Diesel Fuel System

Diesel Engine Basics….

Four stroke cycle

- **Intake stroke**: intake valve opens while the piston moves down from its highest position in the cylinder to its lowest position, drawing air into the cylinder in the process.
- **Compression stroke:** intake valve closes and the piston moves back up the cylinder.

  This compresses the air & therefore heats it to a high temperature, typically in excess of 1000°F (540°C).

  Near the end of the compression stroke, fuel is injected into the cylinder. After a short delay, the fuel ignites spontaneously, a process called *auto ignition*.
- **Combustion stroke:** The hot gases produced by the combustion of the fuel further increase the pressure in the cylinder, forcing the piston down
- **Exhaust stroke:**

  exhaust valve opens when the piston is again near its lowest position, so that as the piston once more moves to its highest position, most of the burned gases are forced out of the cylinder.

Diesel Engine Basics….

Compression Ratio

- **Compression ratio:**
  This is defined as the ratio of the volume of the cylinder at the beginning of the compression stroke (when the piston is at BDC) to the volume of the cylinder at the end of the compression stroke (when the piston is at TDC).

- The higher the compression ratio, the **higher the air temperature** in the cylinder at the end of the compression stroke.

- Higher compression ratios, to a point, lead to higher thermal efficiencies and **better fuel economies**.

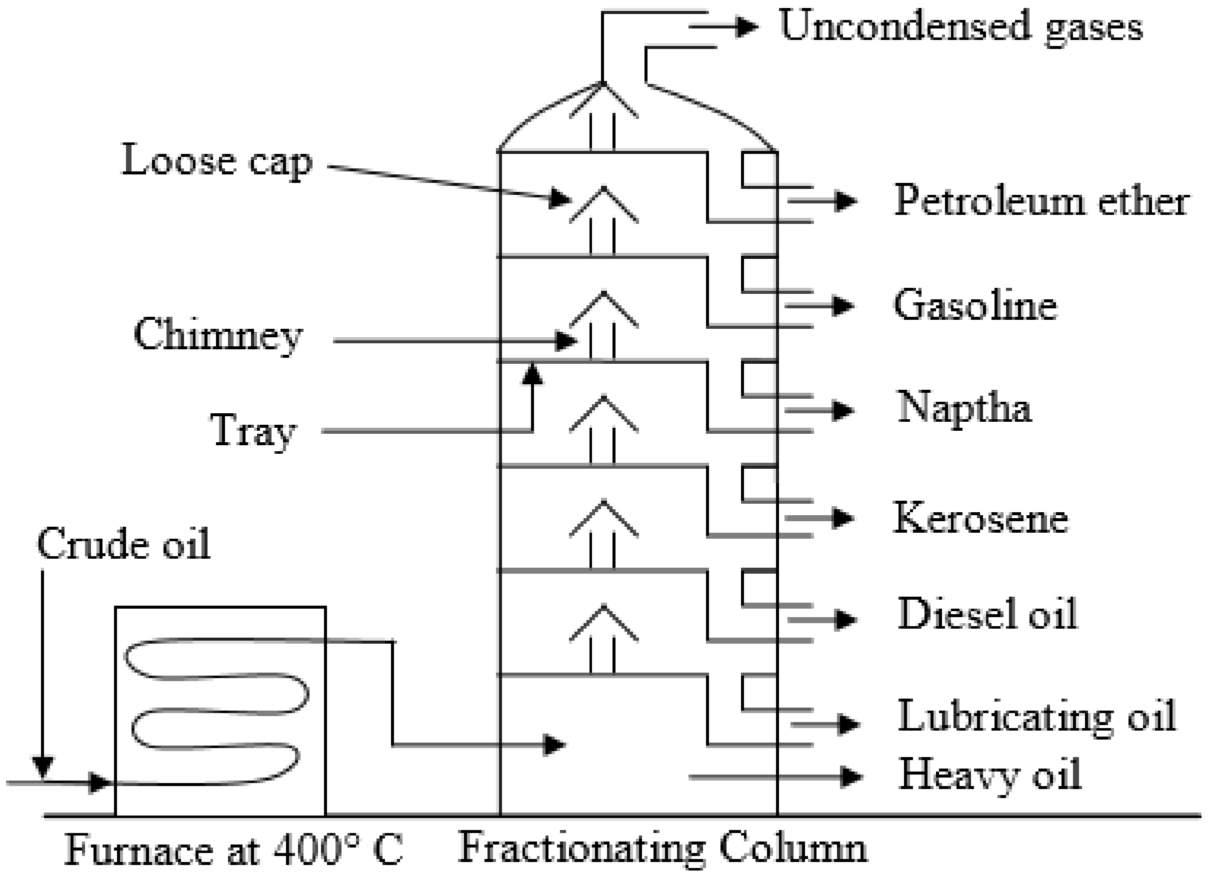
- **Diesel engines need high compression ratios to generate the high temperatures required for fuel auto ignition.**
- In contrast, gasoline engines use lower compression ratios in order to avoid fuel auto ignition, which manifests itself as engine knock or pinging sound.

- Common spark ignition compression ratio: 8:1 to 12:1
- Common compression ignition ration: 14:1 to 25:1

8:1 to 10:1
15:1 to 25:1

Refining of Crude Oil…

The process of removing impurities and separating out the oil into various fractions having different boiling points is known as refining of petroleum.



Diesel Fuel…

- It is relatively a high boiling point fraction of petroleum obtained between 250 - 320° C.
- It is a mixture of hydrocarbons in terms of carbon atoms C_{15} - C_{18}
- Its calorific value is about 11,000 kcals/kg. It is used as fuel for compression ignition engine.
- Its antiknock value can be improved by doping with isoamyl nitrate.

Properties of Diesel for Internal Combustion

- Cetane Number
- Volatility
- Viscosity
- Sulfur Content
- Cloud and Pour Point
- Cleanliness & Stability

Cetane number

Cetane number is a measure of the fuel oil's volatility; the higher the rating, the easier the engine will start and the smoother the combustion process will be within the ratings specified by the engine manufacturer. Current 1D and 2D diesel fuels have a cetane rating between 40 and 50.

Cetane rating differs from the octane rating used in gasoline in that the higher the number of gasoline on the octane scale, the greater the fuel resistance to self ignition, which is a desirable property in gasoline engines with a high compression ratio. Using a low octane fuel will cause premature ignition in high compression engines. However, the higher the cetane rating, the easier the fuel will ignite once injected into the diesel combustion chamber. If the cetane number is too low, you will have difficulty in starting. This can be accompanied by engine knock and puffs of white smoke during warm-up in cold weather.

Volatility

Fuel volatility requirements depend on the same factors as cetane number. The more volatile fuels are best for engines where rapidly changing loads and speeds are encountered. Low volatile fuels tend to give better fuel economy where their characteristics are needed for complete combustion, and will produce less smoke, odor, deposits, crankcase dilution, and engine wear.

The volatility of a fuel is established by a distillation test where a given volume of fuel is placed into a container that is heated gradually. The readiness with which a liquid changes to a vapor is known as the volatility of the liquid. The 90 percent distillation temperature measures volatility of diesel fuel. This is the temperature at which 90 percent of a sample of the fuel has been distilled off. The lower the distillation temperature, the higher the volatility of the fuel. In small diesel engines higher fuel volatility is needed than in larger engines in order to obtain low fuel consumption, low exhaust temperature, and minimum exhaust smoke.

Viscosity

The viscosity is a measure of the resistance to flow of the fuel, and it will decrease as the fuel oil temperature increases. What this means is that a fluid with a high viscosity is heavier than a fluid with low viscosity. A high viscosity fuel may cause extreme pressures in the injection systems and will cause reduced atomization and vaporization of the fuel spray.

The viscosity of diesel fuel must be low enough for it to flow freely at its lowest operational temperature, yet high enough to provide lubrication to the moving parts of the finely machined injectors. The fuel must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. Viscosity also will determine the size of the fuel droplets, which in turn govern the atomization and penetration qualities of the fuel injector spray.

Sulfur Content

Sulfur has a definite effect on the wear of the internal components of the engine, such as the piston ring, pistons, valves, and cylinder liners. In addition, a high sulfur content fuel requires that the engine oil and filter be changed more often because the corrosive effects of hydrogen sulfide in the fuel and the sulfur dioxide or sulfur trioxide that is formed during the combustion process combine with water vapor to form acids. High additive lubricating oils are desired when high sulfur fuels are used. Refer to the engine manufacturer's specifications for the correct lube oil when using high sulfur fuel.

Sulfur content can be established only by chemical analysis of the fuel. Fuel sulfur content above 0.4% is considered as medium or high, and anything below 0.4% is low. No. 2D contains between 0.2 and 0.5% sulfur, whereas No. 1D contains less than 0.1%.

Sulfur content has a direct bearing on the life expectancy of the engine and its components. Active sulfur in diesel fuel will attack and corrode injection system components and contribute to combustion chamber and injection system deposits.

Cloud Point & Pour Point

Cloud point is the temperature at which wax crystals in the fuel (paraffin base) begin to settle out with the result that the fuel filter becomes clogged. This condition exists when cold temperatures are encountered and is the reason that a thermostatically controlled fuel heater is required on vehicles operating in cold weather environments. Failure to use a fuel heater will prevent fuel from flowing through the filter and the engine will not run. Cloud point generally occurs 9-14°F above the pour point.

Pour point of a fuel determines the lowest temperature at which the fuel can be pumped through the fuel system. The pour point is 5°F above the level at which oil becomes a solid or refuses to flow.

Cleanliness & Stability

Cleanliness is an important characteristic of diesel fuel. Fuel should not contain more than a trace of foreign substances; otherwise, fuel pump and injector difficulties will develop, leading to poor performance or seizure. Because it is heavier and more viscous, diesel fuel will hold dirt particles in suspension for a longer period than gasoline. Moisture in the fuel can also damage or cause seizure of injector parts when corrosion occurs.

Fuel stability is its capacity to resist chemical change caused by oxidation and heat. Good oxidation stability means that the fuel can be stored for extended periods of time without the formation of gum or sludge. Good thermal stability prevents the formation of carbon in hot parts such as fuel injectors or turbine nozzles. Carbon deposits disrupt the spray patterns and cause inefficient combustion.

Gasoline versus Diesel

- **Spark ignition:** Gasoline engines use spark plugs to ignite fuel/ air mixture
- **Compression ignition**:

  Diesel engines uses the heat of compressed air to ignite the fuel (intakes air, compresses it, then injects fuel)
- **Fuel injection**:

  -Gasoline uses port fuel injection or carburetion;

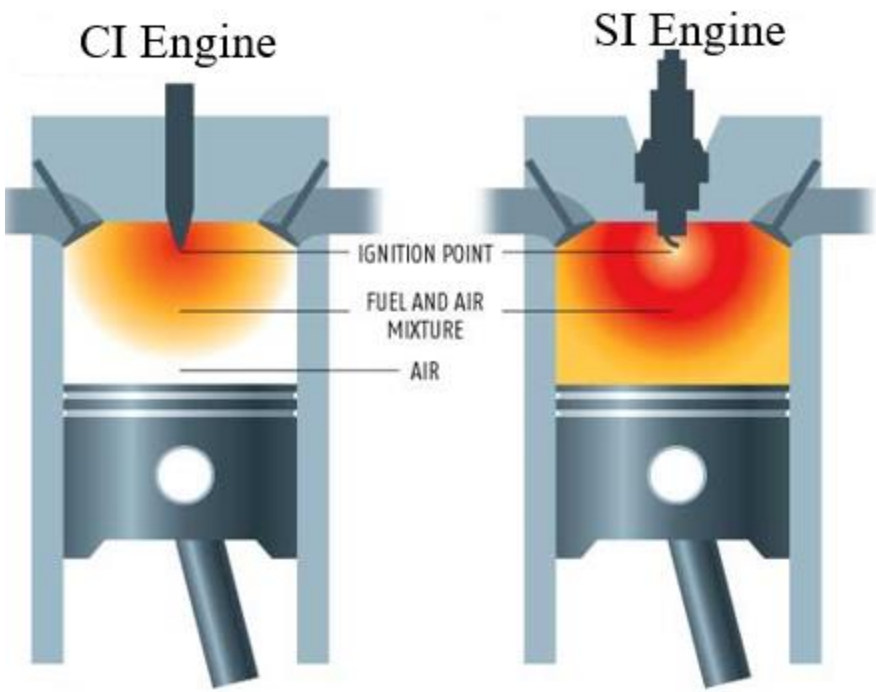
  -Diesel uses direct fuel injection or pre combustion chambers (indirect injection)
- **Glow plugs**:

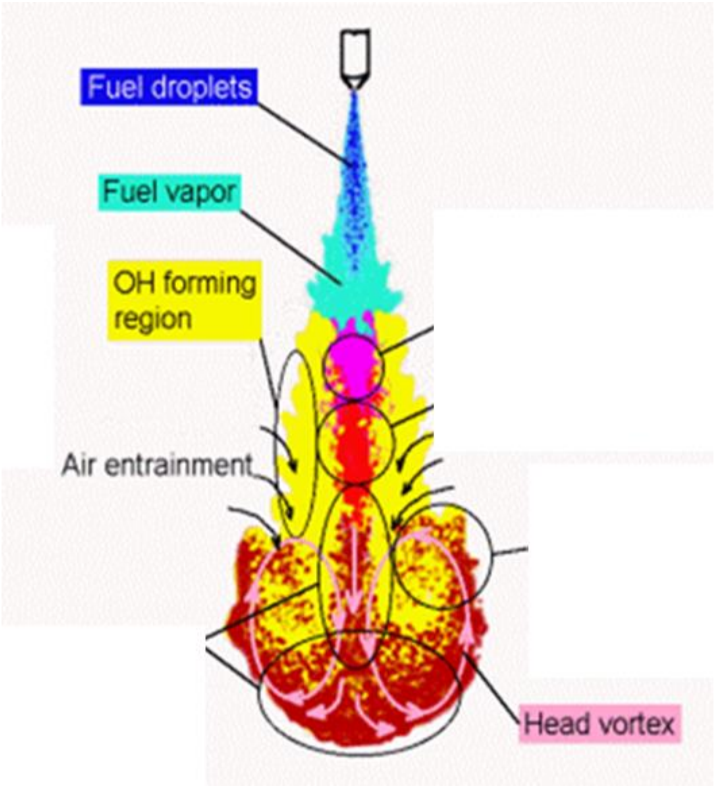
  -electrically heated wire that helps heat pre combustion chambers fuel when the engine is cold

  - when a diesel engine is cold, compression may not raise air to temperature needed for fuel ignition

Type of Fuel Vs Combustion Strategy

- Highly volatile with High self Ignition Temperature: Spark Ignition. Ignition after thorough mixing of air and fuel.
- Less Volatile with low self Ignition Temperature: Compression Ignition , Almost simultaneous mixing & Ignition.





- Combustion in CI Engines

  - Stages/ Phases of combustion

    1. Ignition delay period ;

       Physical delay and chemical delay

    2. Rapid combustion period / rapid pressure rise

    3. Controlled combustion period / mechanically controlled period

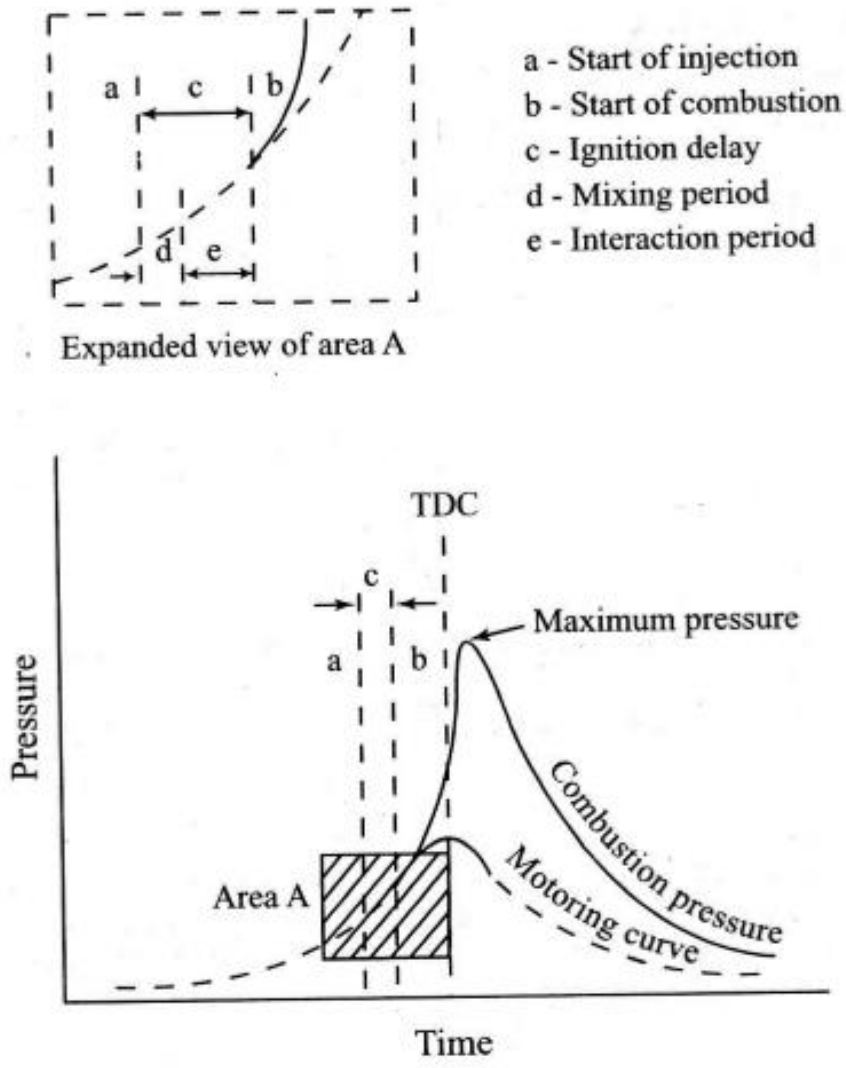
    4. After-Burning period

Stages/ Phases of combustion

1. Ignition delay period ;

- Preparatory phase:some fuel admitted,not ignited
- Period : start of injection to start of combustion
  (p-t curve separates from motoring curve)
- Important : combustion, design, performance,
  emissions
- Fuel does not ignite immediately and total delay period can be explained as; Physical delay and Chemical delay. Details are shown in the figure.

Combustion in CI Engines : Ignition Delay



Ignition Delay

- Ignition delay is defined as the time (or crank angle interval) from when the fuel injection starts to the onset of combustion.
- Both physical and chemical processes must take place before a significant fraction of the fuel chemical energy is released.
- The ignition characteristics of the fuel affect the ignition delay.
- The ignition quality of a fuel is defined by its **cetane number** CN.
- For *low* cetane fuels the ignition delay is long and most of the injected fuel is accumulated in the cylinder before autoignition .
- This leads to rapid combustion.
- Under extreme cases, this produces an audible knocking sound referred to as “diesel knock”.

Processes occurring during Combustion Process

Physical Processes

- Atomization of the fuel
- Vaporization of the fuel
- Mixing of fuel vapor with air

Chemical Processes

- Pre-combustion reactions
- Cracking of the larger hydrocarbons

2. Rapid combustion period / rapid pressure rise

- This is the phase of combustion when the rate of pressure rise is maximum and is also called uncontrolled combustion phase.The rate of heat release is maximum during this phase.
- period ; from end of delay or beginning of combustion to the point of maximum pressure on indicator diagram
- depends ; It may be noted that the maximum pressure reached during this phase depends upon the delay period. Longer the delay the higher is the rate of pressure rise as more fuel gets accumulated during the delay period.

3. Controlled combustion period / mechanically controlled period

- process ; This is the <u>second phase of fuel injection</u> when injected fuel finds more difficult to seek out and react with fresh oxygen in the remaining unburnt air mass.
- period ; from the point of maximum pressure to the point <u>of maximum cycle temperature</u>.

4. After-Burning period : fuel with the air

- Combustion does not cease with completion of fuel injection.The unburnt and partially burnt fuel particles start burning as soon as they come in contact with oxygen. This continue for a certain duration called after- burning period.
- period ; starts from the point of max.cycle temp. and continue over the part of expansion process.
- depends ; rate of after burning depends upon velocity of diffusion and turbulent mixing of unburnt and partially burnt fuel with the air

Diesel Knock

A combustion knock caused when the delayed period of ignition is long so that a large quantity of atomized fuel accumulates in the combustion chamber; when combustion occurs, the sudden high pressure resulting from the accumulated fuel causes diesel knock.

Origin of knock

- Auto ignition of end gas, depends strongly on chemical composition of end-gas mixture.
- If the flame burns all the fresh gas before auto-ignition in the end-gas can occur then knock is avoided.
- Knock is a potential problem when the burn time is long.
- **Theory of auto-ignition**

fuel oxidization occurs during compression of A/F mixture

- **Theory of detonation**

advancing flame velocity to consume end gas is much higher

Limiting parameters for knocks

- end-gas temperature
- time available before flame arrival
- **Compression ratio**
- **Spark timing**
- **Engine speed**
- **Delay period**
- Inlet pressure and temperature, coolant temperature, fuel/air ratio

Fuel factor and knock scale for SI engines

- Octane number ON is measure of resistance to knocking.
- Normal heptane (n-C_7H_{16}) has an octane value of zero and isooctane (C_8H_{18}) has a value of 100.
- The higher the octane number, the higher the resistance to knock.
- Blends of these two hydrocarbons define the knock resistance of intermediate octane numbers: e.g., a blend of 10% n-heptane and 90% isooctane has an octane number of 90.

Fuel factor and knock scale for CI engines

- Ignition quality of a fuel **cetane number** CN.
- For *high* cetane fuels ignition delay is short so very little fuel is injected before autoignition.
- Cetane (n-hexadecane, $C_{16}H_{34}$) has a value of 100.
- In the original procedures α-methylnaphtalene ($C_{11}H_{10}$) with a cetane number of zero represented the bottom of the scale.
- This has since been replaced by heptamethylnonane, (HMN) has a cetane number of 15, which is a more stable compound.
- The higher the CN the better the ignition quality, i.e., shorter ignition delay.
- The cetane number is given by:

$$CN = (\%\ \textit{hexadecane}) + 0.15\ (\%\ \text{HMN})$$

Comparison between spark and diesel knock

- In SI knock occurs near start of compression
- Depends on fuel factor and engine parameters
- Is more significant and limits compression ratio and hence efficiency of engine

- In CI engines knock occurs near start of expansion
- Depends on delay period and engine parameters
- Less significant and gives advantage to higher thermal efficiencies of engines

Factors Affecting on Diesel Knock

- Amount of fuel inject during Ignition delay.
- Injection timing
- Shape of Combustion chamber
- Atomization of fuel
- Fuel injection speed
- Fuel Injection pressure
- Spray pattern
- Volatility of fuel
- Self ignition temperature.

TYPES OF COMBUSTION CHAMBERS - CI Engines

- The most important function of CI engine combustion chamber is **to provide proper mixing of fuel and air in short time.**
- In order to achieve this, an organized air movement called **swirl** is provided to produce high relative velocity between the fuel droplets and the air.

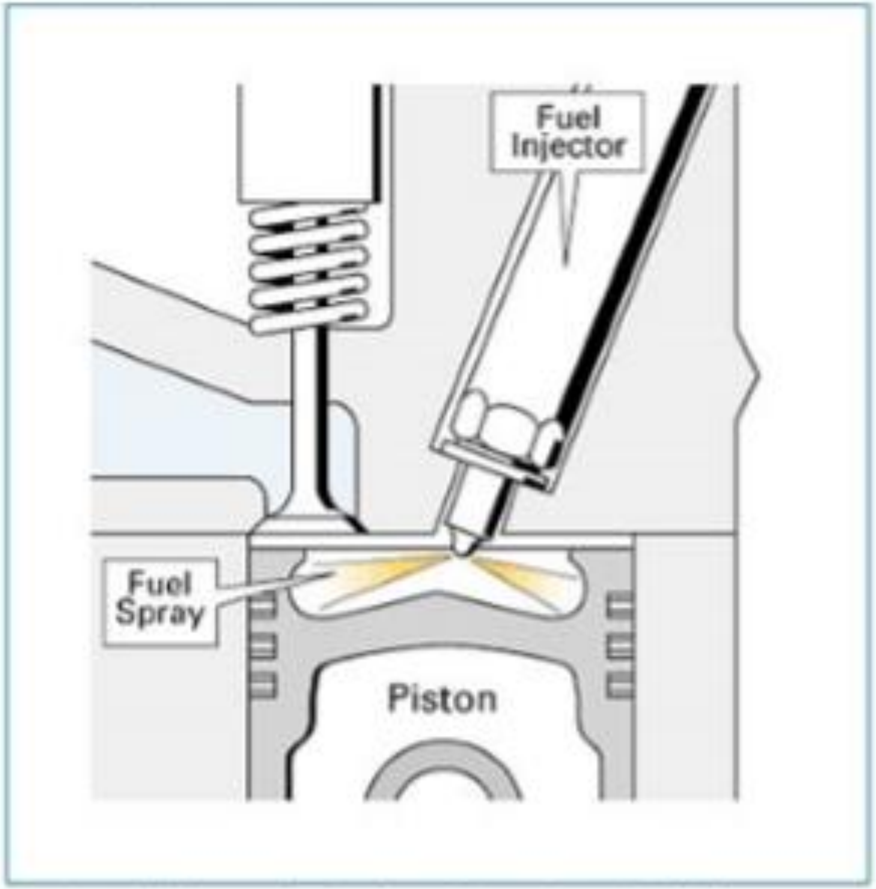
- To study the combustion design in detail C I engine combustion chambers are classified in

1. **DIRECT INJECTION (DI) TYPE :**

✓ This type of combustion chamber is also called a**n Open combustion chamber.**

✓ In this type the entire volume of combustion chamber is located in the **main cylinder** and the fuel is injected into this volume.

Direct-Injection (DI) Process



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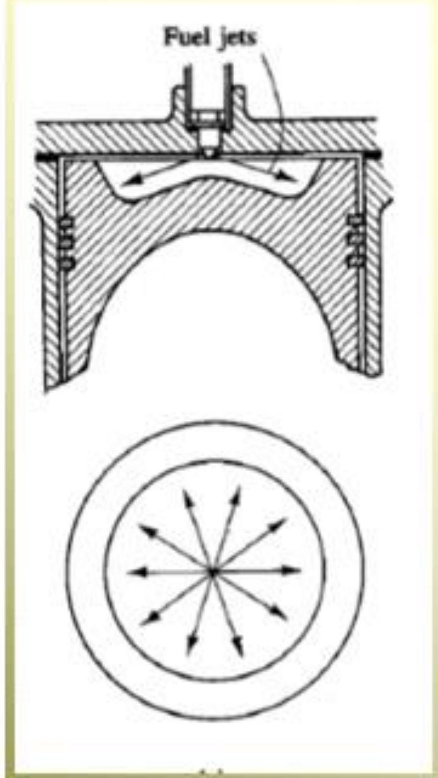
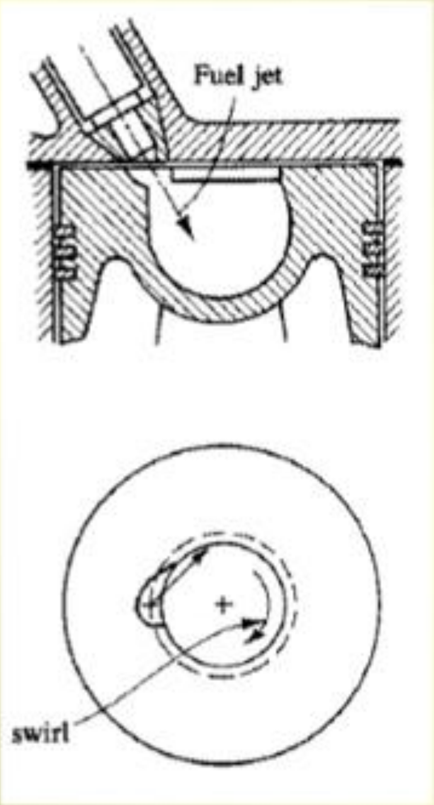


Direct injection:
quiescent chamber



Direct injection:
swirl in chamber

2. INDIRECT INJECTION (IDI) TYPE:

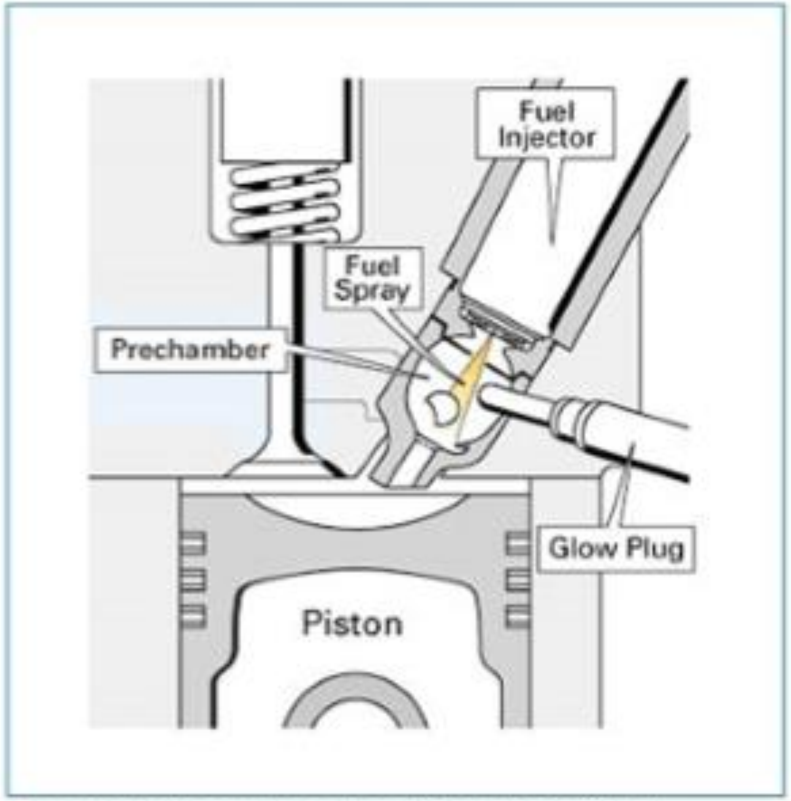
- ✓ In this type of combustion chambers, the combustion space is **divided into two parts**, one part **in the main cylinder** and the other part **in the cylinder head**.
- ✓ The fuel –injection is effected usually into the part of chamber located in the cylinder head. These chambers are classified further into :

a) **Swirl chamber** in which compression swirl is generated

b) **Pre combustion chamber** in which combustion swirl is induced.

c) **Air cell** in which both compression and combustion swirl are induced.

Indirect-Injection (IDI) Process



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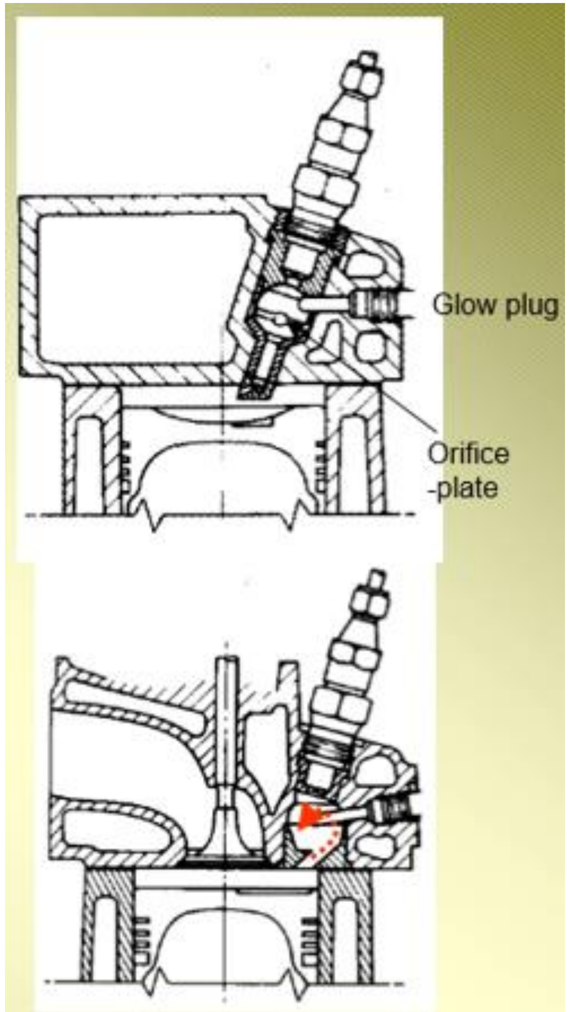


Indirect injection: turbulent and swirl pre-chamber

DIRECT INJECTION CHAMBERS – OPEN COMBUSTION CHAMBERS

- An **open combustion chamber** is defined as one in which the combustion space is essentially a **single cavity** with **little restriction** from one part of the chamber to the other and hence with **no large difference in pressure** between parts of the chamber during the combustion process.

- There are many designs of open chamber some of which are shown below :

In **four-stroke engines** with open combustion chambers, induction swirl is obtained either by careful formation of the air intake passages or by masking a portion of the circumference of the inlet valve whereas in **two-stroke engines** it is created by suitable form for the inlet ports.

- These chambers mainly consist of space formed between **a flat cylinder head** and a **cavity in the piston crown in different shapes**.
- The fuel is injected directly into space.
- The injection nozzles used for this chamber are generally of **multi hole type** working at a relatively **high pressure (about 200 bar)**

- The **main advantages** of this type of chambers are:

✓ **Minimum heat loss** during compression because of lower surface area to volume ratio and hence, better efficiency.

✓ **No cold starting problems**.

✓ **Fine atomization** because of multi hole nozzle.

- The **drawbacks** of these combustion chambers are:

✓ **High fuel-injection pressure** required and hence **complex design of fuel injection pump**.

✓ **Necessity of accurate metering of fuel** by the injection system, particularly for small engines Shallow

IN DIRECT INJECTION CHAMBERS

- A divided combustion chamber is defined as one in which the combustion space is **divided into two or more distinct compartments** connected by **restricted passages**.
- This creates considerable pressure differences between them during the combustion process.

PRE COMBUSTION CHAMBER

- Typical pre-combustion chamber consists of an **anti chamber** connected to the **main chamber through a number of small holes** (compared to a relatively large passage in the swirl chamber).
- The **pre-combustion chamber** is **located** in the **cylinder head** and its volume accounts for about **40% of the total combustion**, space.
- During the compression stroke the piston forces the air into the pre-combustion chamber.

- The fuel is injected into the pre-chamber and the combustion is initiated.
- The resulting pressure rise forces **the flaming droplets together with some air and their combustion products** to rush out into the main **cylinder at high velocity through the small holes.**
- Thus it creates both **strong secondary turbulence** and **distributes the flaming fuel droplets throughout the air** in the main combustion chamber where bulk of combustion takes place.
- About **80% of energy is released in main combustion chamber.**

- The rate of pressure rise and the maximum pressure is lower compared to those in open type chamber.
- The initial shock if combustion is limited to pre-combustion chamber only.
- The pre-combustion chamber has multi fuel capability without any modification in the injection system because the temperature of pre-chamber.
- The variation in the optimum injection timing for petrol and diesel operations is only 2 deg. for this chamber compared to 8 to 10 deg in other chamber design.

- **Advantages:**

(i) 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.

(ii) The combustion in the third stage is rapid.

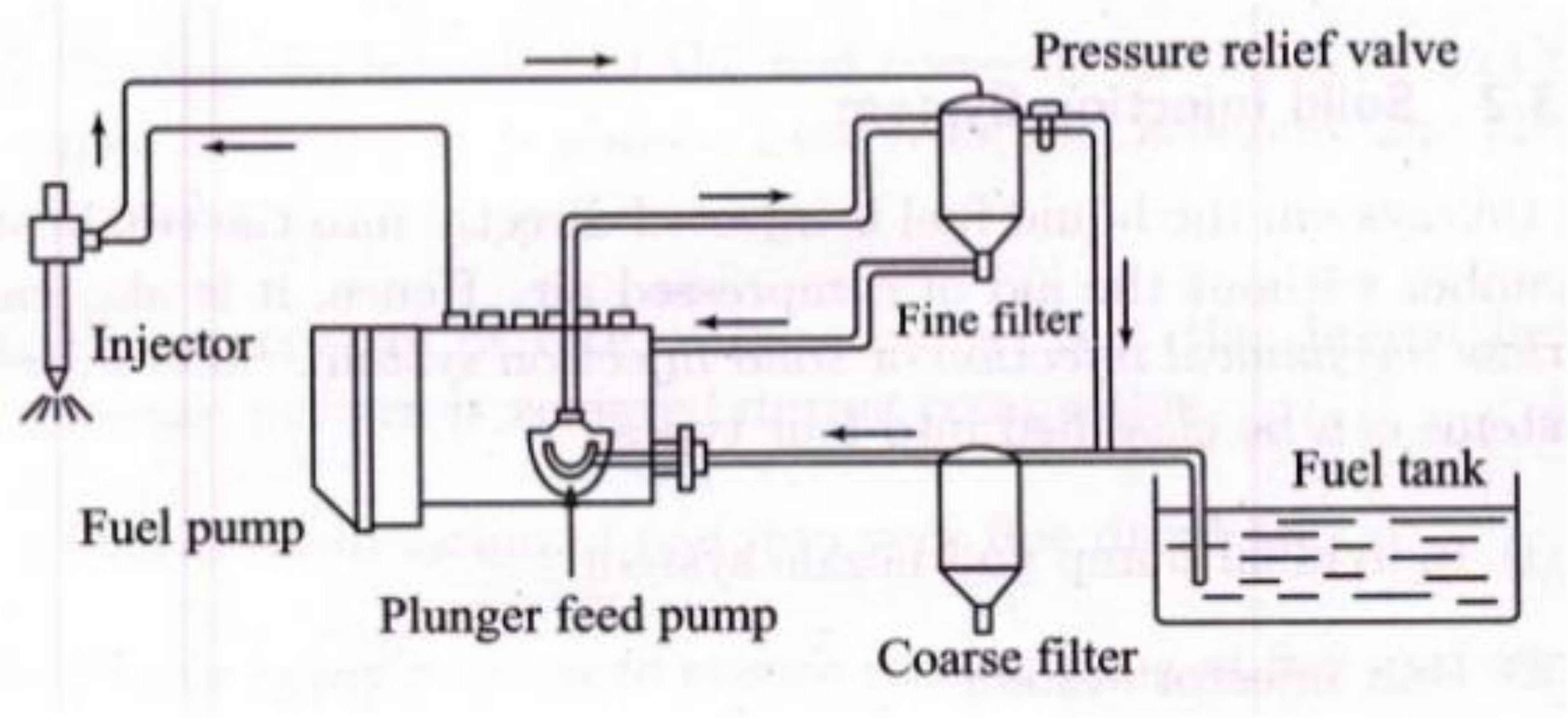
(iii) The fuel injection system design need not be critical. Because the mixing of fuel and air takes place in pre-chamber,

- **Disadvantages:**

(i) 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.

(ii) **Cold starting will be difficult** as the air loses heat to chamber walls during compression.

Diesel Fuel System Components



Diesel Fuel System Components

- Fuel Tank

  Main storage reservoir. Size depends on the requirements and limitations of the vehicle

  Made of non-corrosive materials

  Must be able to withstand 2 times the operating pressure without leaking

  Safety valves allow excess pressure to vent to the atomsphere without allowing fuel to escape

Diesel Fuel Filter with water seperator

Debris will enter fuel and contaminate it due through processing, storing, handling, transporting and pumping.

PRIMARY FORMS OF CONTAMINATION:

Water and dirt

It is critical that the supply of fuel is extremely clean due to the nature and construction of the fuel system

Clearances between moving parts in a injection pump can be as little as 0.0001 in.

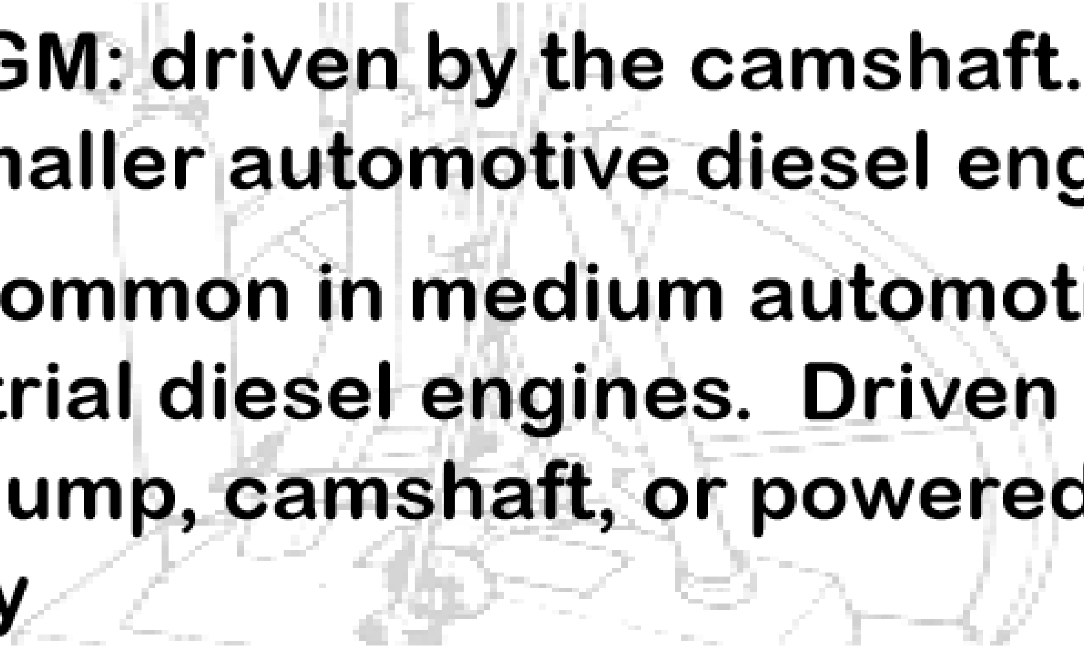
Water is always present in diesel fuel due to being in our atomsphere. Its removal is vital in a diesel fuel system.

Water can cause great damage to a fuel system and is the most common cause of fuel system failure.

Water will break down lubrication of fuel system components which can lead to metal to metal contact, rusting of machined parts and even explosion of the water in fuel injector tips, as the water turns to steam


A
C
A
Sealing
Fitting flange
Double beading
B
B
Multilayer filter medium
Water chamber
Water drain screw

Fuel Pump



DIAPHRAGM: driven by the camshaft. Used in smaller automotive diesel engines

PISTON: common in medium automotive and industrial diesel engines. Driven by injection pump, camshaft, or powered electrically

FUEL LINES AND FITTINGS:

Diesel systems use low pressure and high pressure lines

Low pressure lines carry fuel to the injection pump

High pressure lines deliver fuel from the injection pump to the injection nozzles.

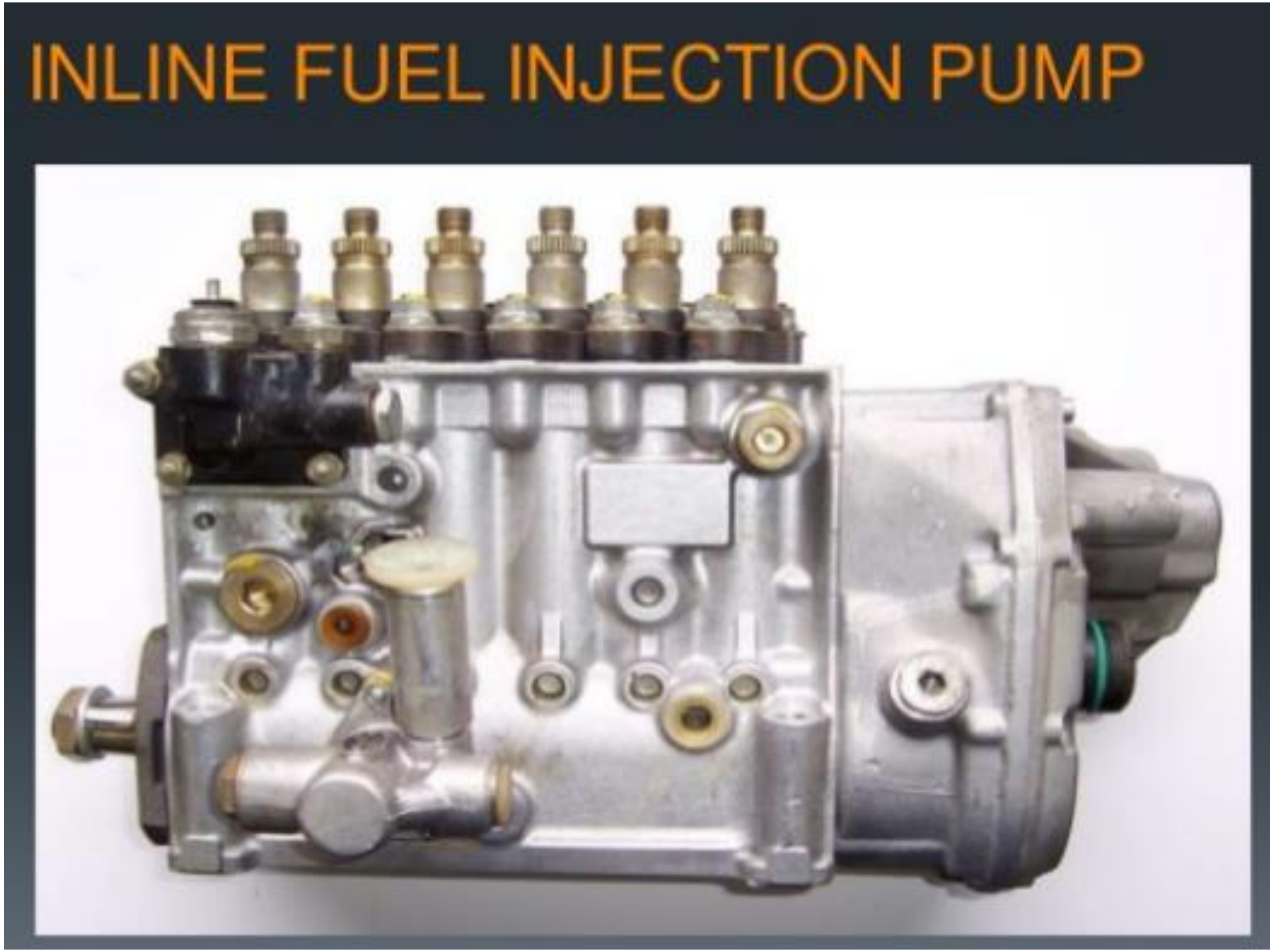
Injection Pump

A fuel injection pump is the pump that takes the fuel from the fuel manifold and pushes it under high pressure through the fuel lines to the fuel injectors. The fuel injection pump, or metering pump, boosts low and medium fuel pressures to the high pressures needed for injection.

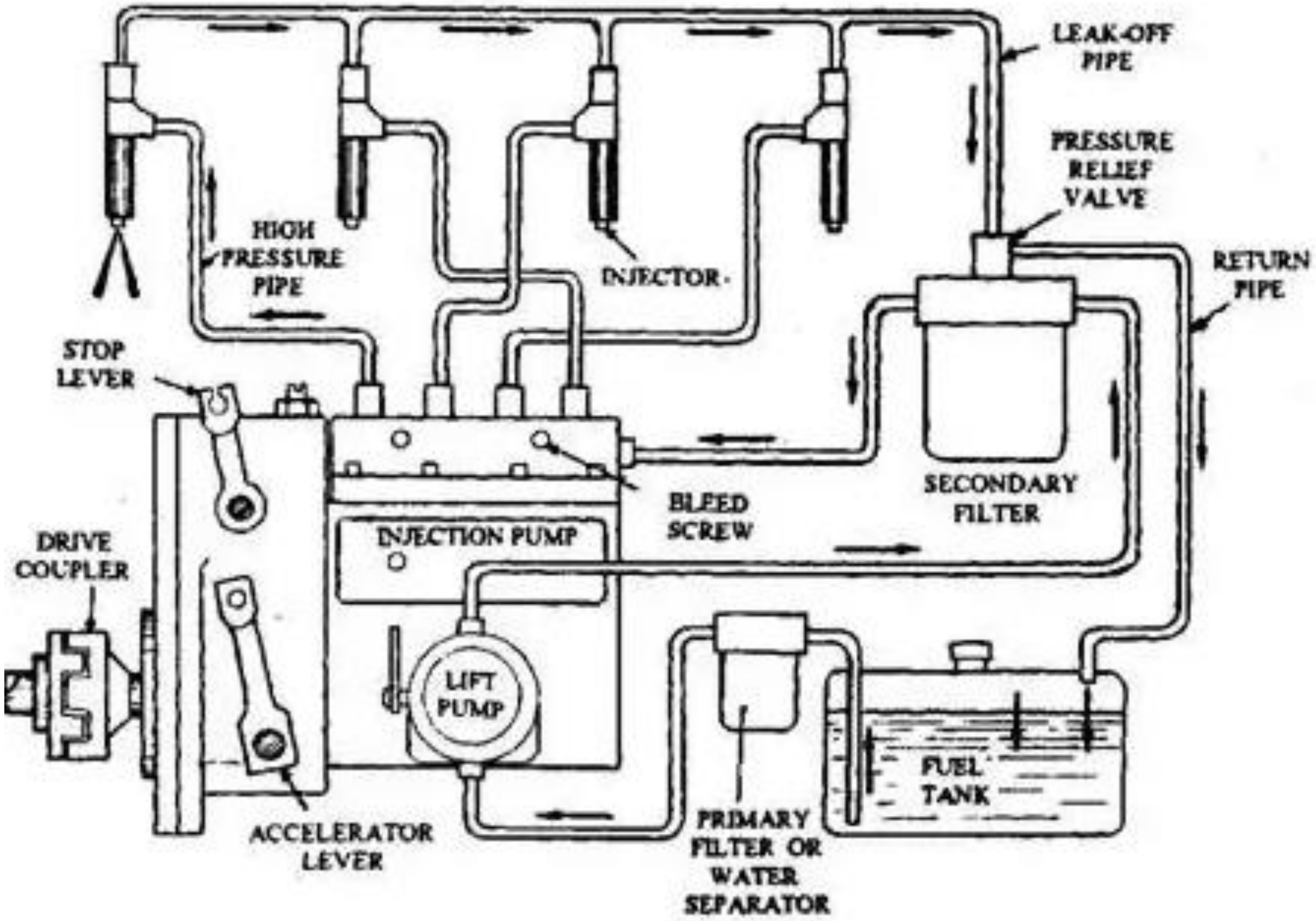
Two types :

Inline type

Distributor type

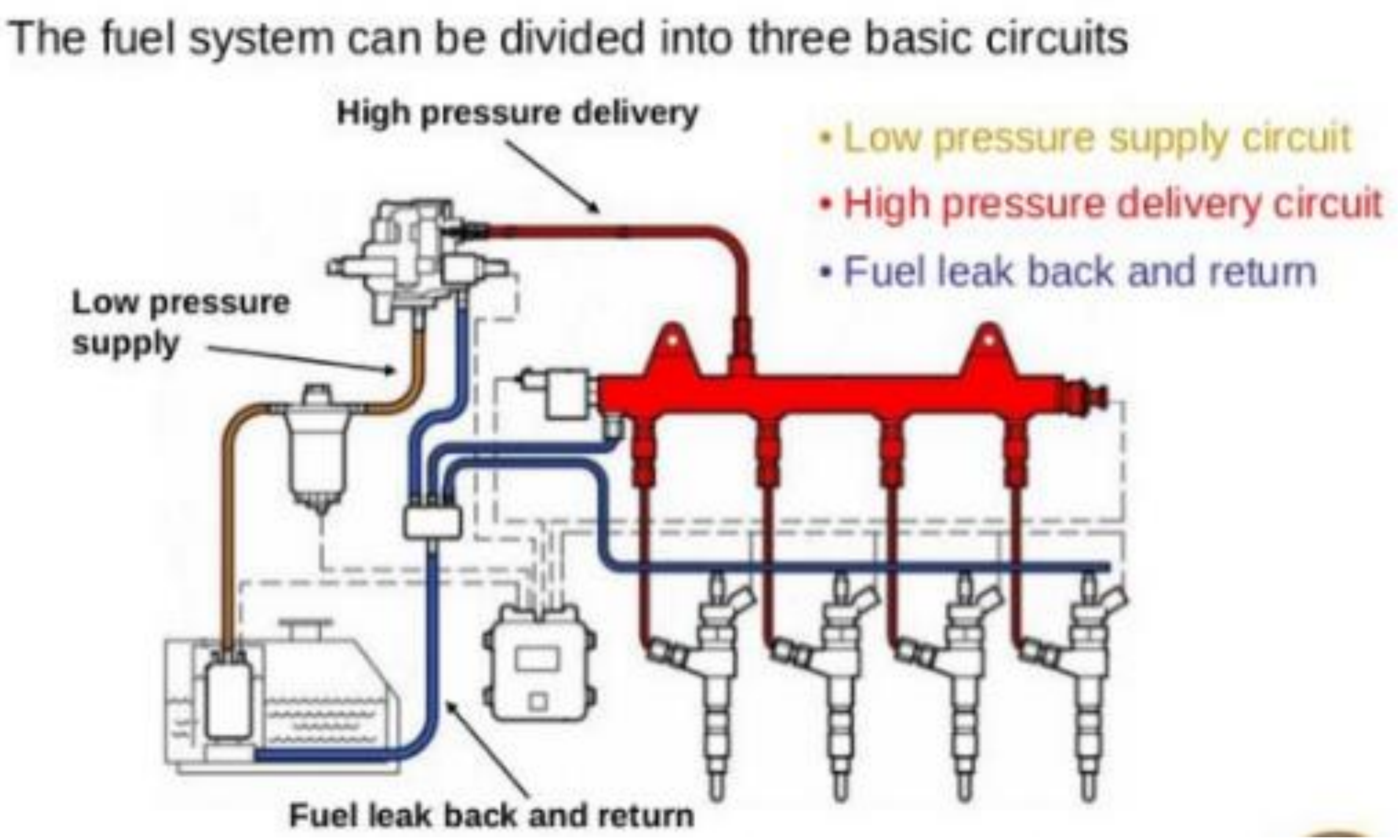


This unit has separate pump element to each nozzle.



0.9. In-line injection pump fuel system layout.

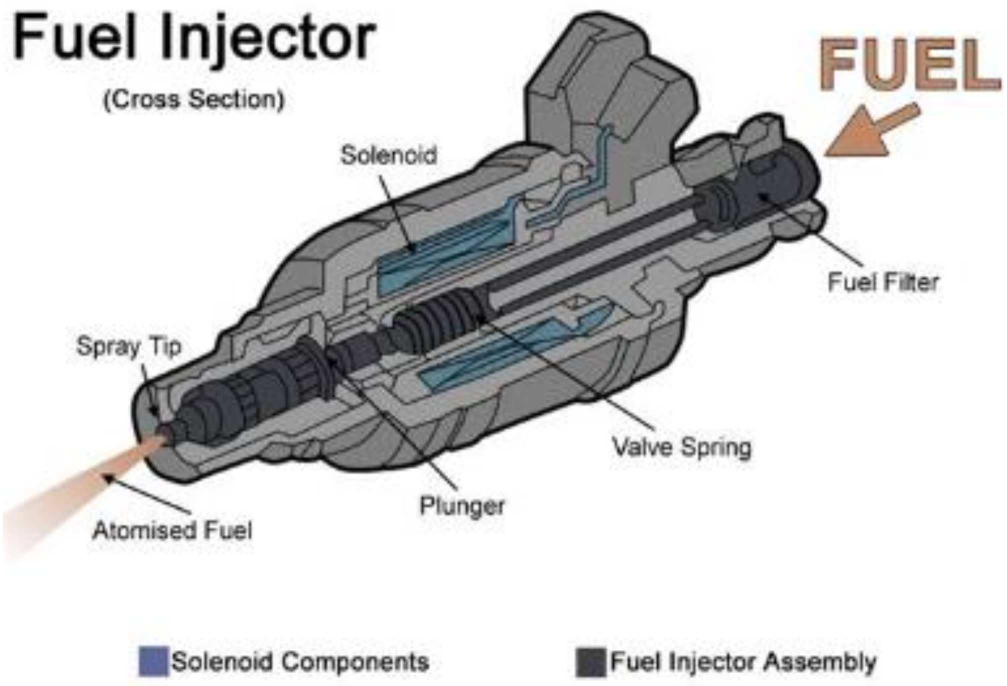
Distributor type pump



One pumping element, connected to each cylinder in a specific firing order

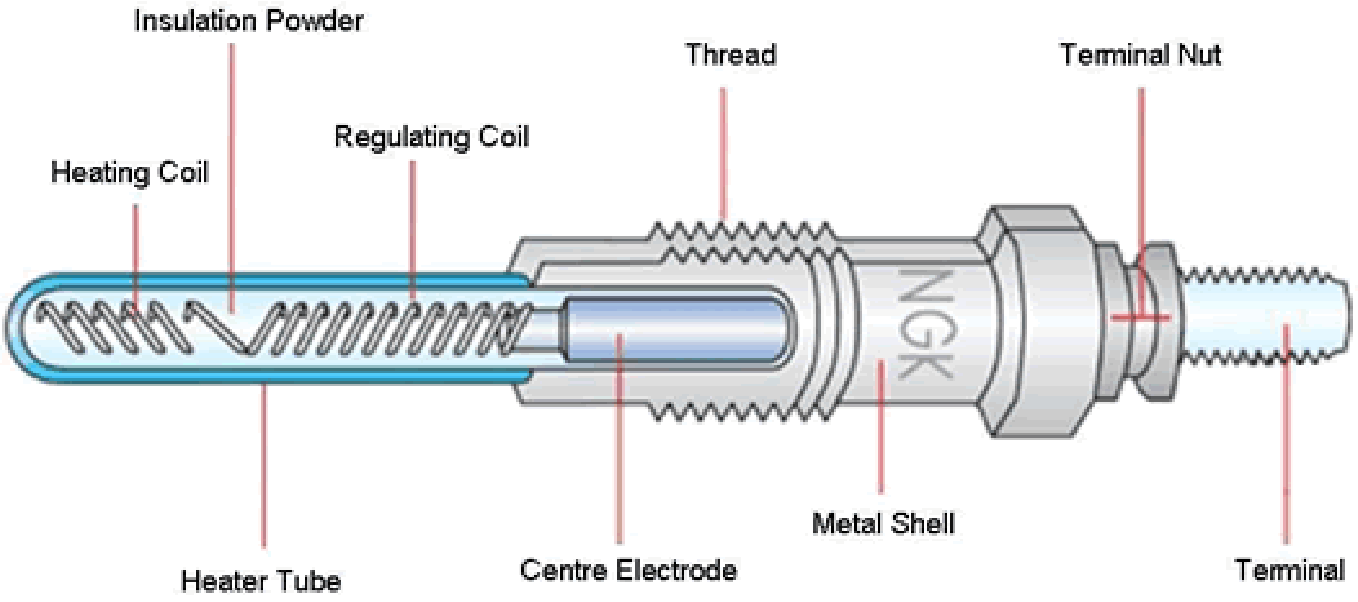
Fuel Injector

Fuel injectors are located in the intake manifold and spray **fuel** through a tiny nozzle. The **fuel injector** uses a special nozzle to spray the **fuel** as mist, instead of a strong jet stream.



Glow Plug

A **glowplug** (alternatively spelled as **glow plug** or **glow-plug**) is a heating device used to aid in starting diesel engines. In cold weather, high-speed diesel engines can be difficult to start because the mass of the cylinder block and cylinder head absorb the heat of compression, preventing ignition.



Diesel Smoke

A brand new diesel engine running at full load will experience a little bit of blow-by upon startup. Blow-by is a condition where diesel fuel, air and vapor are pushed past the rings into the crankcase of the engine. Correct pressure should be maintained in the cylinder chamber in order for proper combustion to occur. In a new diesel engine the rings need time to seat properly and develop an air-tight seal. After a short period of break-in hours under load, the blow-by problem should correct itself. Consequently, a proper running diesel engine should produce no visible smoke from the exhaust. If there is smoke coming from the exhaust it could indicate a more serious problem with the engine. This article will help

White Smoke:

White smoke coming from the exhaust usually points to one point of failure: the injectors. Usually, white smoke indicates that the diesel fuel is not burning correctly. Unburned diesel fuel will make its way through the exhaust completely unused. Be careful of white smoke as it will irritate your eyes and skin. If white smoke occurs during a startup in freezing temperatures, then goes away, it usually indicates frozen deposits of soot which expanded around the rings then burned away once the engine warmed up. The use of glow plugs during cold startsand/or the use of a flushing solvent to remove engine sludge is recommended.

Common Causes of White Smoke:

- Damaged Injectors
- Faulty Injection Timing
- Damaged Crankshaft Keyway
- Damaged Timing Gear
- Low Cylinder Compression
- Damaged Rings or Cylinder Liners
- Water mixed in the Diesel Fuel (Cracked Head Gaskets, Cylinder Head or Block)
- Damaged Fuel Lines
- Low Fuel Pressure to the Fuel Pump
- Damaged or Incorrect Fuel Pump Timing

Black Smoke:

Black smoke, unlike white smoke, contains a high concentration of carbon exhaust particles. The combustion of diesel fuel in the cylinders breaks down the long chain of carbon molecules to smaller and smaller molecular chains. When the exhaust leaves the engines the byproduct is a combination of carbon dioxide and water. If something goes wrong during combustion the chemical reaction taking place is not as robust, causing long tail hydrocarbons to be left completely intact and then expelled in the form of smog or soot. Partial burning of diesel fuel results in large carbon dioxide particles as well as greenhouse gasses which contribute to air pollution. The advent of the Selective

Common Causes of Black Smoke:

- Clogged Air Cleaner
- Damaged Injectors
- Bent Injector Nozzles
- Incorrect Injector Timing
- Clogged Air, Fuel or Oil Filters
- Damaged Injection Pump
- Damaged/Clogged EGR Cooler
- Damaged Turbocharger
- Damaged Intercooler
- Over-Fueling the Engine
- Wrong Blend of Diesel Fuel For Temperature
- Cracked or Clogged Valves in Cylinder Head
- Improper Valve Clearance
- Low Compression due to Damaged Piston Rings

Blue Smoke:

Blue engine smoke is the rarest type of smoke emanating from a diesel engine. The presence of blue smoke is an indication of burning oil. Blue smoke should not be ignored but is common when starting an engine in a cold weather. The oil thins out when it is cold and some could escape into the cylinder and be burnt. Cold temperatures can cause older more worn rings to unseat just a bit due to deposits found around the rings or cylinders. Cylinder glaze, or the smooth deposits left behind from the piston going up and down, can also build up over time and burn.

Common Causes of Blue Smoke:

- Damaged or Worn Piston Rings
- Damaged or Worn Cylinders
- Damaged or Worn Guides
- Damaged or Worn Stem Seals
- Overfill of Engine with Oil
- Damaged Lift Pump
- Fuel Mixed with Oil
- Cylinder Glaze Burning
- Wrong Grade of Oil