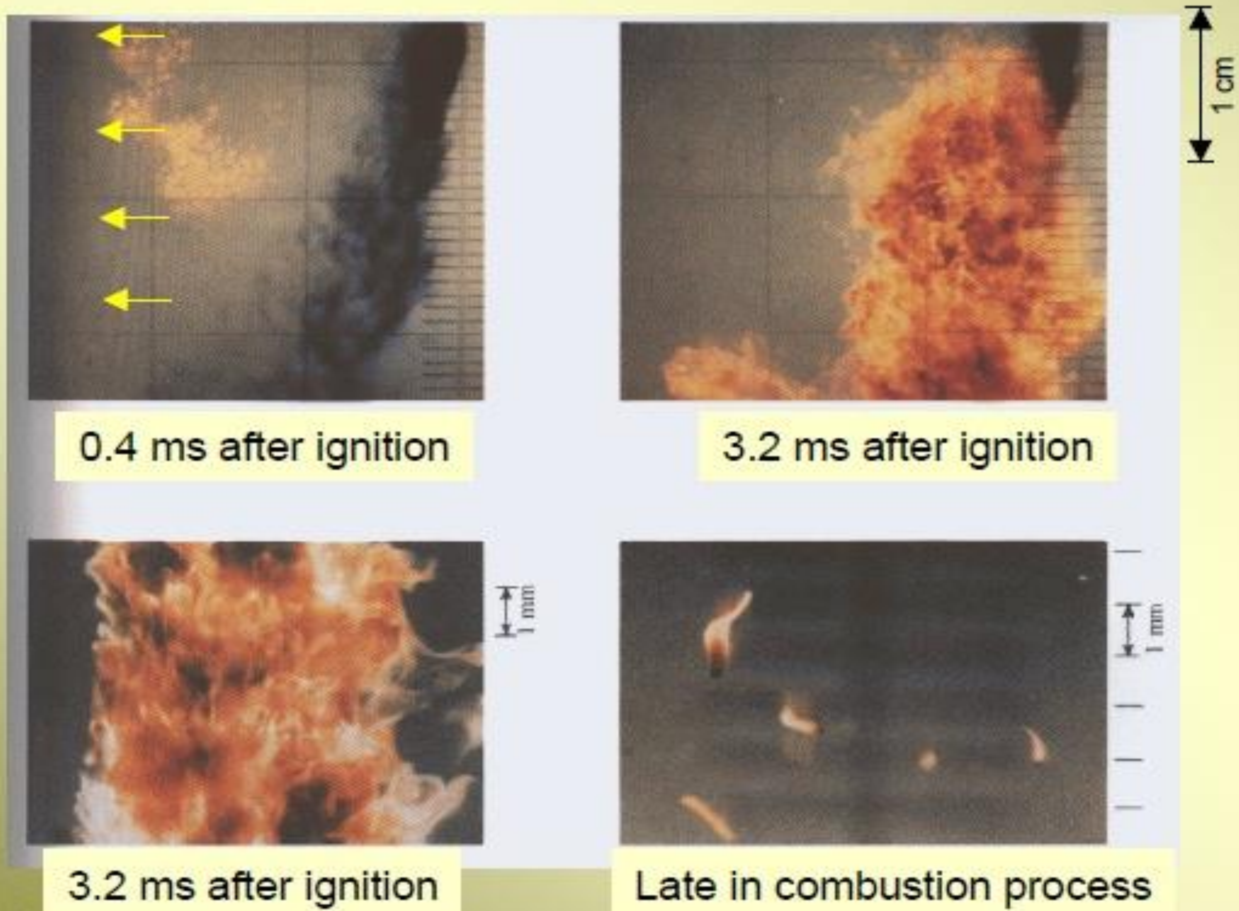
3 sufficient **air turbulence** should be **created during injection** of the fuel for **better mixing** and **vaporization of the fuel**.

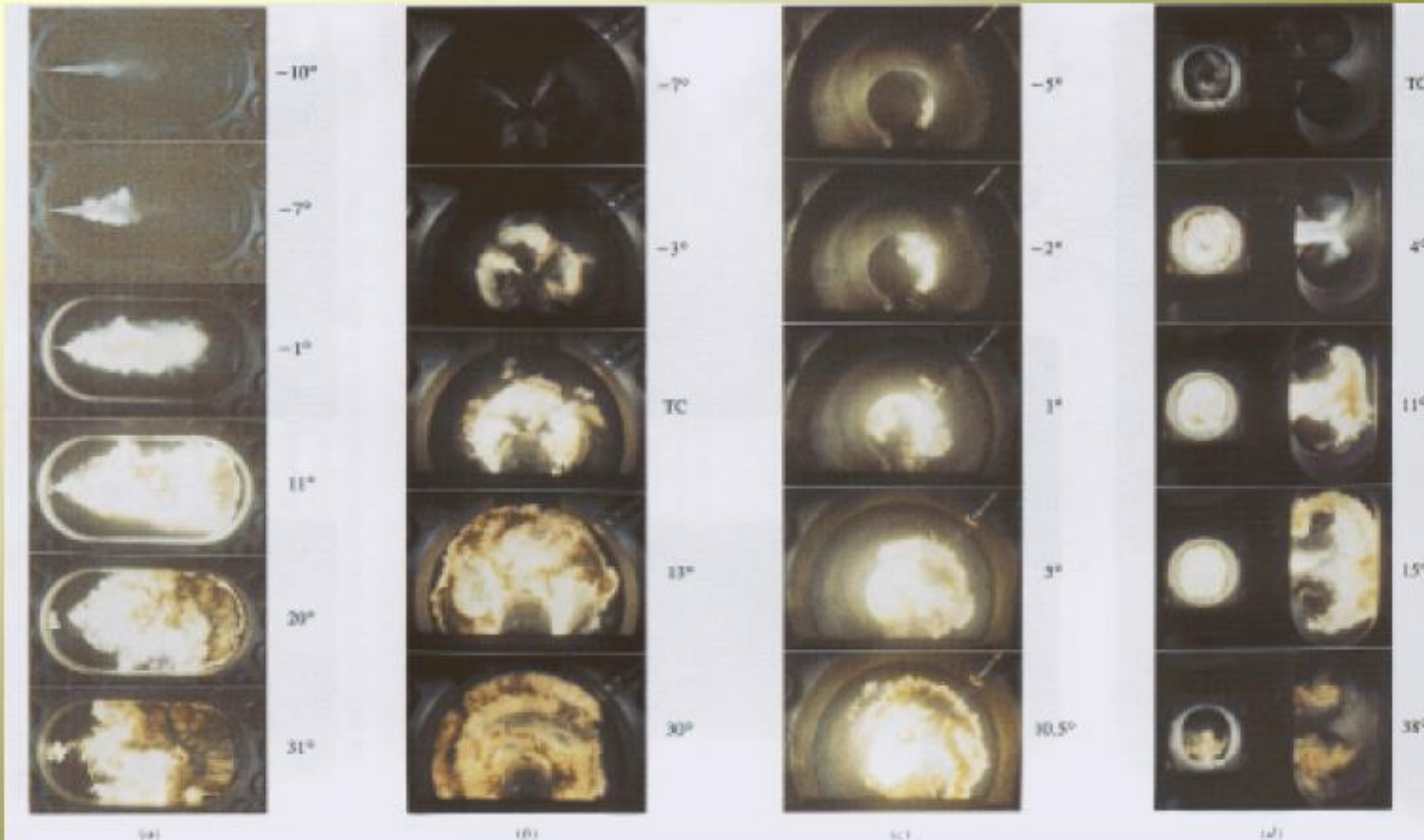


Pressure
e
d
f
Fired cycle
c
a
b
Motored
cycle
x
α
y
Crank angle
TDC

Combustion in CI Engine

- In a CI engine the fuel is sprayed directly into the cylinder and the fuel-air mixture ignites spontaneously. These photos are taken in a RCM under CI engine conditions with swirl air flow





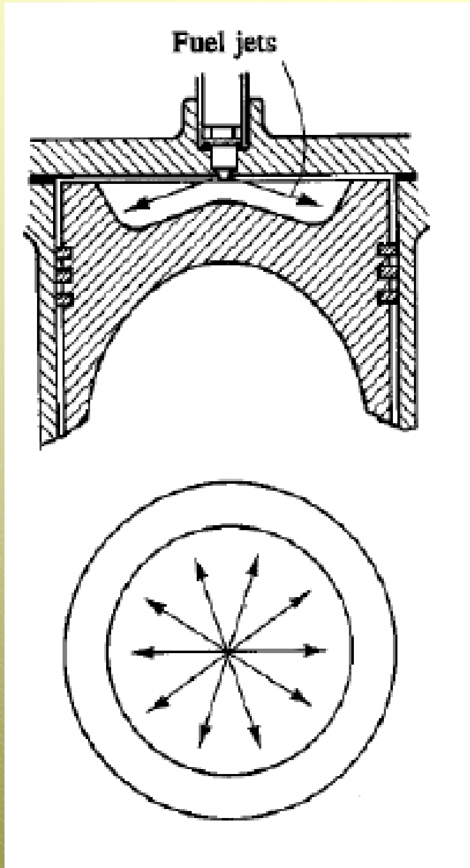
Direct Injection
quiescent chamber

Direct Injection
multi-hole nozzle
swirl in chamber

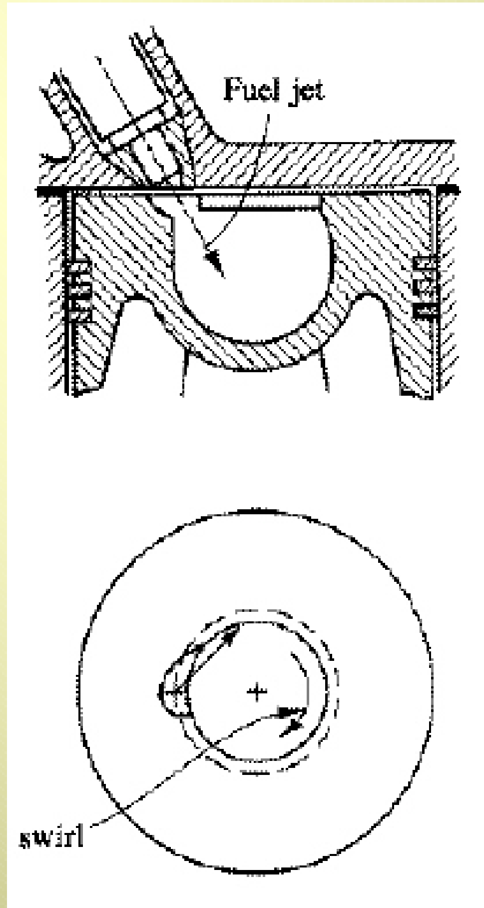
Direct Injection
single-hole nozzle
swirl in chamber

Indirect injection
swirl pre-chamber

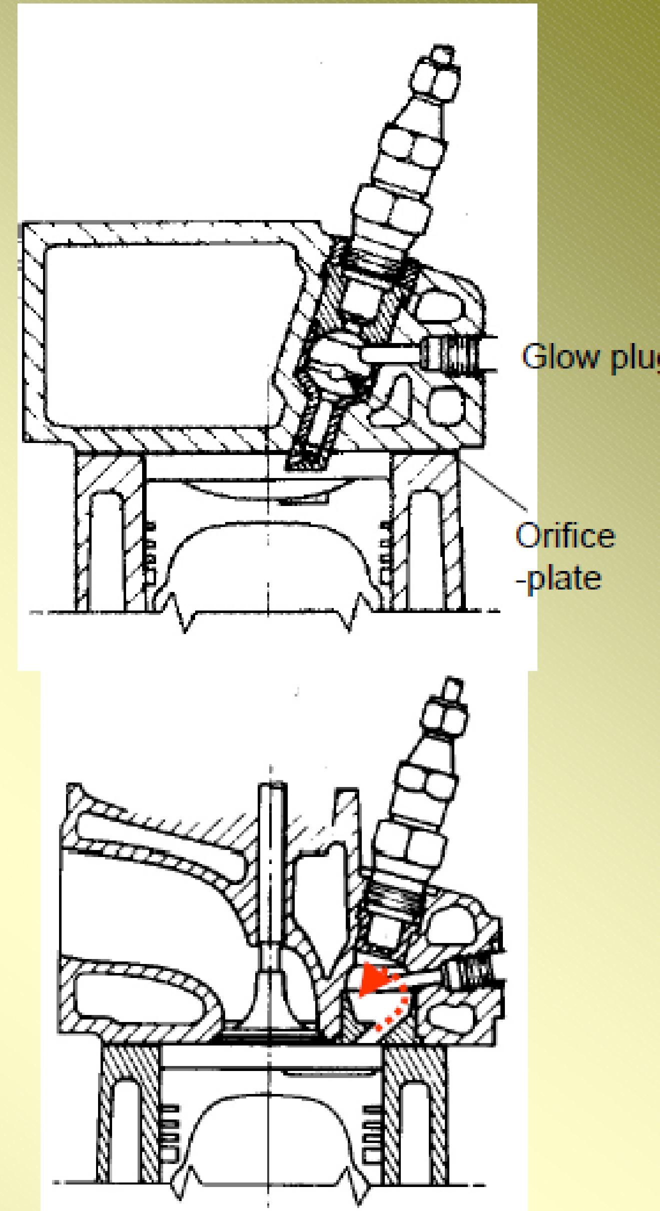
Types of CI Engines



Direct injection:
quiescent chamber



Direct injection:
swirl in chamber



Indirect injection: turbulent and swirl pre-chamber

Delay period or Ignition Lag

- **Between the start of injection** and **starting of combustion**.

tf= tp+tc

tp - physical delay, tc - chemical delay

- Physical delay is the **time required for the fuel mix properly with the air** by **fuel particles are atomized, mixed with the air and vaporized** as preparation for **combustion.**
- the chemical delay is the **time from the end of physical delay** to the **time of ignition**. It **physical property of fuel** and it **depends upon** many chemical characteristics of the fuel.
- The physical **delay small for light fuels** while for **heavy** and viscous fuels, the physical delay is **one of the controlling factors**.
- The physical delay can be **reduced** by using **high injection pressure and better turbulence.**

Delay period or Ignition Lag

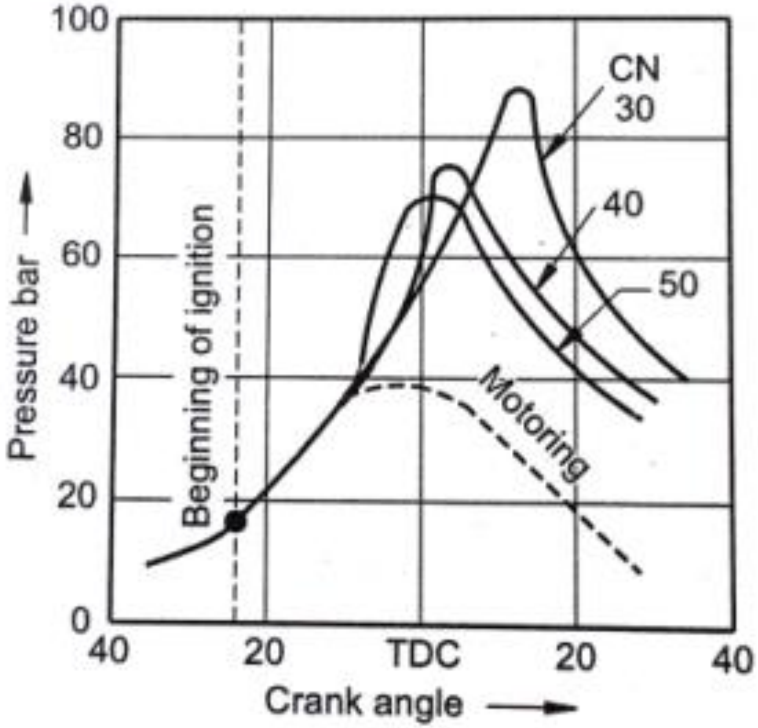
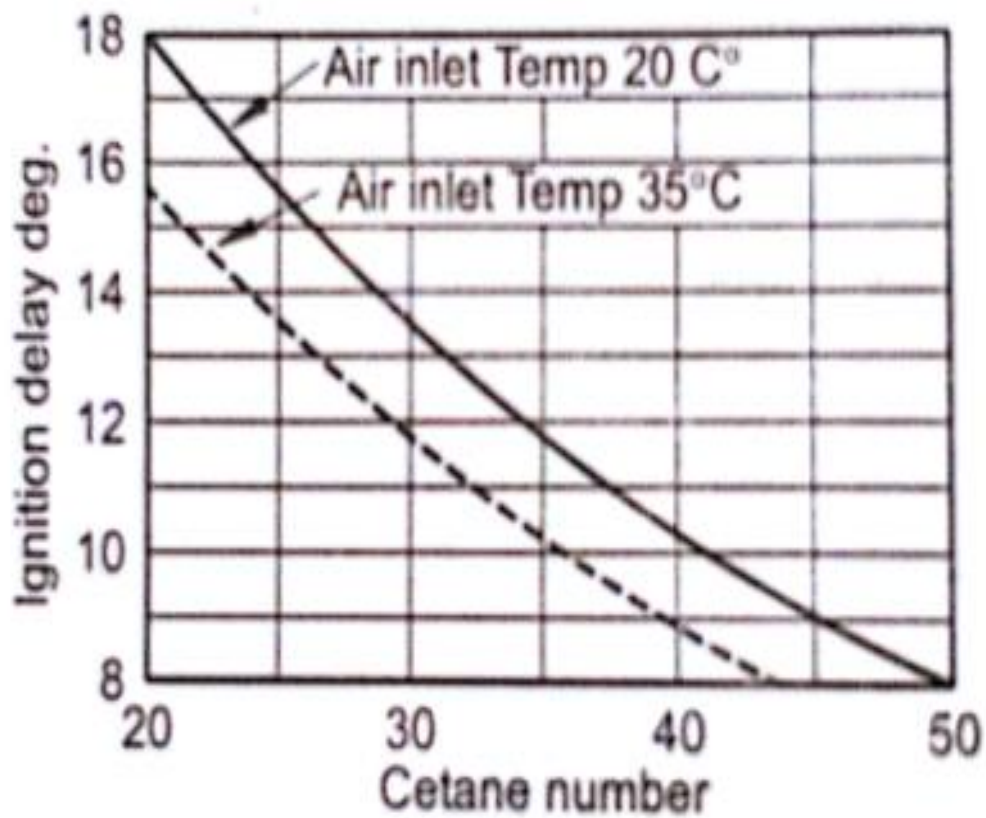


Fig. 18.2. Effect of CN on indicator diagram



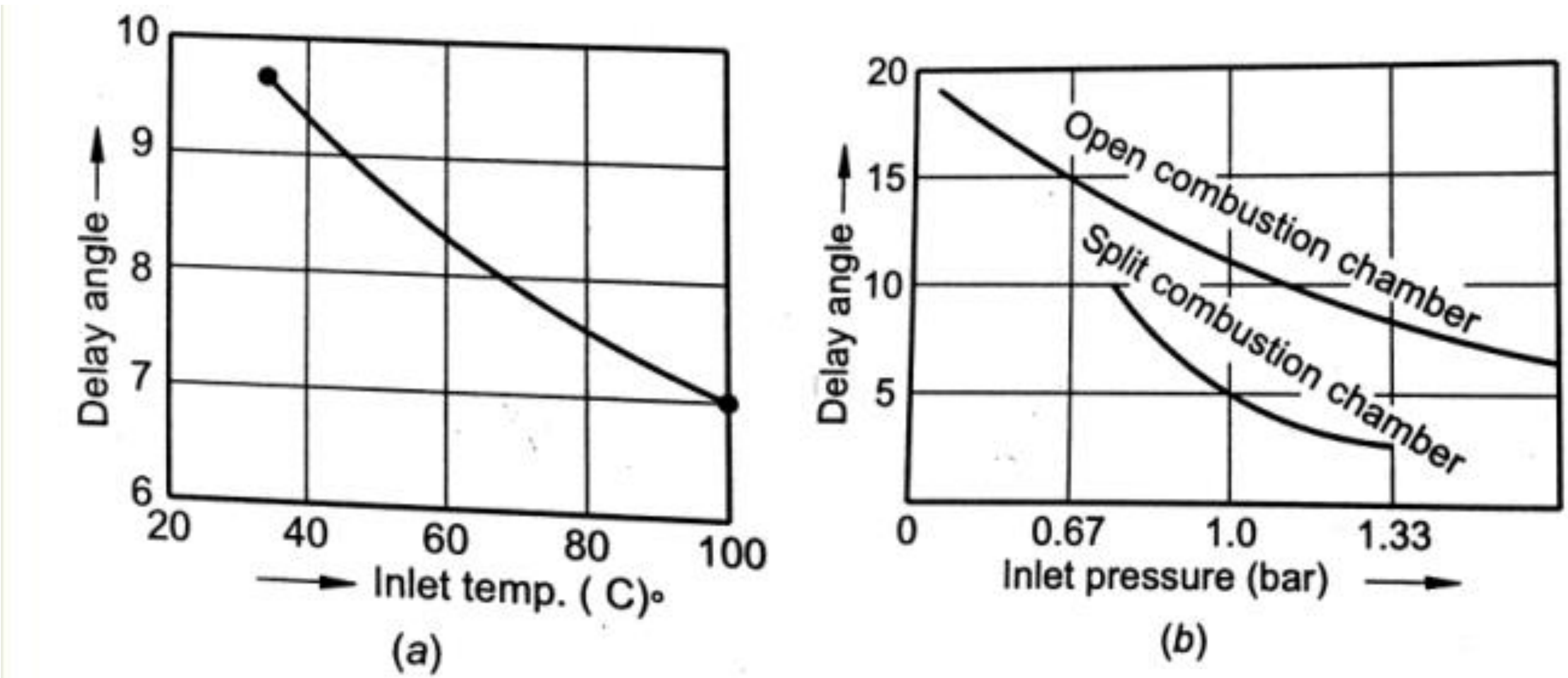
Delay period or Ignition Lag

2 temperature and pressure of intake air

- Delay period Reduced either with **increased temperature** or **pressure** of the **intake air** because, the **vaporization rate increases** with an **increase** of either **temperature or pressure or both.**
- The **rate of pressure rise** during combustion also **decreases** with an **increase in inlet pressure** and gives **smooth operation** of the engine.
- Increasing the intake air temperature by **exhaust gases** is not at all **desirable** as it **will reduce density of air** and **engine output.**
- This loss would be much **greater than** small reduction in delay period as 100 c air temperature hardly **reduces** the delay period by **3 degree crank angle**.

Delay period or Ignition Lag

•

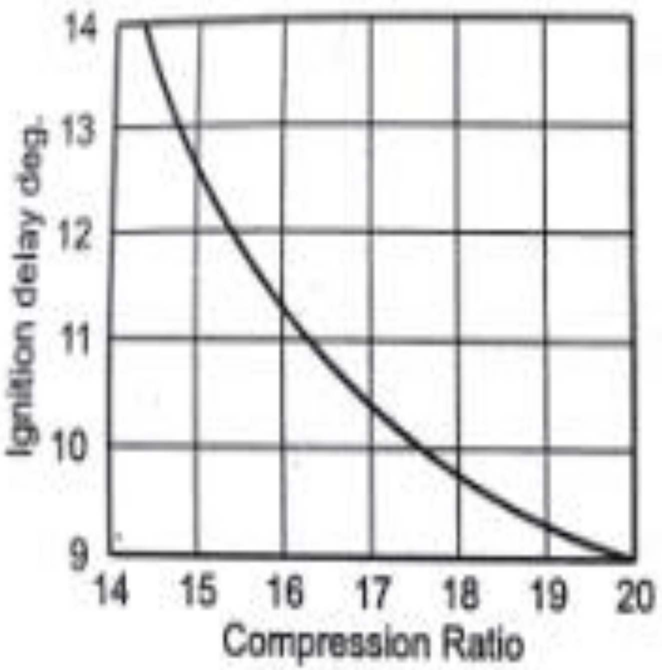


Delay period or Ignition Lag

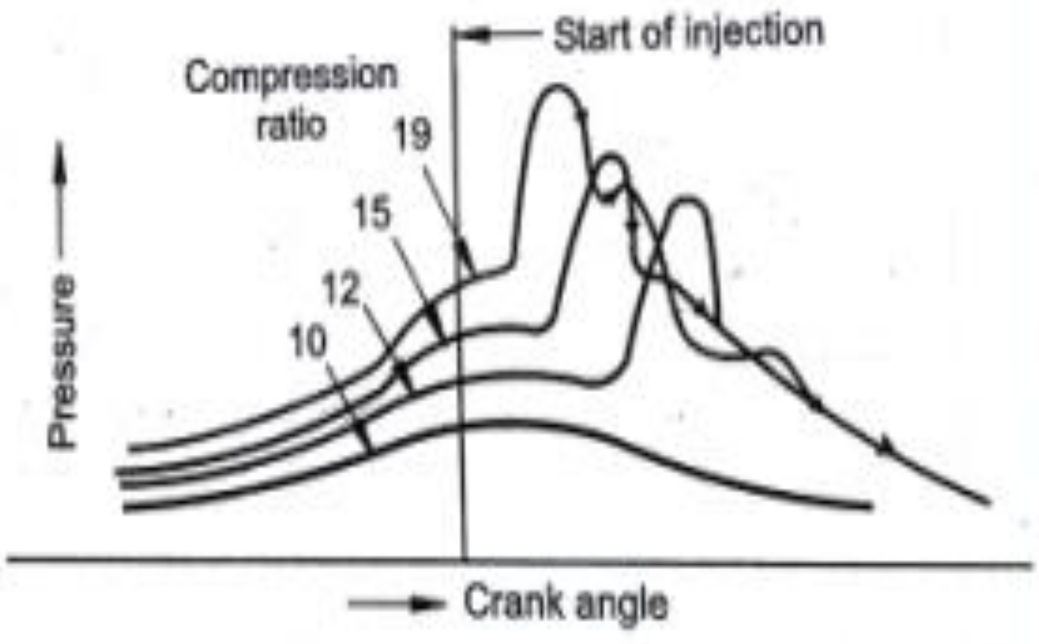
3 compression ratio

• the **delay period decreases** with **increasing pressure ratio** because both **pressure and temperature** at the end of **compression**, **increase** with **increasing compression ratio**.

•**peak pressure** increases rapidly with **increasing compression ratio**.

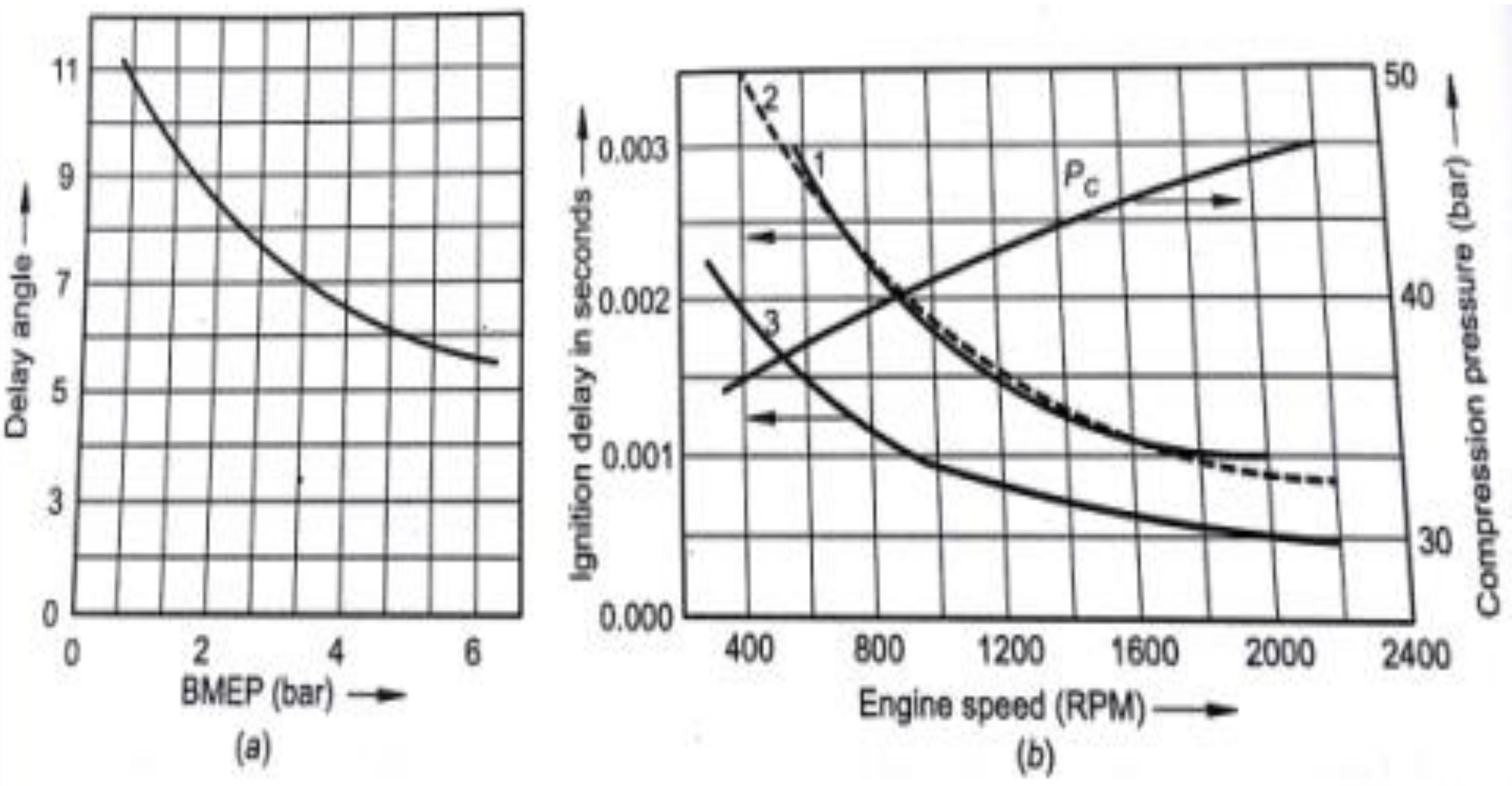


(a)



(b)

Delay period or Ignition Lag



Variable increases	Effect on Delay Period	Reason
Fuel (Cetane No.)	Reduces	Self ignition temp. reduces
Intake air/fuel/Jacket water temp.	Reduces	As temp. increases, better vaporization improve combustion
Intake Pressure (Supercharging)	Reduces	Density of mixture increases - reduce auto ignition temp.
Load (F:A Ratio)	Reduces	More combustion and heat release decrease delay period
Injection Pressure	Reduces	Atomization, vaporization and mixing of fuel improve
Injection advance angle	Increases	Less temp. and pressure in combustion chamber at the time of fuel injection
Engine size	Less effect in time but crank angle decreases	Low speed, smooth working
Speed	Reduces in Milli second, increases in crank angle	Due to more crank angle in given time, heat loss reduces
Compression ration	Reduces	Increase in temp. and Pressure

Knock in the C.I.Engine is due to **sudden ignition** and abnormally **rapid combustion** of accumulated fuel in the combustion chamber which produce very **high pressure.**

Sr. No	Variable increases	Effect on knocking tendency
1	Fuel (Cetane No.)	Decreases
2	Intake air/fuel/Jacket water temp.	Decreases
3	Intake Pressure (Supercharging)	Decreases
4	Load (F:A Ratio)	Decreases
5	Injection Pressure	Decreases
6	Injection advance angle	Increases
7	Engine size	Decreases
8	Speed	Increases
9	Compression ration	Decreases

Controlling the Knocking

1 **Using a better fuel**

Higher CN fuel has lower delay period which is fully responsible for detonation. Cetane Number of **40** means a mixture containing **40 % cetane** and **60 % alpha – methyl naphthalene** by volume

2 **Controlling the rate of fuel supply**

a **small amount of fuel** should be **supplied** till the **combustion starts** and then **more amount of fuel** should be supplied as **inside combustion chamber** condition is suitable to burn more fuel.

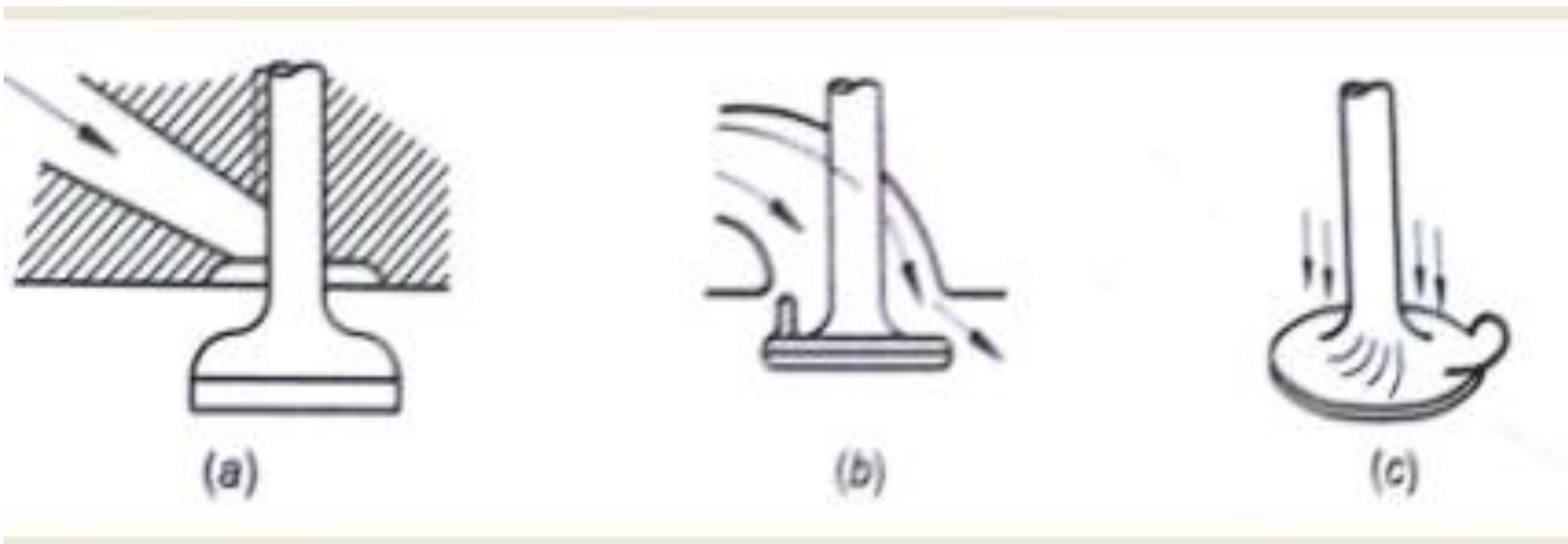
3 **Knock reducing fuel injector**

this type of injector is developed which can **avoid the sudden increase** in the **pressure** inside the combustion chamber because of accumulated fuel.

in this case, injection pressure of **100 bar** is used a semi – flexible needle valve.

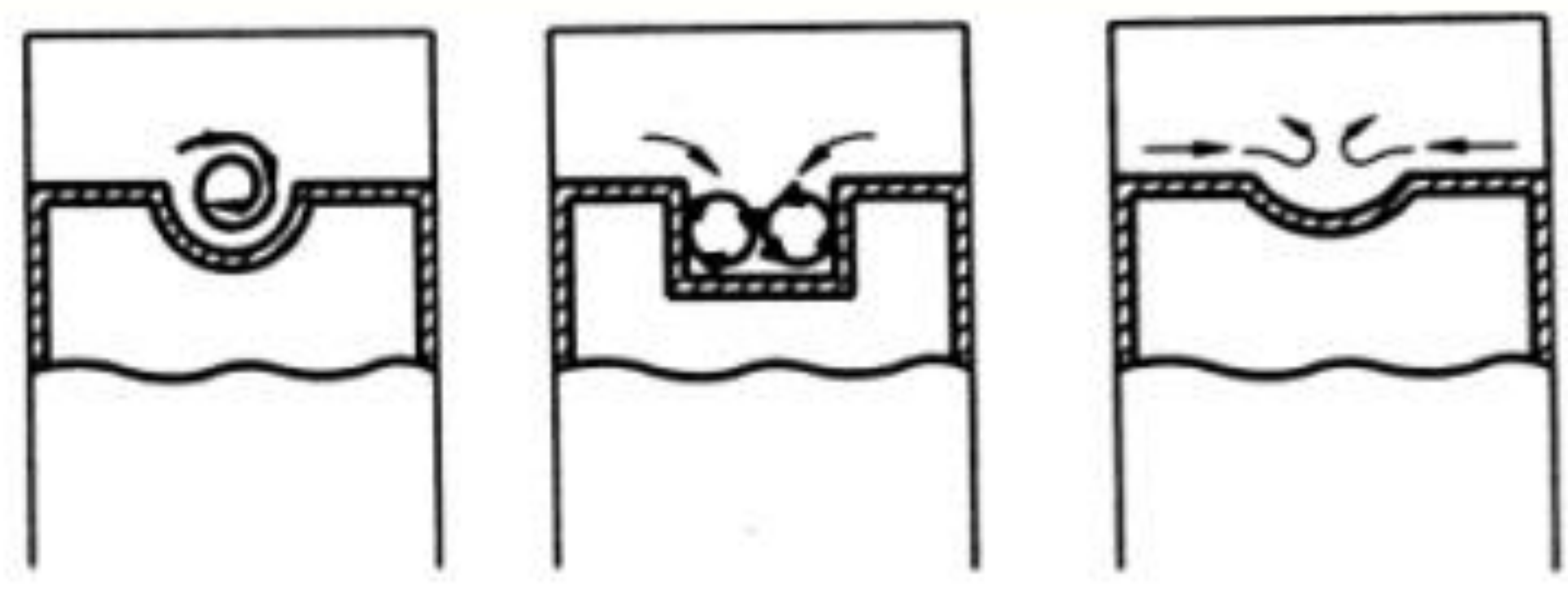
Combustion chamber for C.I.Engine

- **1 induction swirl**
- Providing during the **suction stroke** as the air entry is made tangential or forcing air to take a rotational movement.
- Fig.(a) **tangential port method** for producing swirl.
- Fig. (b) M**asking one side** of the inlet valve so that air is admitted only around a part of the periphery of the valve and in desired direction.
- Fig. (c) Casting a **lip over one side of the inlet valve.**



Combustion chamber for C.I.Engine

- **2 compression swirl or squish swirl**
- **Air from periphery** is forced to the **centre cavity** of the **piston during compression stroke.**
- The squishing of air is created and **forced to enter tangentially** in the **piston cavity** when the piston reached to TDC.



Combustion chamber for C.I.Engine

•**3 combustion swirl**

•This is created due to partial combustion therefore known as **combustion swirl.**

• **pre – combustion chamber & Air cell**

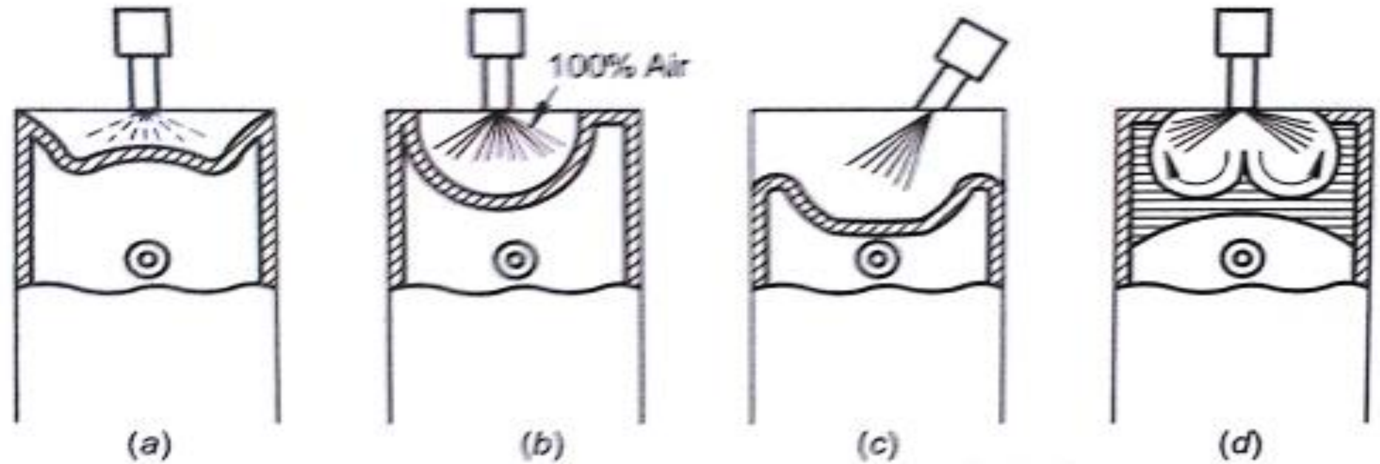
•**upward movement of piston** during compression forces the **air tangentially** and the fuel is injected in the pre-combustion chamber.

•When the combustion of accumulated fuel during **delay period** burns rapidly in **pre-combustion chamber** as A:F mixture is rich and forces the gases at a **very high velocity** in the main combustion chamber.

Open or Direct Injection Combustion chamber

- It is one that **open** to the cylinder.
- In this arrangement, all the **combustion air** is **compressed** and at the **time of fuel injection**, all the **air is contained in a single space.**
- Therefore, this type of chamber is also known as **direct injection chamber.**
- The fuel is injected at a considerably **high pressure** to provide sufficient **distribution and penetration**.
- **Various shapes of piston** crown used in this case with **flat cylinder heads are shown in fig.**

Open or Direct Injection Combustion chamber



(a) is a **shallow depth combustion chamber** generally used **for large capacity engines** running at low speed

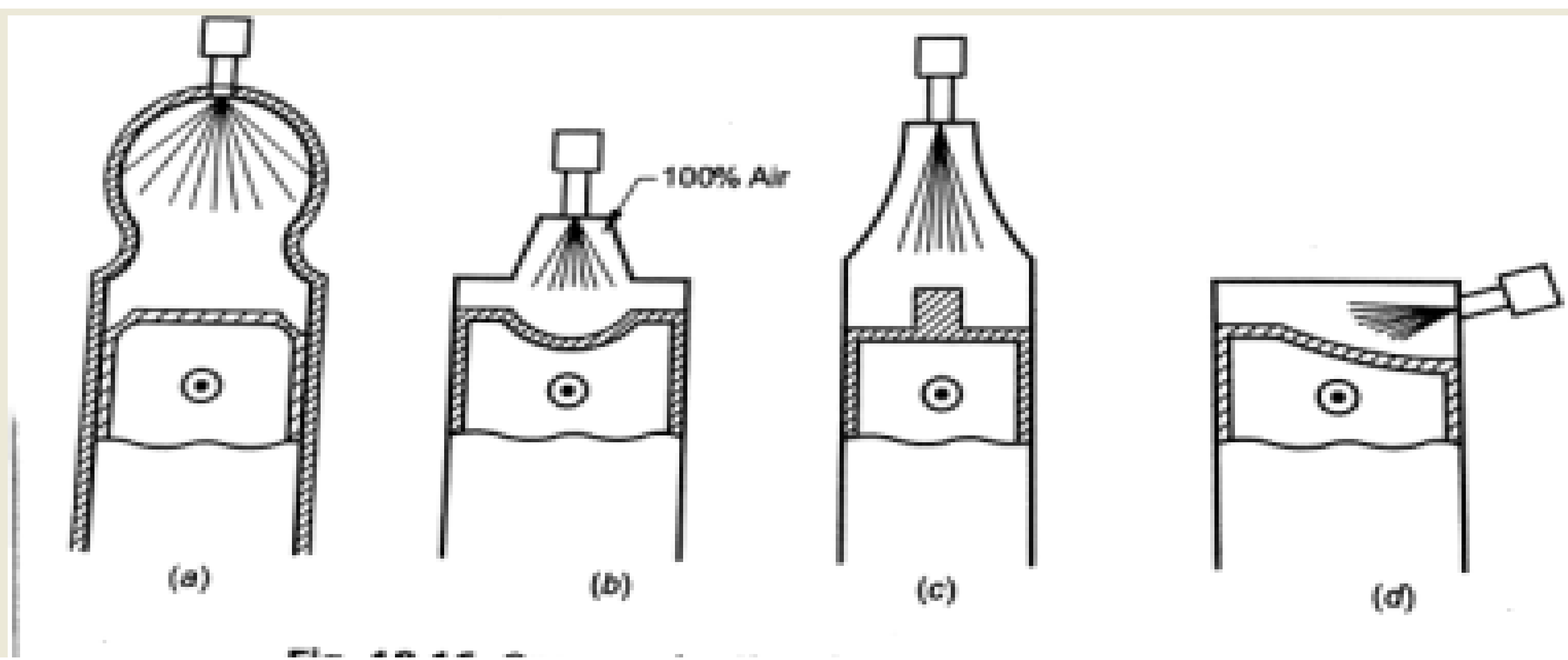
(b) Shows a **hemispherical cavity in piston**. The squish is **better than previous**.

(c) is a **cylindrical type cavity** which provides much better squish than **the previous two** used in **ashok leyland heavy vehicles.**

•The desired squish can be achieved by **varying the depth diameter and angle of cone.**

(d) **Truncated cone powerful squish** and provides better **combustion** and **reduces delay period** as **better mixing is provided**.

- In some cases, the **shape of cylinder head** provides a cavity to create favorable conditions for **better mixing and better burning**.
- Engines with open combustion chambers are **very sensitive** to **spray characteristics and mixing pattern**.
- **Multihole nozzles** and **high pressure of fuel injection** are more desirable for **better working of the combustion system**.



Combustion chamber for C.I.Engine

- **Advantages**

1 it is simple in construction
2 heat losses are less therefore the thermal efficiency is higher
3 starting of the engine is easy as heat losses are less.
4 less costly fuel with long delay period can be used particularly in low speed engines.
5 it gives higher mechanical efficiency.

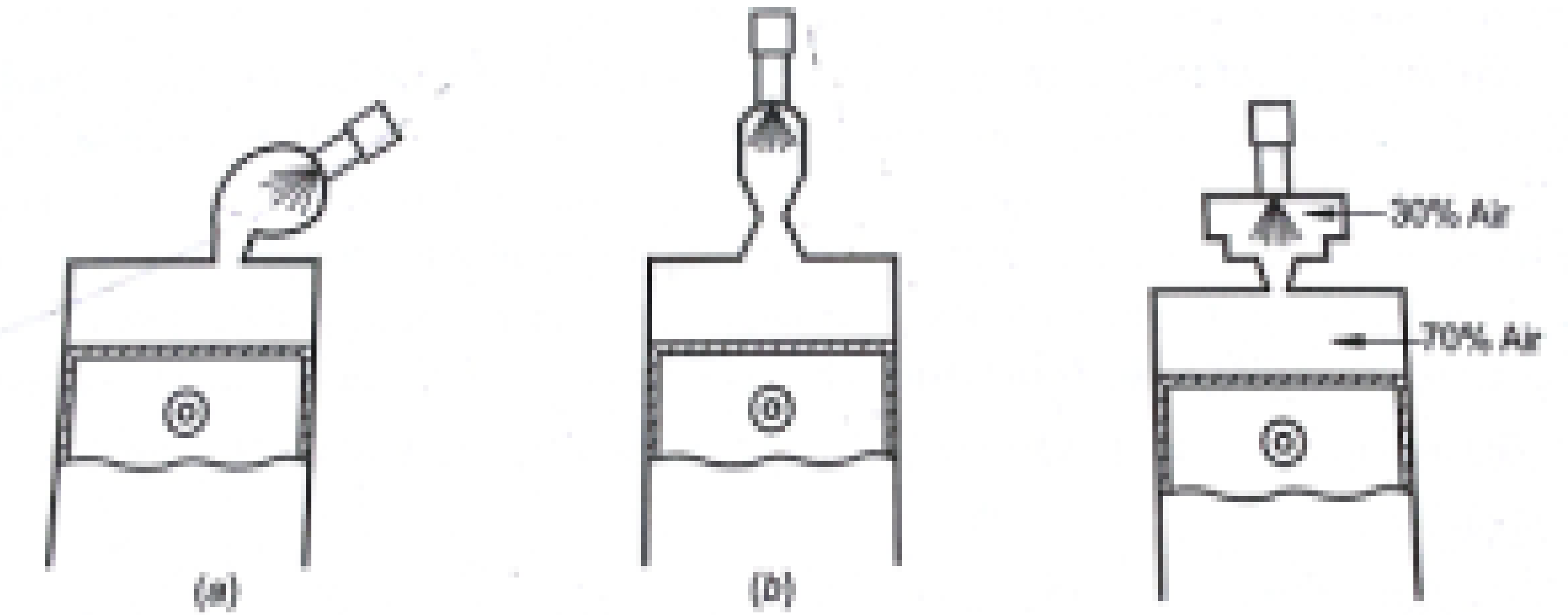
- **Disadvantages**

1 the excess air required is large.
2 higher injection pressure with Multihole nozzle is required.
3 higher maintenance cost.

Combustion chamber for C.I.Engine

- **Pre-combustion chamber**
- A **small passage** is provided. The **upward movement** of the **piston forces** the **air to flow into the small pre – combustion chamber** importing a **directional movement to the air (swirl.)**
- This swirl is maximum at about **15 before TDC close** to the time of fuel injection.
- Fuel is injected into the **pre – combustion chamber**.
- The high pressure created in the **pre – combustion chamber** during initial **combustion forces** the burning fuel into the **main combustion chamber** at a **high velocity** where it combines rapidly with the rest of the air.

•The **orifice passage** connecting the **pre and main combustion chamber** is **designed to distribute** the **unburned** and **partially burned** fuel through **main chamber** so that efficient utilization of the air can be achieved.
•Pre – combustion chamber contains **25 to 30%** of the total air.
•The **passage** area connecting the **two – chambers** is normally kept below **25 %** of the cylinder bore.
•The pre-combustion chamber **runs hot** and helps for **easy evaporation of fuel injected** and **reduced the delay period.**



•**Advantages**

1 low injection pressure can be used so single hole nozzle can be used.

2 it can use wide range of fuels.

3 smooth combustion results in quitter engine.

4 knocking tendency is totally removed due to no delay.

5 the air and fuel spray patterns are not important in this case.

6 the engine can be operated at high RPM.

•**Disadvantages**

1 The fuel consumption is high.

2 heat loss from the pre – combustion chamber is higher.

3 the cylinder requires special type of materials.

4 starting is difficult, higher heat losses through the throat during starting process.

5 the heat loss through the throat passage.

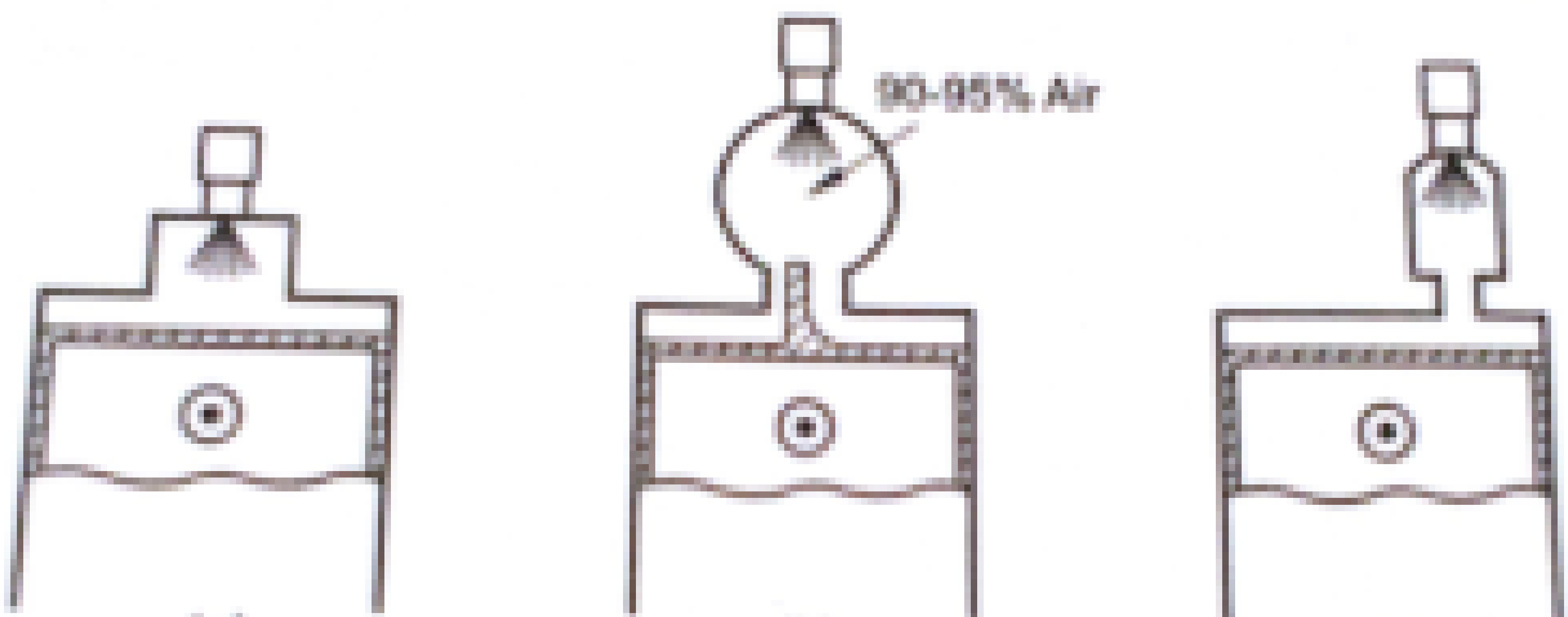
•Turbulent combustion chamber or IDI CC

•Also known as **swirl chambers** as very high swirl is created.

•The arrangement of these chambers is exactly same as **pre – combustion chambers** except 90 to 95% of the total air is pushed in the pre – combustion chamber.

•The chamber and passage way are shaped and designed to give **high swirling motion in the chamber.**

•The **temperature of the chamber** remains sufficiently hot and reduced the delay period.



(a) (b) (c)

Combustion chamber for C.I.Engine

- **Advantages**

1 Large range of cetane no. fuel can be used.

2 Low A:F ratio can be used as air is heavily swirled. Makes engine compact for given output.

3 Engine can be operated at high RPM.

4 Injection pressure and pattern are not very important due to swirl. Simple nozzle can be used.

5 Low rate of pressure rise and smooth running of the engine.

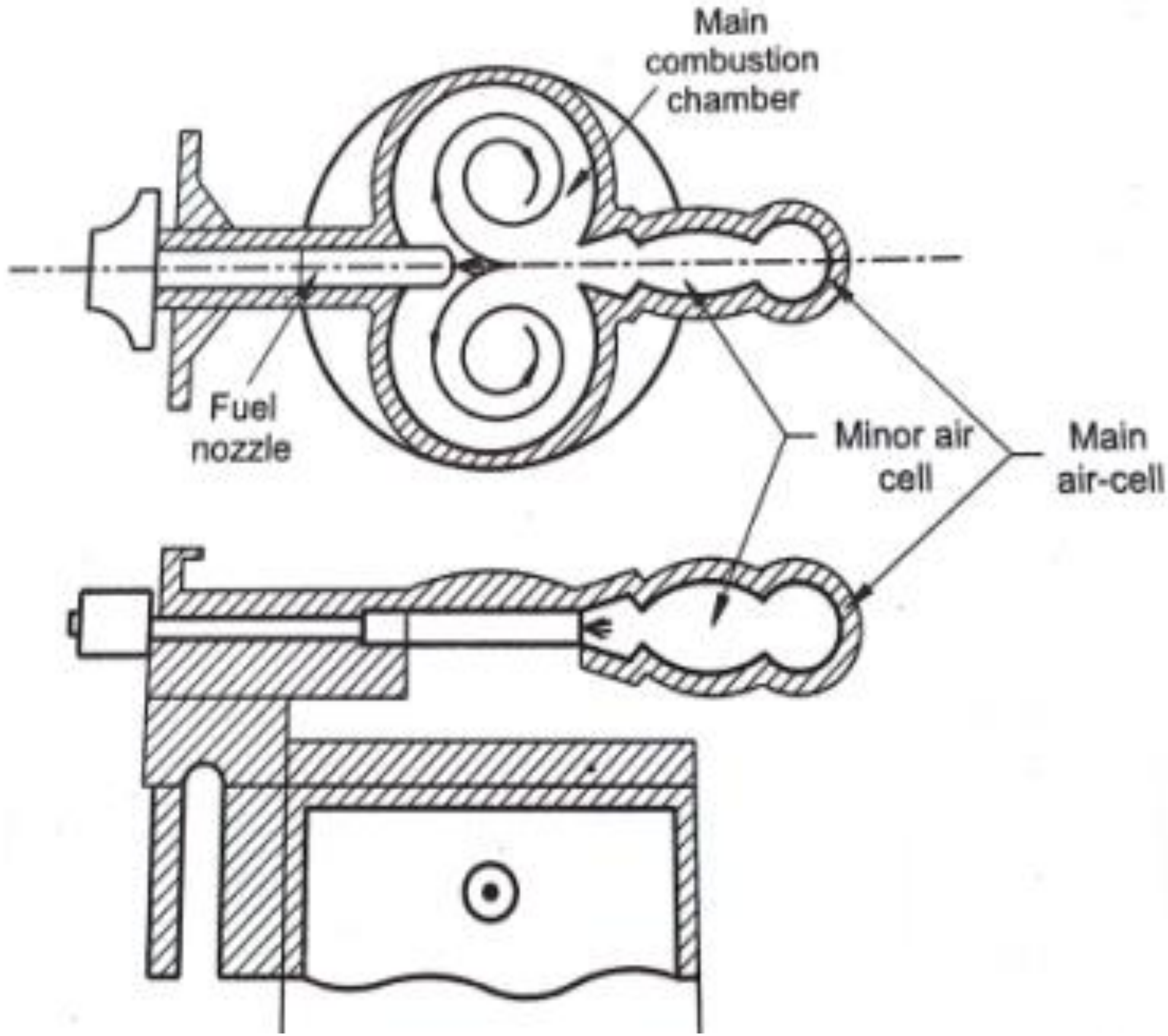
disadvantages

1 Starting of the engine is difficult as heat losses are high.

2 Thermal efficiency is low.

3 Because of high heat losses, fuel consumption increases. BSFC is higher.

- **Special combustion chambers**
- **1 Lanovo or air – cell combustion chamber**
- This chamber consists of a **small pre – combustion chamber** into which the **fuel is sprayed from a single hole nozzle.**
- The walls of the chamber **run hot** so that the **injected fuel evaporates and starts burning instant.**
- The air – cell has **two parts** as **major and minor** which are **separated** from **each other** and from the **main combustion** chamber by narrow orifices.
- The **first burning starts** in the **minor cell** and pushes the burning air in the main chamber.
- Suitable only for constant speed engines.


Main
combustion
chamber
Fuel
nozzle
Minor air
cell
Main
air-cell

Combustion chamber for C.I.Engine

•**Advantages**

1 the rate of pressure is low as mixing of air and fuel is minimized after starting the combustion.

2 Easy starting can be obtained by cutting off the cell from the main space by a valve which increases the combustion ratio.

3 High power output is possible without excessive high pressure in the main combustion chamber.

4 Very good mixing of fuel and air takes place and avoids late burning and ensures complete combustion.

5 Engine runs smoothly as the maximum pressure in the main chamber is low.

Disadvantages:

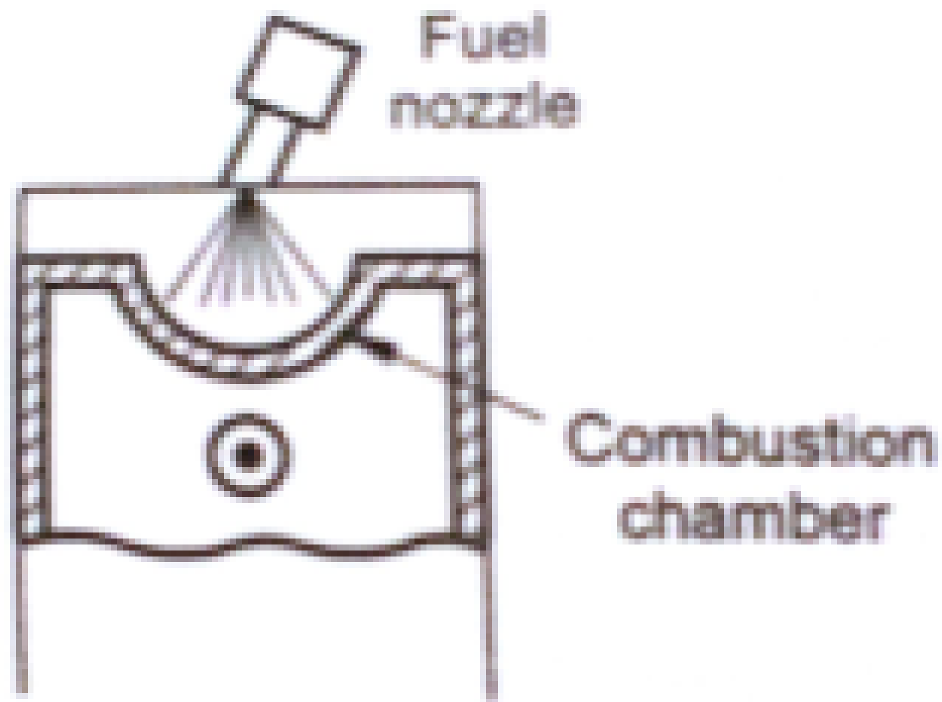
1 Low thermal efficiency

2 High fuel consumption

3 Can’t be used for variable speed engine.

2 M. combustion chamber

- Dr. Meurer of Germany designed M- CC in 1954 having a combustion Spherical **cavity in the piston** .
- In this design, the fuel was **directly injected** on the **surface of the cavity** in the direction of the air – swirl.
- As the cavity remains **very hot**, the fuel evaporates quickly and mixed with swirling air and combustion takes place near homogeneous A:F mixture. Rate of energy release is equal to rate of fuel evaporator.



Advantages

- More power because of high volumetric efficiency.
- Low rate of pressure rise
- Low peak pressure
- Ability to operate on a wide range of liquid fuels
- No combustion noise

Disadvantages

- Cold starting difficulty as vaporization of fuel depends upon the surface temperature of the combustion chamber.
- Some white smoke, diesel odour and high hydro – carbon emission may occur during starting and idling condition of the engine.
- Poor performance and high emission at low load on engine.

Figure shows the pressure crank angle diagram for different types of combustion chambers used in diesel engine.

- The **peak pressure** is highest for open combustion chamber and lowest for pre – combustion chamber.

Combustion chamber for C.I.Engine