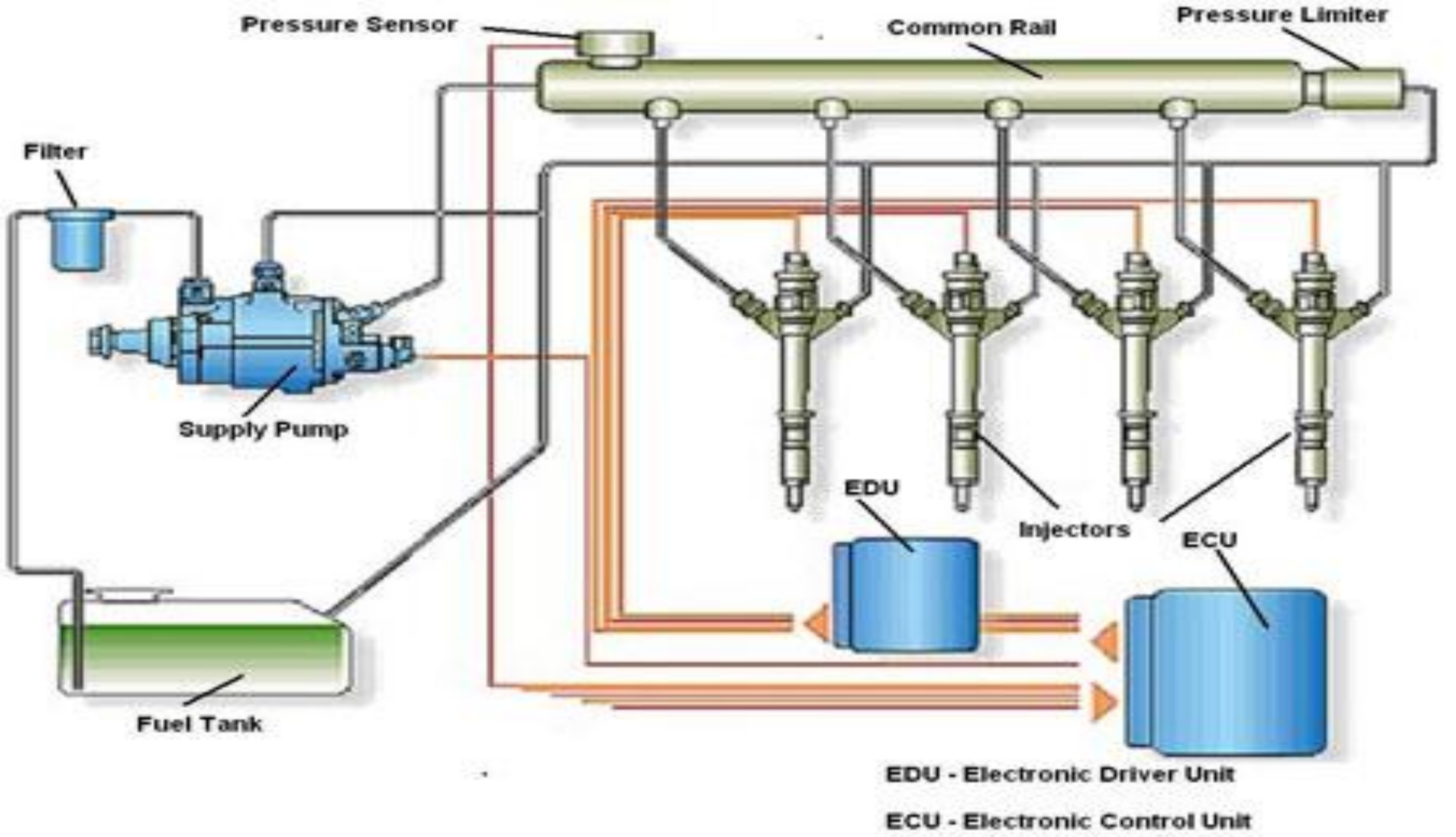
Fuel Injection Systems
for
Compression Ignition Engine

Introduction:

- In CI engines, the air is taken in during the suction stroke and compressed to a high pressure (28 to 70 bar) and high temperature (520 to 720 ^{o}C) according to the compression ratio used (12:1 to 20:1). The high temperature of air at the end of stroke is sufficient to ignite the fuel.
- Fuel is injected into the cylinder at *the end of compression stroke*.
  - ✓ the pressure of fuel injected lies between 100 to 200 bar. During the process of injection the fuel is broken into *very fine droplets*.
  - ✓ The droplets vaporize taking the heat from the hot air and a combustible mixture and start burning.
  - ✓ As the burning starts, the vaporization of is accelerated as more heat is available.
- The period between the start of injection and start of ignition, called *the ignition delay*,
  - ✓ The ignition delay is about 0.001 second for high speed engines and 0.002 second for low speed engines.
  - ✓ The injection period covers about 25^{o} of crank rotation.


Pressure Sensor
Common Rail
Pressure Limiter
Filter
Supply Pump
EDU
Injectors
ECU
Fuel Tank
EDU - Electronic Driver Unit
ECU - Electronic Control Unit

Functional Requirements of an Injection System:

- Introduction of fuel into the combustion chamber should take place within a precisely defined period of the cycle.
- The metering of amount of fuel injected per cycle should done very accurately.
- The quantities of fuel metered should vary to meet the changing load and speed requirements.
- The injection rate should be such that it results in the desired heat release pattern.
- The injected fuel must be broken into very fine droplets.
- The pattern of spray should be such as insure rapid mixing of fuel and air.
- The beginning and end of injection should be sharp.
- The timing of injection should change as per the requirements of load and speed.
- The weight and size of the fuel injection system must be minimum. It should be cheaper to manufacture and least expensive to attend to adjust or repair.

Functions of Fuel Injection System:

- Filter the fuel.
- Meter or measure the correct quantity of fuel to be injected.
- Time the fuel injection.
- Control the rate of fuel injection.
- Automise or break up the fuel to fine particles.
- Properly distribute the fuel in the combustion chamber.

  - The injection systems are manufactured with *great accuracy*, especially the parts that actually meter and inject the fuel.

Methods of Fuel Injection :

1. **Air injection**
2. **Solid or Airless injection.**

Air injection

- Here, air is compressed in the *compressor* to a very high pressure and then injected through the fuel nozzle into the engine cylinder.
  - ✓ The rate of fuel admission can be controlled by varying the pressure of injection air.
  - ✓ Storage air bottles which are kept charged by an air compressor supply the high pressure air.

- **Advantages:**
  - ✓ Provides better automisation and distribution of fuel.
  - ✓ The combustion is more complete, the bmep is higher than with other types of injection system.
  - ✓ Inferior fuel can be used.

- **Disadvantages:**
  - ✓ It is required a high pressure multi stage compression, which make the system complicated and expensive.
  - ✓ The fuel valve sealing requires considerable skill.
  - ✓ A separate mechanical linkage is required to time the operation of fuel valve.
  - ✓ The fuel in Combustion chamber burns very near to injection nozzle which many times leads to over heating and burning of valve and its seat.

Solid or Airless Injection

- Here, Injection of fuel directly into the combustion chamber without primary automisation . It also called *mechanical injection.*

- **Main Components of Fuel Injection System**
  - ✓ Fuel tank
  - ✓ Fuel feed pump to supply the fuel from the main fuel tank to injection pump.
  - ✓ Fuel filters to prevent dust and abrasive particles from entering the pump and injectors.
  - ✓ Injection pump to meter and pressurise the fuel from injection.
  - ✓ Gavernor to ensure that the amount of fuel is in accordance with variation in load .
  - ✓ Fuel piping and injectors to take the fuel from the pump and distribute it in the combustion chamber by atomising it in fine droplets.

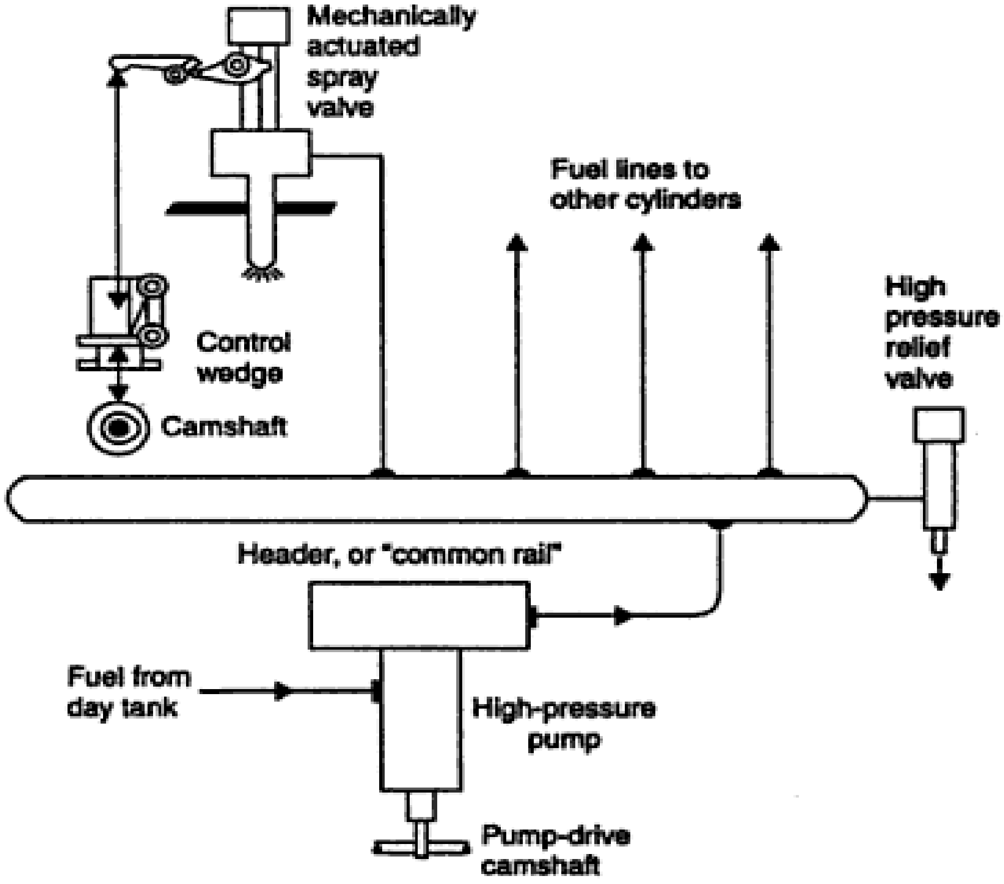
- **Main Types of Modern Fuel Injection System**
  - ✓ Common-rail injection system.
  - ✓ Individual pump injection system.
  - ✓ Distributor system.

Common-rail injection system

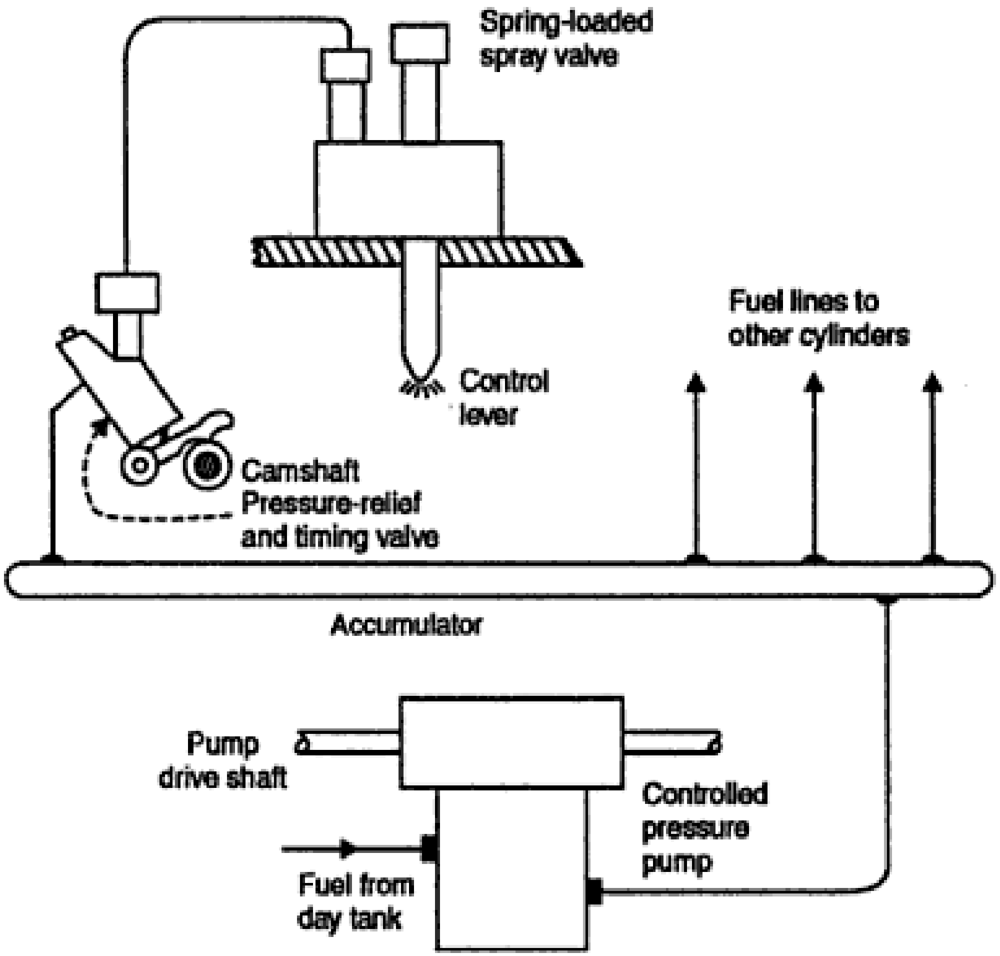
- Two types of common-rail injection system are:

✓ A single pump supplies high pressure fuel to header, a relief valve holds pressure constant.

✓ The control wedge adjusts the lift of mechanical operated valve to set amount and time of injection.



- ✓ Controlled-pressure system has pump which maintains set head pressure.
- ✓ pressure relief and timing valves regulate injection time and amount.
- ✓ Spring loaded spray valve acts merely as a check.

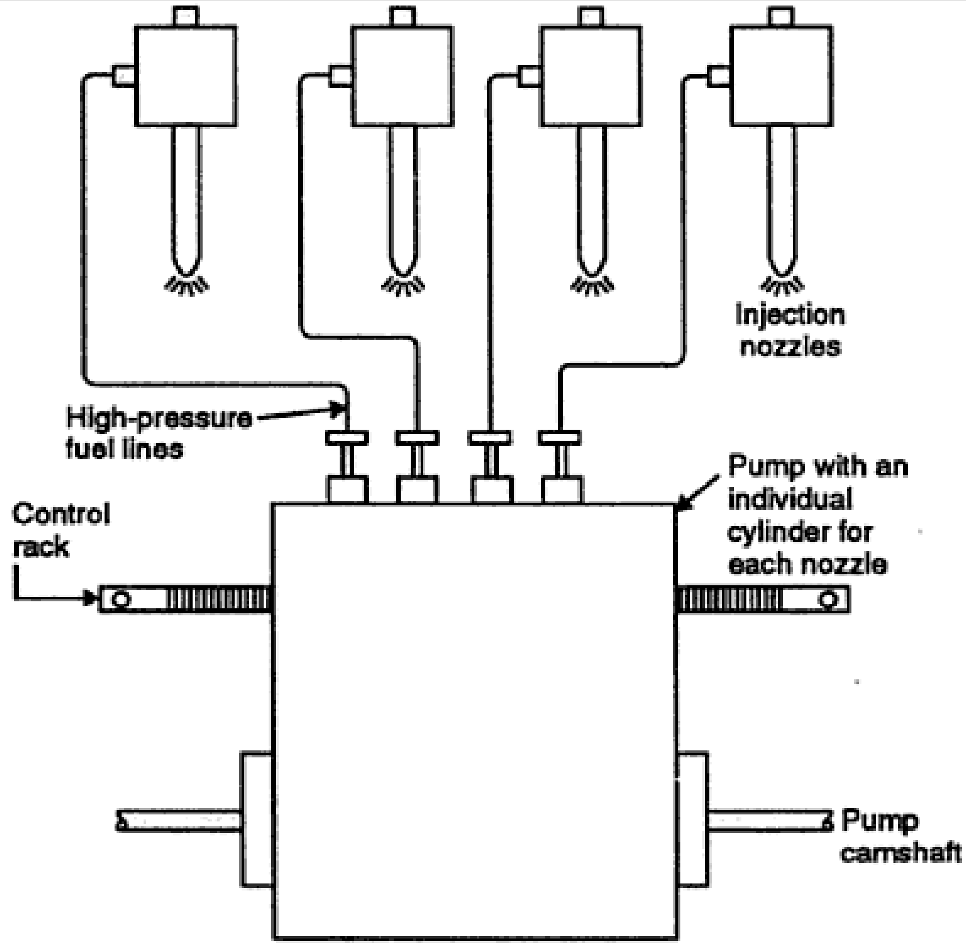


Individual pump injection system

- ✓ Here, an individual pump or pump cylinder connects directly to each fuel nozzle.
- ✓ Pump meters charge and control injection time.
- ✓ Nozzles contain a delivery valve actuated by the fuel oil pressure.

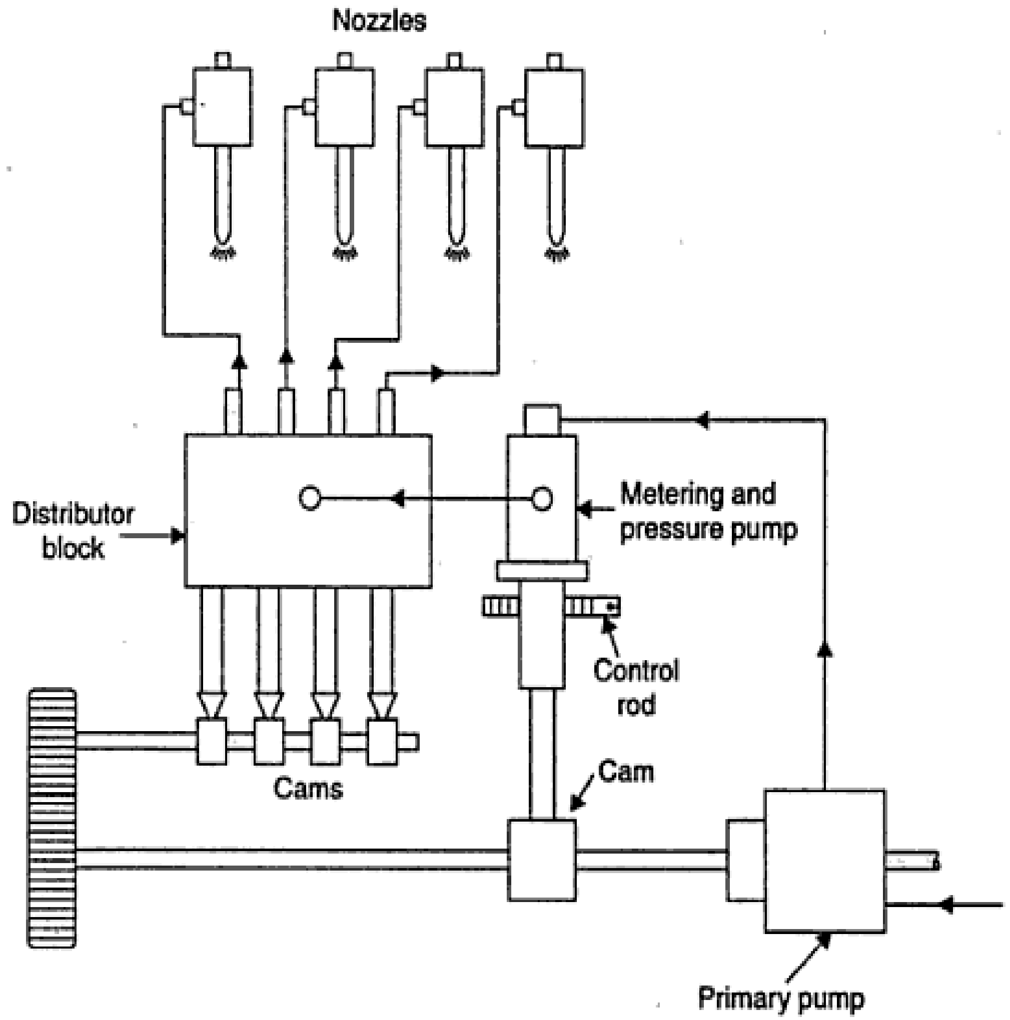
- ✓ The time allowed for injecting such a small quantity of fuel is limited (1/450 second at 1500 rpm for engine providing injection through 200 crank angle)

- ✓ The pressure requirement is 100 to 300 bar.



Distributor system

- ✓ Fuel is metered at a central point; a pump pressurizes meters the fuel and times the injection.
- ✓ The fuel is distributed to cylinders in correct firing order by cam operated poppet valves which open to admit fuel to the nozzles.

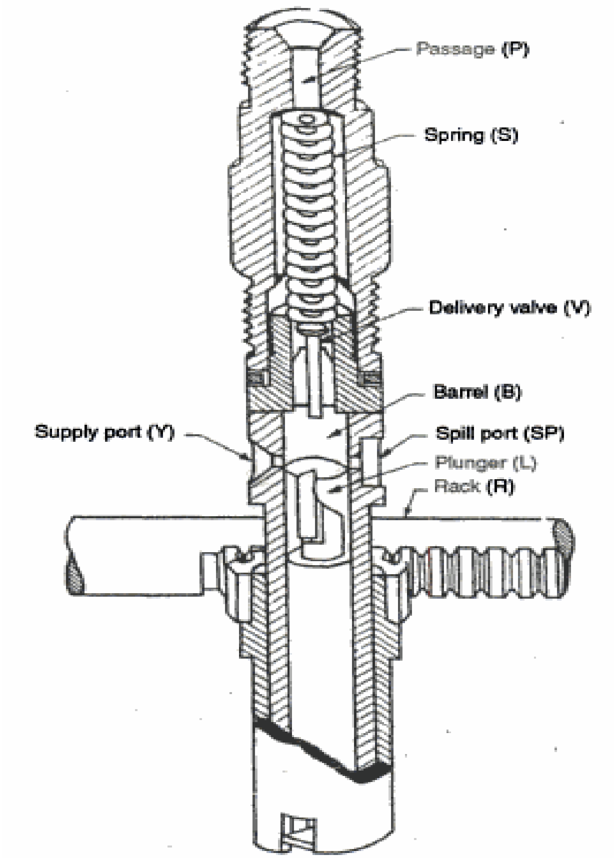


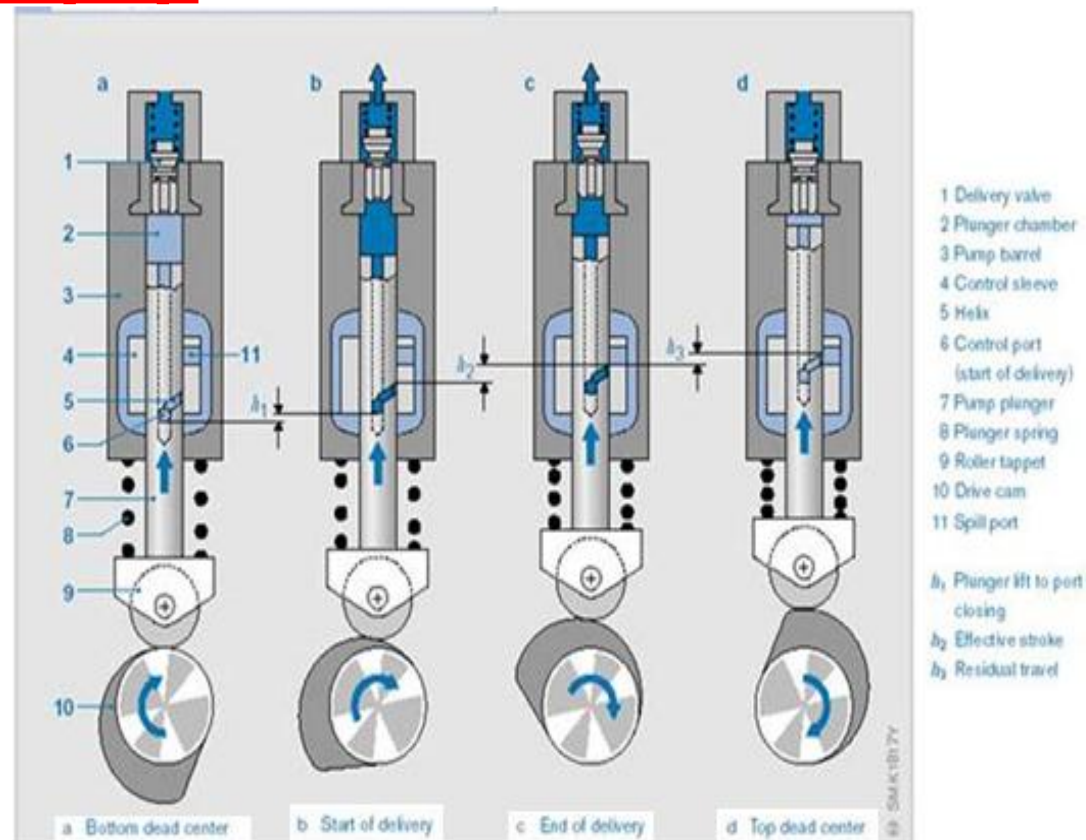
Fuel Pump and Fuel Injector

Fuel Pump:-

- Large number of igneous fuel pump designs have been developed by manufacture.

- **Example:-** **Bosch fuel injection pump:**





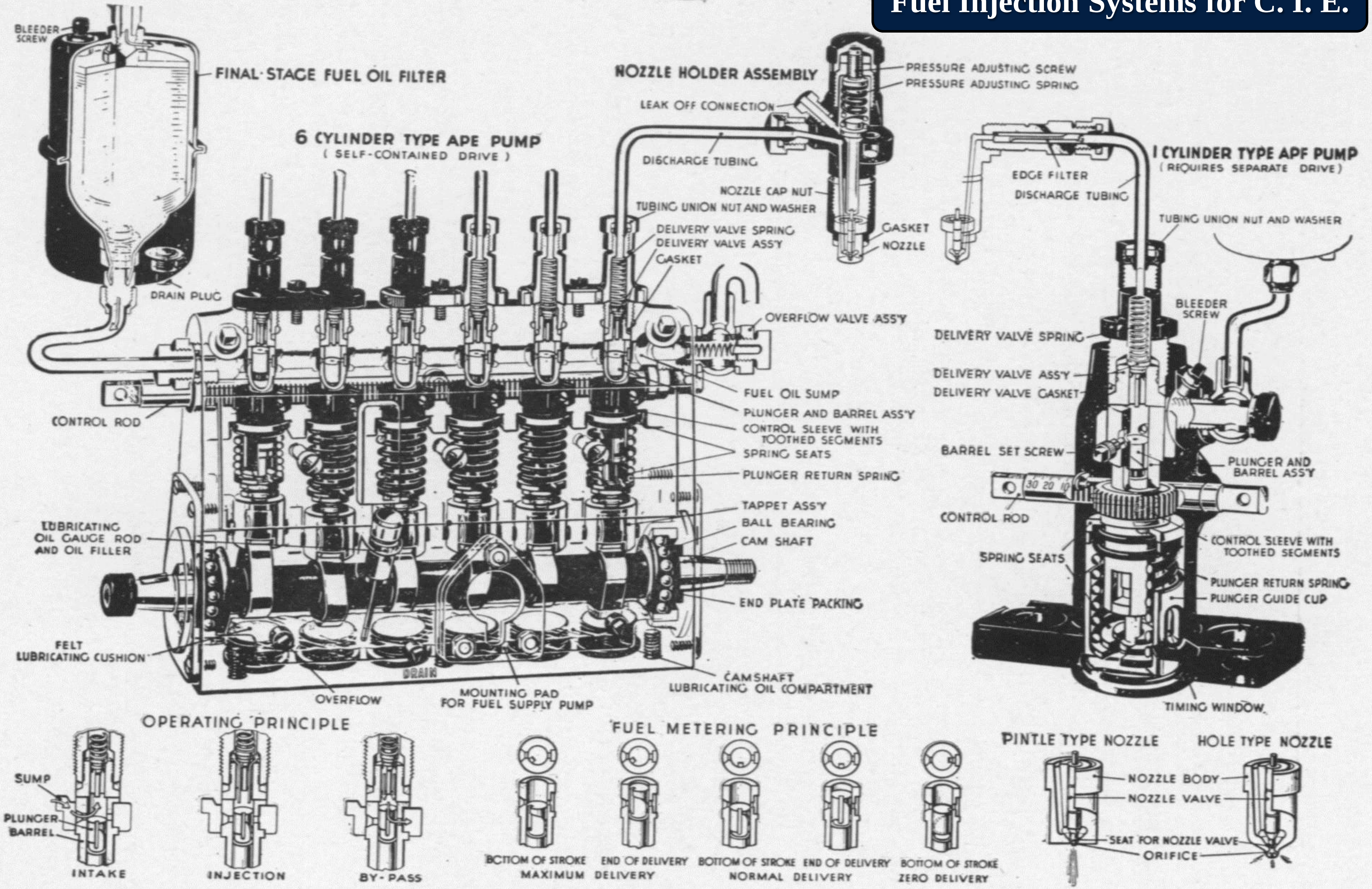


Fig. 24.—*Bosch fuel injection system and equipment.*

Bosch fuel injection pump

- ✓ **L** is the **plunger**…. Which is driven by cam and tappet mechanism at the bottom.

(the plunger have a rectangular vertical groove which extends from top to another helical groove)

- ✓ **B** is the **barrel** …... In which the plunger reciprocates.
- ✓ **V** is the **delivery valve**…. Which lifts off its seat under the liquid fuel pressure and the spring force.
- ✓ **P** is the **passage**….. Which is connected the fuel pump to fuel atomizer.
- ✓ **SP** and **Y** are the **spill port** and **supply port**.

- ❖ when the plunger is at bottom stroke the SP and Y are uncovered, so oil from low pressure pump is forced into the barrel.
- ❖ When the plunger moves up due to cam and tappet mechanism, a stage reaches when both SP and Y are closed and the fuel gets compressed.
- ❖ The high pressure developed lifts the delivery valve off its seats and fuel flows to atomizer through the **passage P.**

Fuel Injector:-

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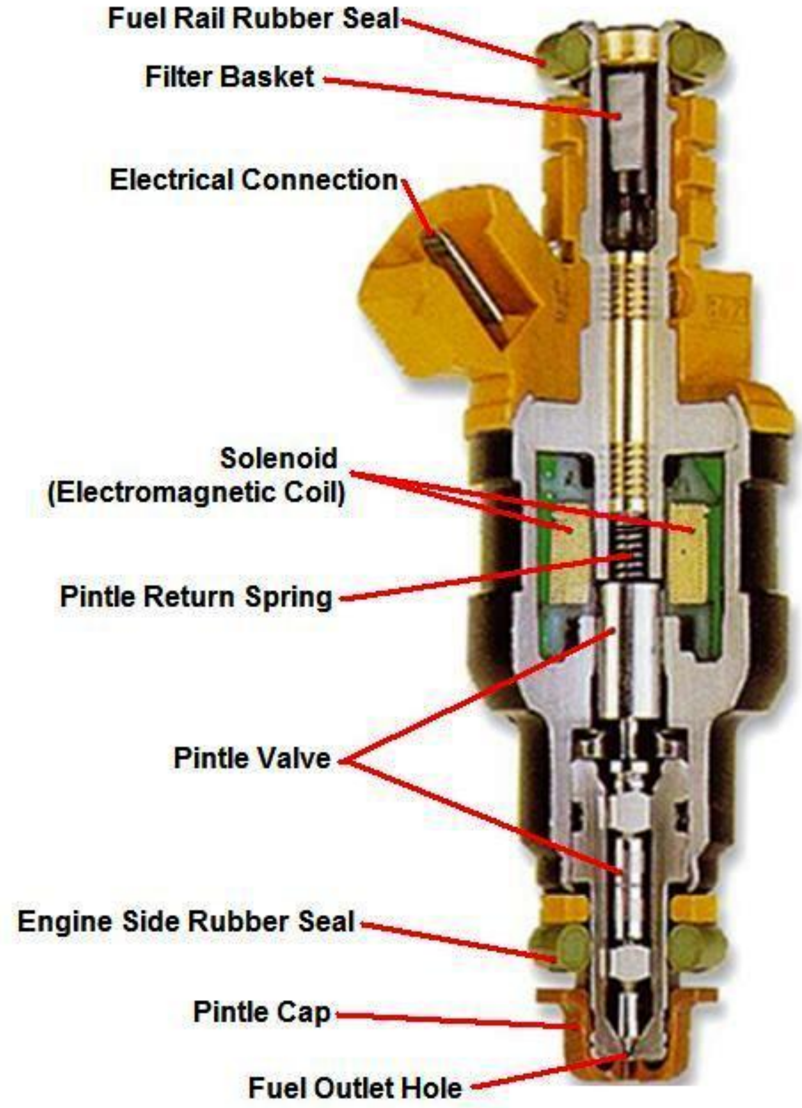
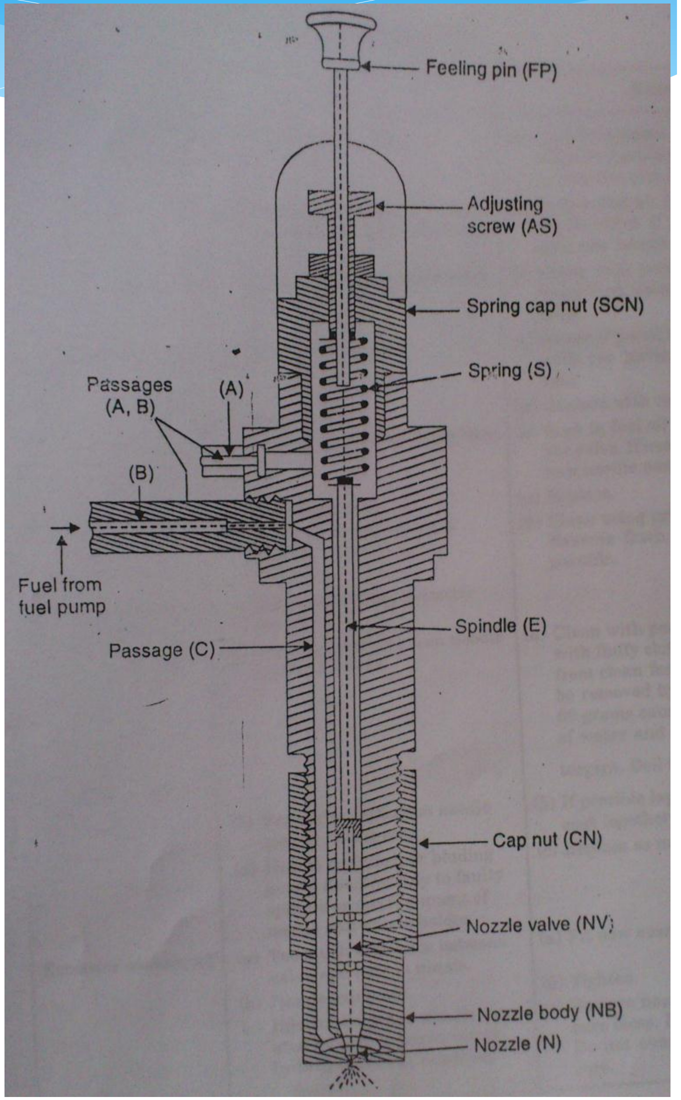


Fuel Injector:-

The injector consists of :-

- ***A nozzle valve*** **fitted in the nozzle body.**
- **The nozzle valve is held on its seat by *spring* which exerts pressure through *the spindle*.**
- **The *adjusting screw* by which the nozzle valve lift can be adjusted.**
- ***Feeling pin*** **which indicates whether valve is working properly or not.**

- **The fuel under pressure from fuel pump enter the injector through the *passage (B and C)* and left the nozzle valve.**
- **The fuel travels down nozzle and injected into the engine cylinder in form of fine spray.**
- **The pressure of oil falls, the nozzle valve occupies its seat under spring force and fuel supply is cut off.**
- **Any leakage of fuel accumulated above is lead to the fuel tank through passage *(A).***



<u>The main required of an Injector nozzle:-</u>

- **inject fuel at sufficient *high pressure* so the fuel enter the cylinder with *high velocity. (whit high velocity the droplet size be smaller also the momentum of smaller droplet is less)***
- **Penetration should not be high so as to impinge on cylinder walls, which case poor starting.**
- **Fuel supply and fuel cut off should be rapid.**

<u>Classification and description of nozzle:-</u>

- **The type of nozzle used is *depend on* the type of combustion chamber.**
- **The nozzles are classified *according to* <u>type</u> and <u>number</u> of orifice used to inject fuel as:**
  - ✓ **Single hole nozzle**
  - ✓ **Multi hole nozzle**
  - ✓ **Circumferential nozzle**
  - ✓ **Pintle nozzle**
  - ✓ **Pintaux nozzle**

Single Hole Nozzle

- It is used in open combustion chamber.
- It is consists of a single hole bored centrally through the nozzle body and closed by needle valve.
- The hole size be large than 0.2 mm.
- The spray cone angle varies from 5 to 15 degree.

- Advantages:
  - ✓ Simple in construction and operating.

- Disadvantages:
  - ✓ Very high injection pressure is required.
  - ✓ This type of nozzle has a tendency to dribble.
  - ✓ This type does not facilitated good mixing unless higher air velocities are provided.

Multi Hole Nozzle

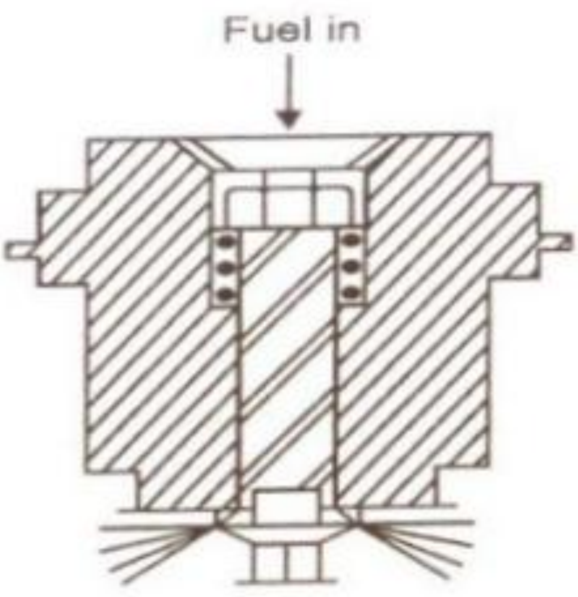
- **It is used in open combustion chamber.**
- **It is mixes the fuel with air properly even with slow air movement available.**
- **The number of holes varies from 4 to 8 with diameter from 0.25 to 0.35 mm.**
- **The spray cone angle varies from 20 to 45 degree.**

- **Advantages:**
  - ✓ **Gives good automisation**
  - ✓ **Distributes fuel properly even with lower air motion available.**

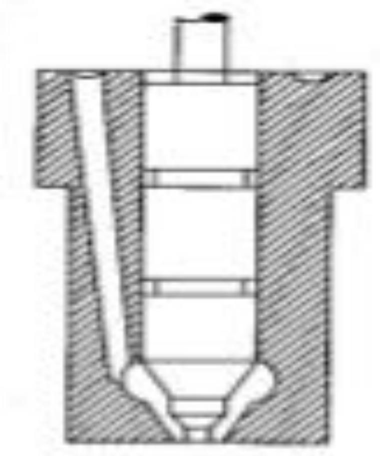
- **Disadvantages:**
  - ✓ **Holes are small and liable to closing.**
  - ✓ **Dribbling between injections.**
  - ✓ **Very high injection pressures (180 bar and above).**
  - ✓ **Close tolerance in manufacture (due to small holes) and hence costly).**

Circumferential Nozzle

- **The spray characteristics are similar to a plate opening.**
- **The injection fuel particles tend to projected in form of plane, with wide angle cone.**



Pintle Nozzle



- **The stem of nozzle valve is extended to form a pin or pintle which protrudes through the mouth of nozzle body.**
- **It may be cylindrical or conical in shape.**
- **The spray core angle is generally 60 degree.**
- **The spray obtained by the pintle nozzle is hollow conical spray.**

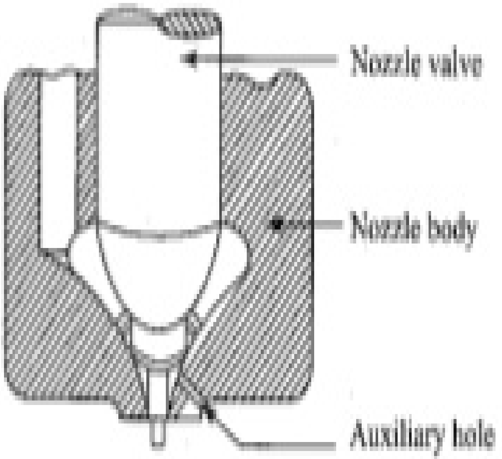
- **Advantages:**
  - ✓ **It is self cleaning type and prevents the Carbone deposition on the nozzle hole.**
  - ✓ **It avoids weak injection and dribbling.**
  - ✓ **It results in good atomization.**
  - ✓ **Its injection characteristics are more near the required one.**

- **Disadvantages:**
  - ✓ **It is not suitable for open combustion chamber due to poor distribution and penetration.**

Pintaux Nozzle

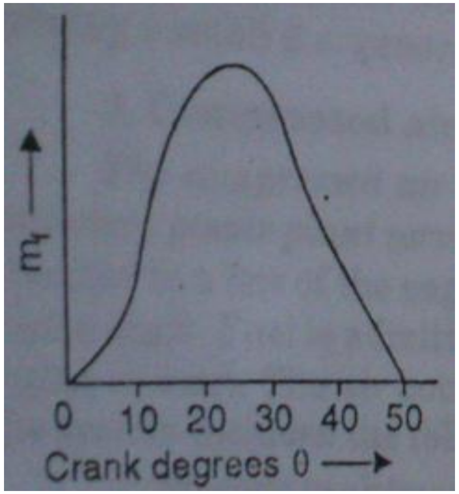
- **It is a type of pintle nozzle which has an auxiliary hole drilled in the nozzle body.**
- **It injects a small amount of fuel through this additional hole in the upstream slightly before the main injection.**
- **At low speed, the needle valve does not lift fully so that most of fuel is injected through the auxiliary hole to give good cold starting.**

- **Disadvantages:**
  - ✓ **The tendency of auxiliary hole to choke.**
  - ✓ **The injections characteristics are even poorer than multi hole nozzle.**

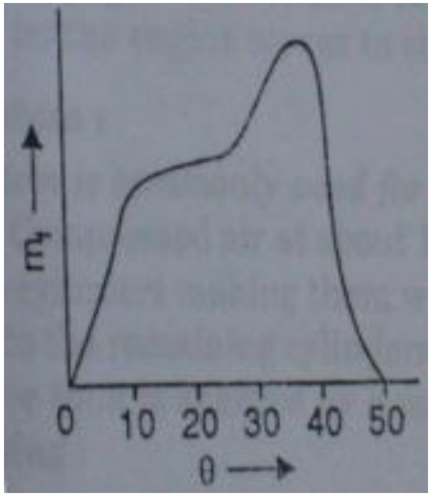


Injection Rate Characteristics:-

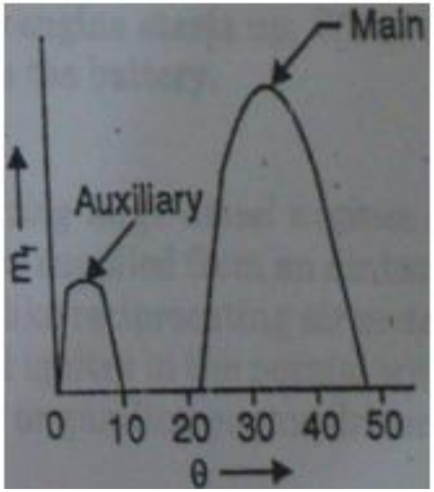
- In order to avoid knocking in the engine it is always desirable to supply *less* quantity of fuel.



Multi hole nozzle



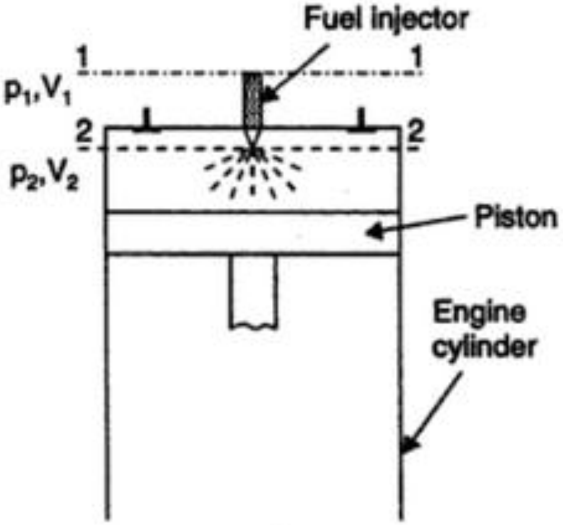
Pintle nozzle



Pintaux nozzle

Fuel Injection Computation In C.I. Engine:-

- The fuel injector should develop a pressure higher than the highest pressure desired to be obtained in the engine also to import high velocity head and adequate atomization



Let p_1 = Injection pressure,
V_1 = Velocity at section 1-1,
p_2 = Pressure in the cylinder when injection of fuel takes place,
V_2 = Velocity at section 2-2,
ρ_f = Density of fuel, and
v_f = Specific volume of fuel (assumed in compressible).

$$\frac{V_1^2}{2} + p_1 v_f = \frac{v_2^2}{2} + p_2 v_f$$

Neglecting V_1, being very small compared to V_2, we have

$$V_2 = \sqrt{2v_f(p_1 - p_2)} = \sqrt{\frac{2(p_1 - p_2)}{p_f}}$$

if V_f = Actual fuel velocity of injection (the velocity of fuel for good atomisation is of the order of 400 m/s), and

C_f = Flow coefficient of orifice,

Then, $$V_f = C_f \sqrt{\frac{2(p_1 - p_2)}{\rho_f}}$$

The volume of the fuel injected per second Q_f is given by :

Q_f = Area of all orifices × fuel jet velocity × time of injection × number of injections per second for one orifice

$$Q_f = \left[\frac{\pi}{4} d_0^2 \times n_0\right] \times V_f \times \left[\frac{\theta}{360} \times \frac{60}{N}\right] \times \frac{N_i}{60}$$

where, d_0 = Diameter of fuel orifice, m^2,

n_0 = Number of orifices,

V_f = Velocity of flow of fuel through orifice,

θ = Duration of the injection in degrees of crank angle,

N = r.p.m., and

N_i = Number of injection per min.

$= \frac{\text{r.p.m.}}{2}$ ... for 4-stroke cycle engine

$=$ r.p.m. ... for 2-stroke cycle engine