Diesel Engine Power Plants

Energy Conversion Engineering

Diesel Engine Power Plants

Introduction

Diesel electric plants are generally available in the range of 2 to 50 MW capacity and they can be used for the following applications:

- ***Peak load plant*** – Diesel plants are used as peak load units in combination with hydro or thermal plants. They can be easily started and stopped to meet the peak load demand.

- ***Mobile plant*** – They can be mounted on trailers and used for temporary or emergency purposes such as supplying power to large civil engineering projects.

- ***Emergency plant*** – They are used to support during power interruptions in vital establishments like hospitals, airports, railway stations etc.

Introduction

- ***Nursery station*** – In the absence of main grid, a diesel plant can be installed to supply power to villages. In course of time, when electricity from main grid becomes available, the diesel unit can be shifted to another village. Such diesel plants are called "Nursery Stations".
- ***Starting stations*** – Diesel units can be used to run power plant auxiliaries like forced and induced draft fans, boiler feed pumps etc for starting a large steam power plant.
- ***Central stations*** – Diesel electric plants can be used as central station where the capacity required is small.

Advantages of Diesel Electric plants

- They are available in standard capacities and easy to install.
- Limited cooling water requirement.
- Standby losses are less compared to other power plants.
- They can be started and stopped quickly.
- Capital cost is less.
- They respond to load fluctuations with ease.
- Less staff needed for operation and maintenance.
- Higher efficiency at part load compared to other power plants
- Less floor space and civil engineering work.
- No problem of ash or effluent handling.

Disadvantages of Diesel Electric plants

- Operating and maintenance costs are high – dictated by increasing cost of fuel and lubricants.
- Plant cost per kW is more compared to other power plants.
- Restricted capacity of plant. Large capacity plants not economical.
- Life of diesel plant is small due to large maintenance requirements
- Noise levels are high.
- Can not support overload

Classification of IC Engines

Internal Combustion (IC) engines are classified in different ways:

1. **According to cycle of operation**
   - **Two stroke cycle engines**
   - **Four stroke cycle engines**
1. **According to cycle of combustion**
   - **Otto cycle (constant volume combustion)**
   - **Diesel cycle (constant pressure combustion)**
   - **Semi-Diesel cycle (Combustion partly constant volume and partly constant pressure)**
1. **According to cylinder arrangement**
   - **Horizontal engine**
   - **Vertical engine**
   - **'V' type engine**
   - **Radial engine**

Classification of IC Engines

4. **According to the use**
   - **Stationary engine**
   - **Portable engine**
   - **Marine engine**
   - **Automobile engine**
   - **Aero engine**
5. **According to the fuel used and the method of fuel supply to engine cylinder**
   - **Oil engine**
   - **Petrol engine**
   - **Gas engine**
   - **Kerosene engine**
   - **Carburettor, hot bulb, fuel injection, air injection etc.**

Classification of IC Engines

6. According to the speed of the engine
   - Low speed engine
   - Medium speed engine
   - High speed engine
7. According to the method of ignition
   - Spark ignition engine
   - Compression ignition engine
8. According to the method of cooling the engine
   - Air cooled engine
   - Water cooled engine
9. According to the method of governing
   - Hit-and-miss governed engine
   - Quality governed engine
   - Quantity governed engine

Classification of IC Engines

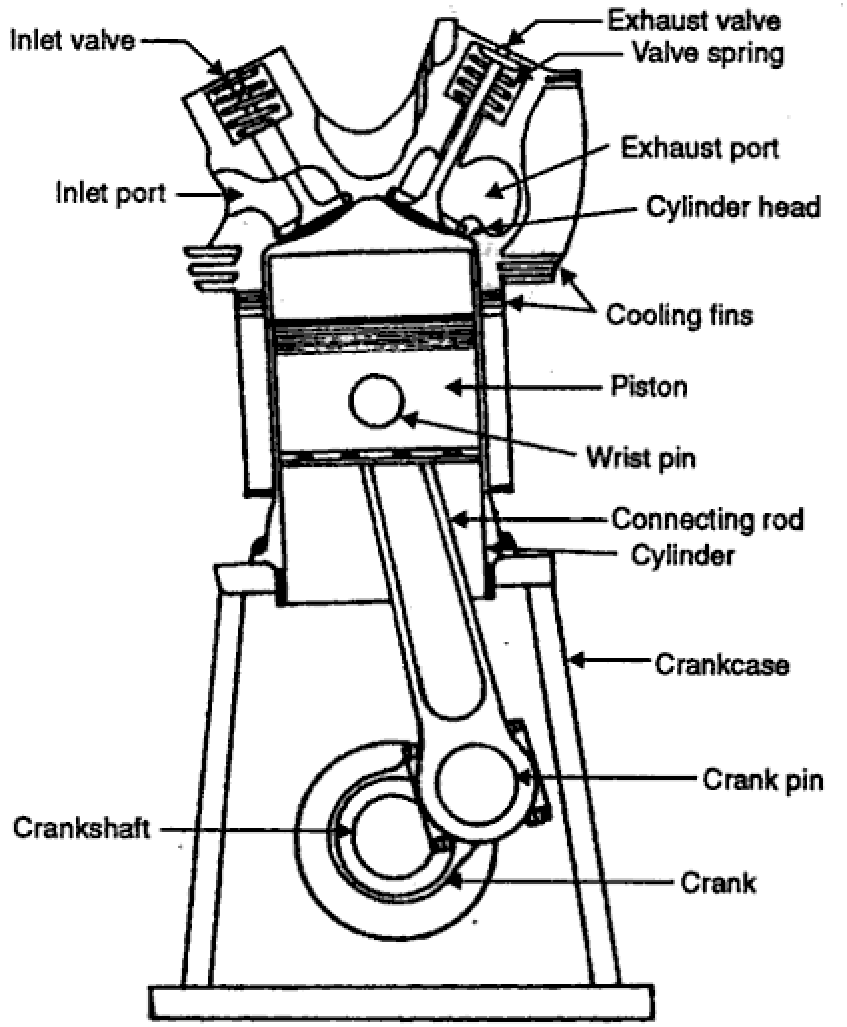
10. According to valve arrangement

- Overhead valve engine
- L-head type engine
- T-head type engine
- F-head type engine

11. According to number of cylinders

- Single cylinder engine
- Multi-cylinder engine

Parts of a typical IC Engine



Air cooled single cylinder engine

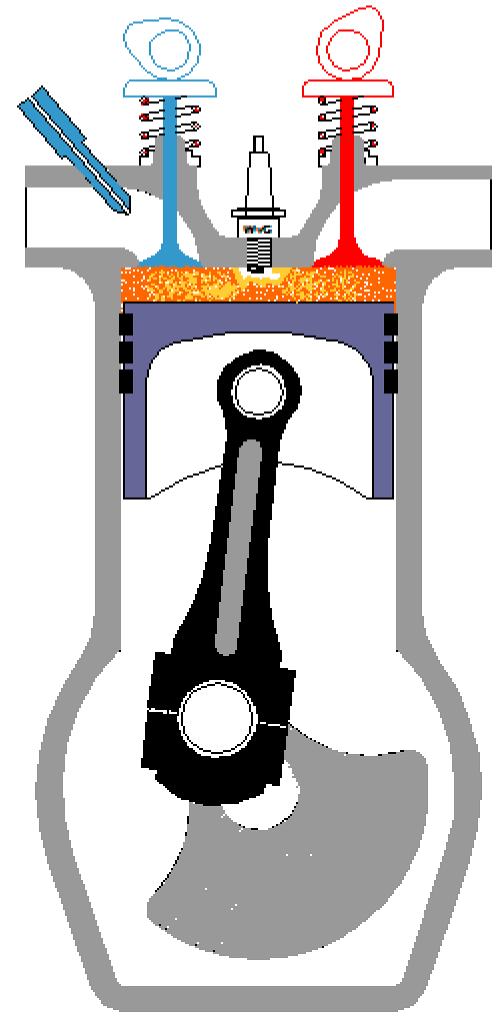
Working of 4-stroke IC Engines

1. Intake

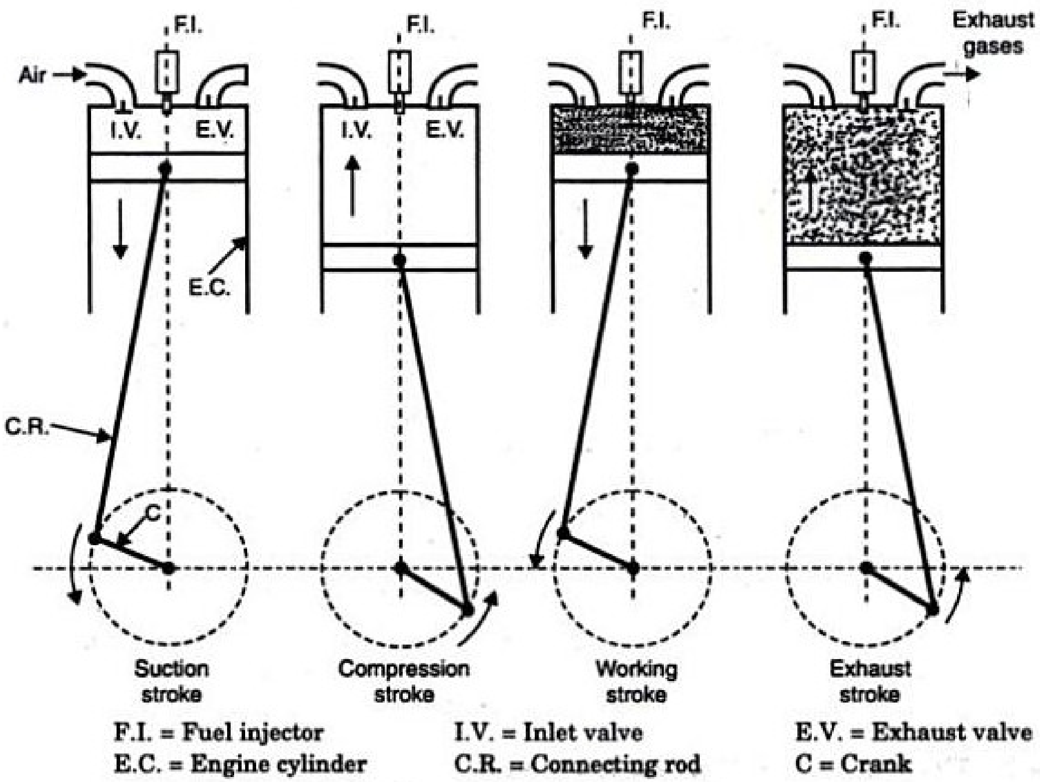
2. Compression

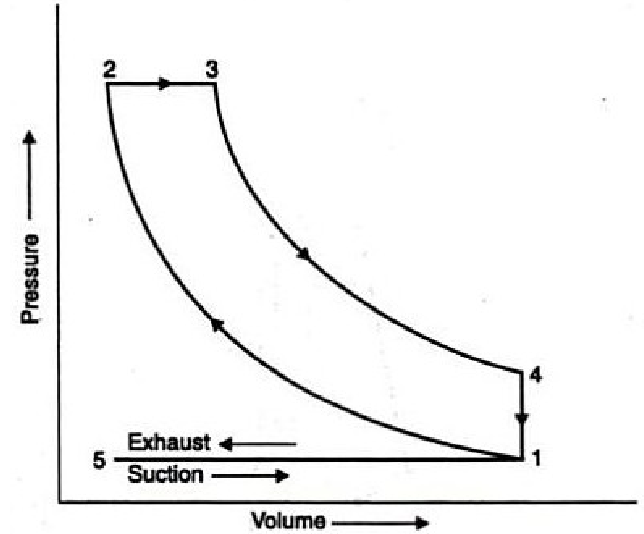
3. Power

4. Exhaust

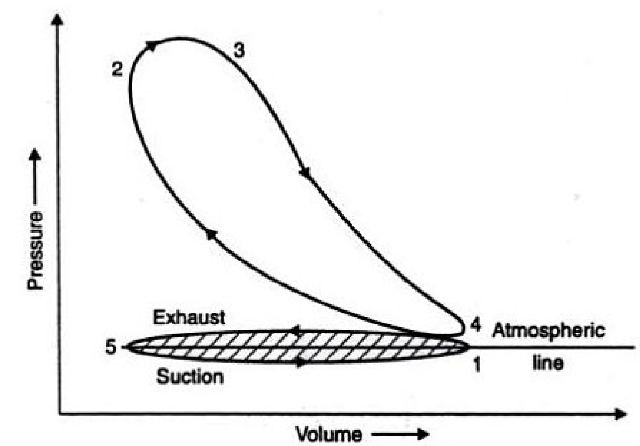


4-stroke cycle Diesel Engines



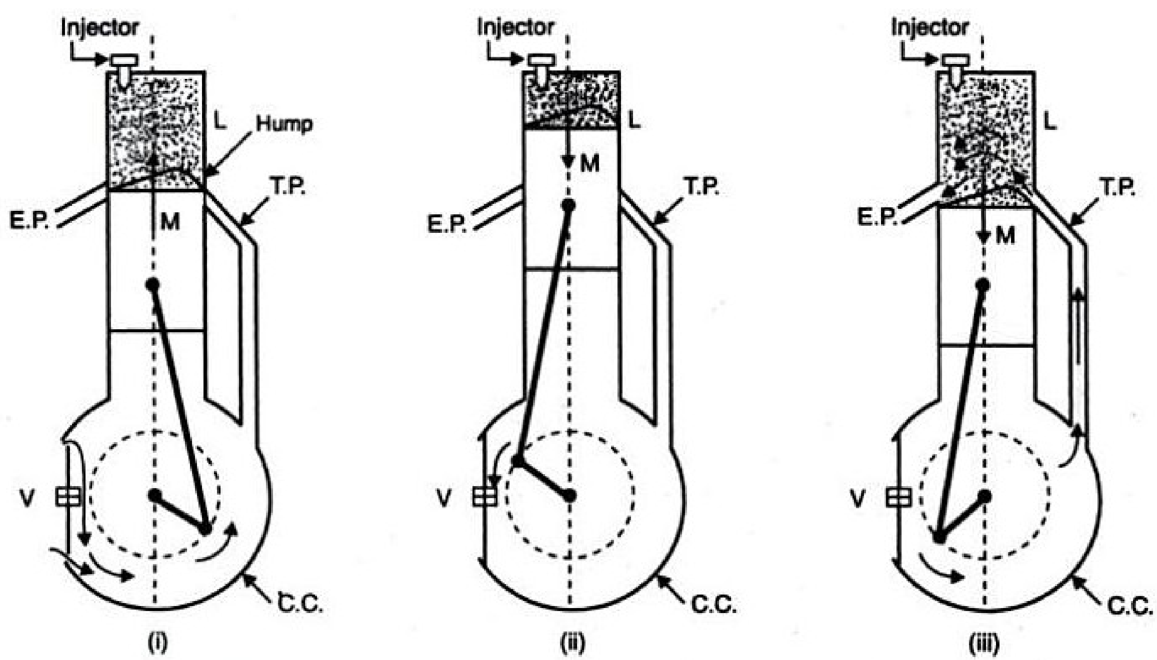


Theoretical p-V diagram

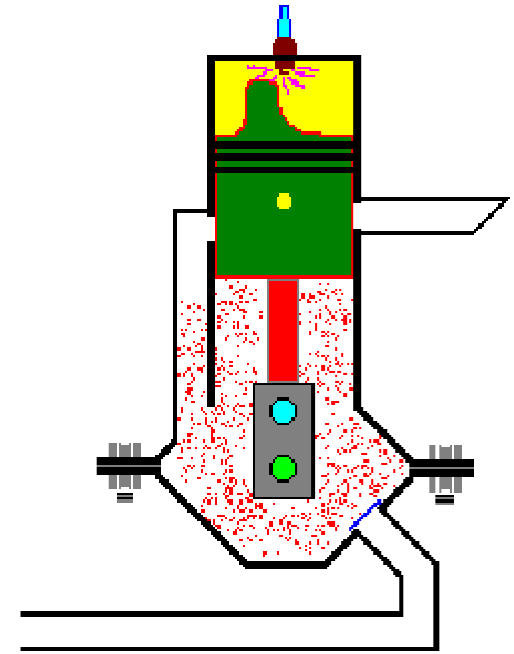


Actual p-V diagram

2-stroke cycle Diesel Engines



L = Cylinder ; M = Piston ; E.P. = Exhaust port ; T.P. = Transfer port ; C.C. = Crank chamber ; V = Valve



- During upward movement of piston, air is compressed in the cylinder (L). At the same time, fresh air enters the crank chamber through valve (V).
- At the end of the stroke, fuel is injected into compressed air and combustion takes place starting the power stroke.
- During the power stroke, valve (V) is closed and air in crank chamber is compressed and transferred to cylinder via transfer port (TP)
- At the same time, exhaust port (EP) opens to drive away burnt gases

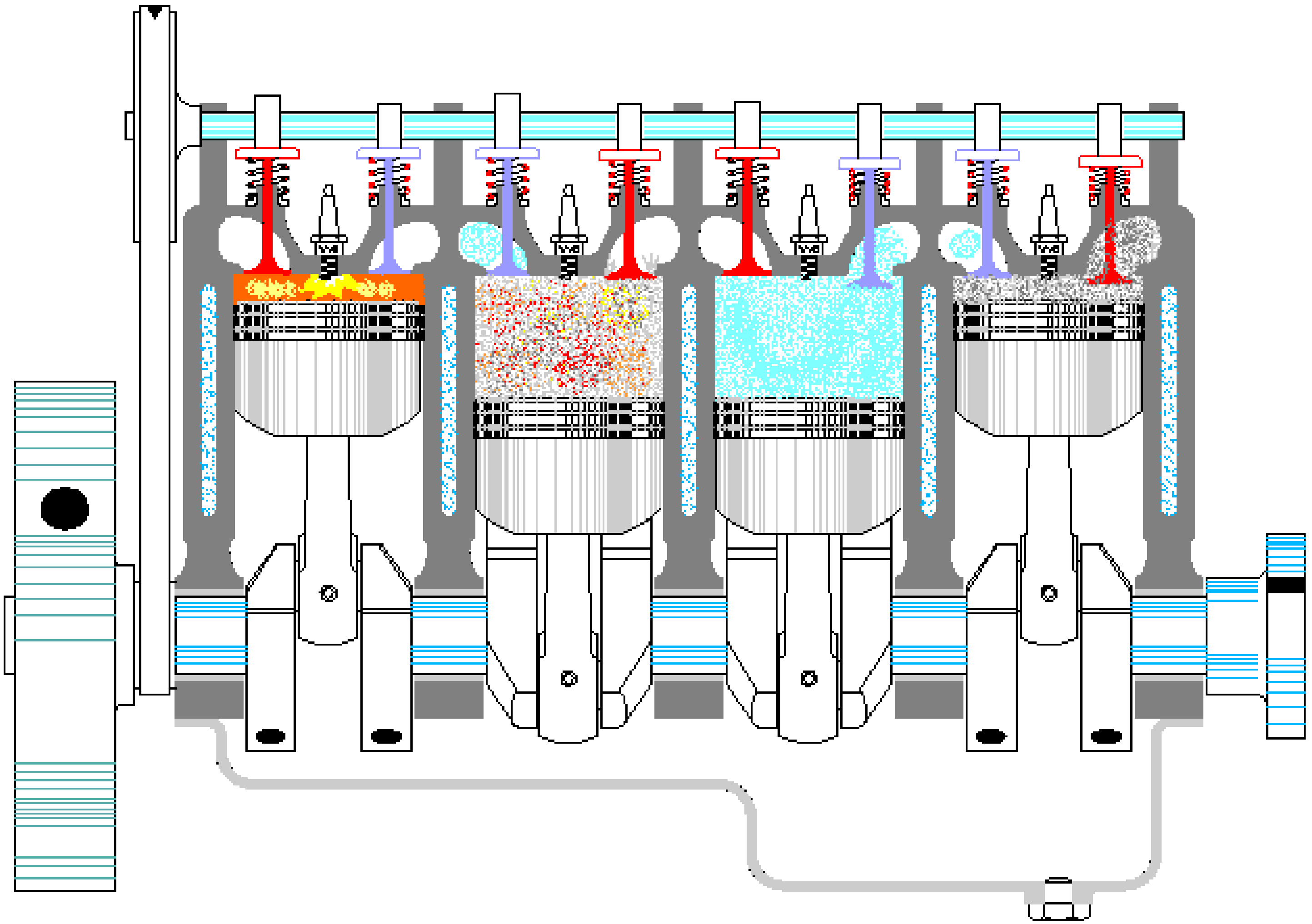
Characteristics of 4-stroke Diesel Engines

- Cycle is completed in 4 strokes of piston, or one power stroke in two revolutions of crankshaft.
- Turning movement is not uniform and hence requires heavy flywheel.
- Because of one power stroke in two revolutions, engine is heavy for a given power.
- Less wear and tear and hence lesser cooling and lubrication needs.
- Contains valve and valve drive mechanism.
- Higher volumetric efficiency due to higher air induction time.
- Better thermal and part load efficiency compared to two stroke engines.
- Used in applications where efficiency is important, e.g., cars, buses, trucks, tractors, aeroplanes, power generators etc.
- Higher initial cost.

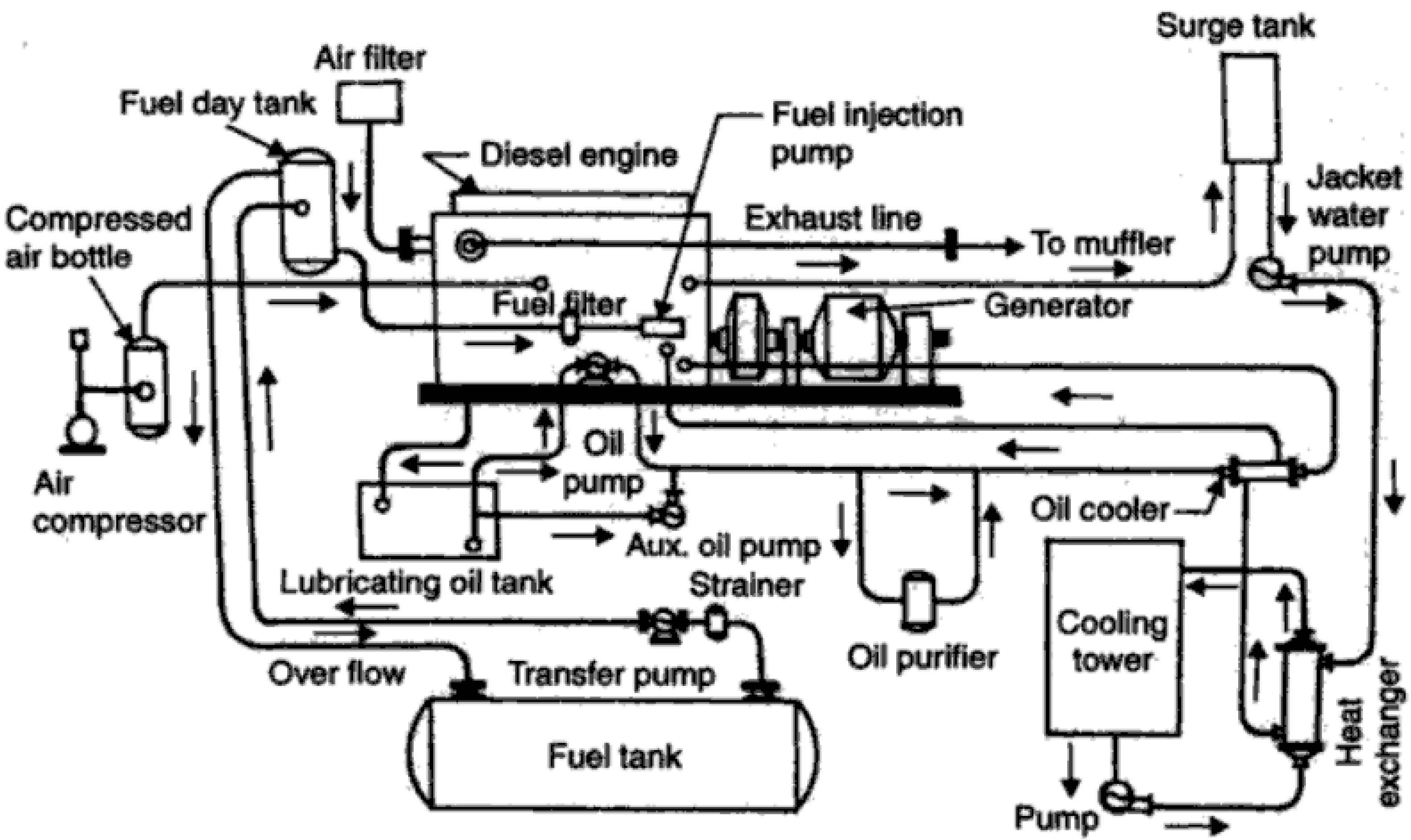
Characteristics of 2-stroke Diesel Engines

- Cycle is completed in two strokes of piston, or one power stroke for every rotation of crankshaft.
- More uniform turning movement and hence requires smaller flywheel.
- Theoretically the power developed is 2 times (~ 1.8 in practice) that of a 4-stroke engine. Hence lighter in weight for a given power level.
- Higher wear and tear and hence higher cooling and lubrication needs.
- Absence of valves and valve drive mechanism makes the engine simple and less expensive.
- Volumetric efficiency less due to lesser time available for air induction.
- Lower thermal and part load efficiency compared to 4-stroke engines.
- Used where low cost, low weight and compactness are desired.
- 2-stroke engines are used in very large sizes (~600 mm bore) for ship propulsion because of low weight and compactness.

Working of multi-cylinder 4-stroke IC Engines



General schematic of Diesel Power Plant



Schematic arrangement of diesel power plant

Essential Components of Diesel Power Plant

The essential components of a diesel power plant are:

1) Engine
2) Air intake system
3) Exhaust system
4) Fuel system
5) Cooling system
6) Lubrication system
7) Engine starting system
8) Governing system

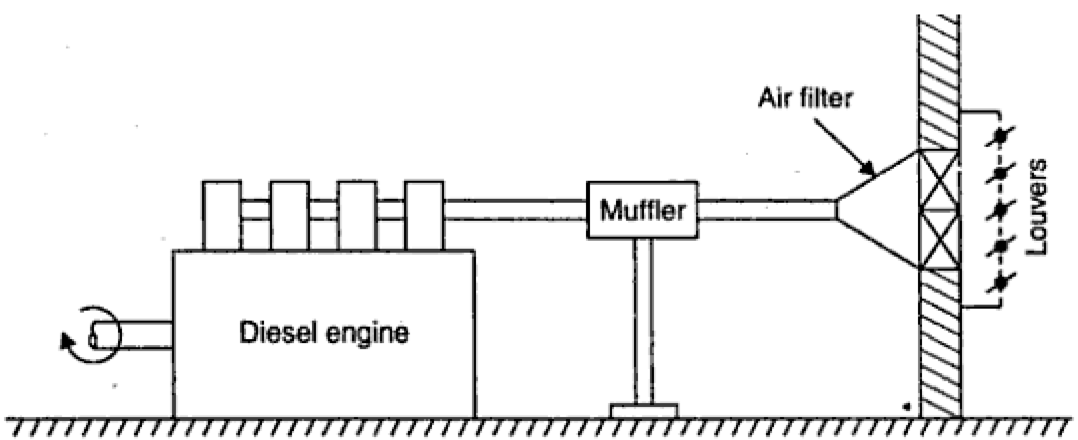
Engine and Air intake

Engine

This is the main component of the plant which develops the required power. The electrical generator is usually direct coupled to the engine.

Air intake system

The air intake system conveys fresh air through pipes or ducts to *(i)* air intake manifold of 4 stroke engine *(ii)* The scavenging pump inlet of a two stroke engine *(iii)* The supercharger inlet of a supercharged engine.



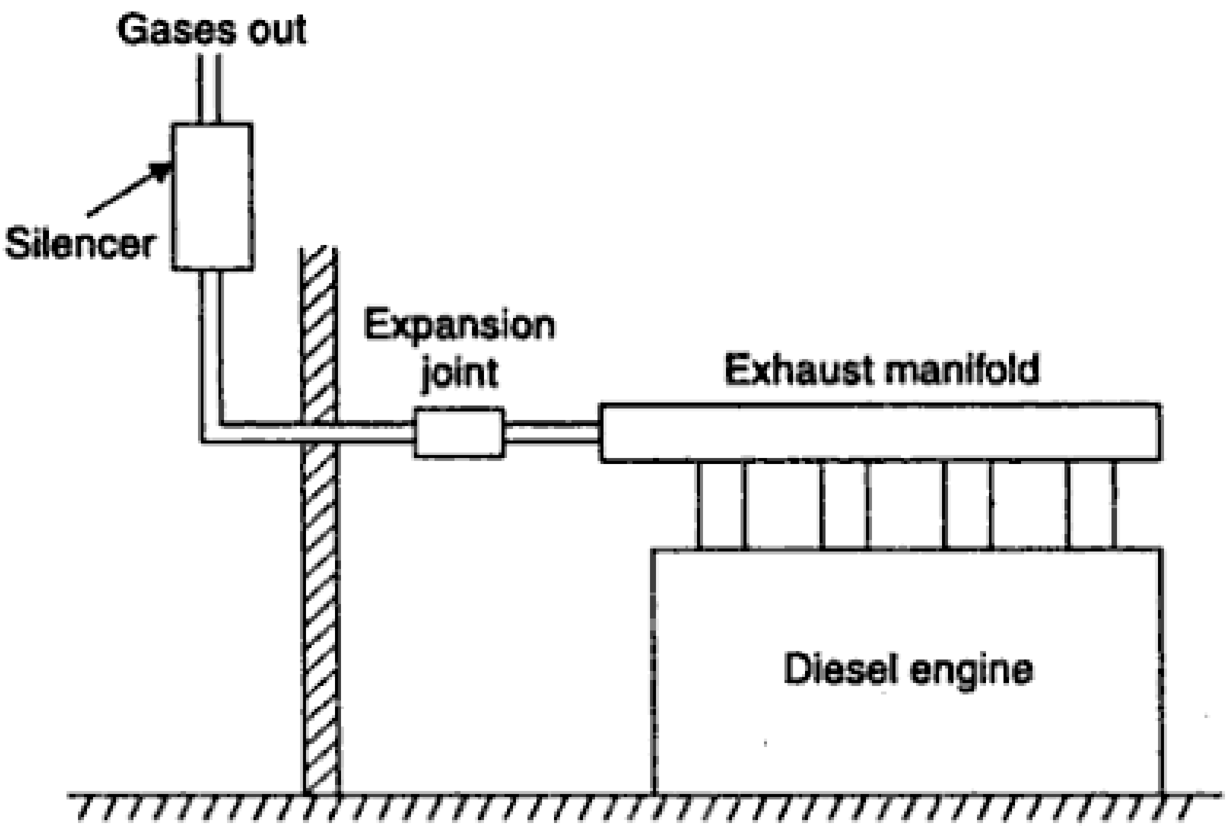
Air intake

- Air is first drawn through a filter to catch dirt or particles that may cause excessive wear in cylinders. Filters may be of following types:
  - Dry type (paper, cloth, felt, glass wool etc)
  - Wet type (oil impingement type, oil bath type where oil helps to catch particles)
- Following precautions should be taken while designing air intake systems
  - Air intake should be located outside the engine room.
  - Air intake should not be located in confined places to avoid undesirable acoustic vibrations.
  - Pressure drop in the air intake line should be minimum to avoid engine starvation.
  - Air filters should be accessible for periodic cleaning.
  - In some cases a muffler may be introduced to prevent engine noise from reaching outside air.

Engine exhaust system

Exhaust system

The exhaust system discharges the engine exhaust to the atmosphere outside the building.



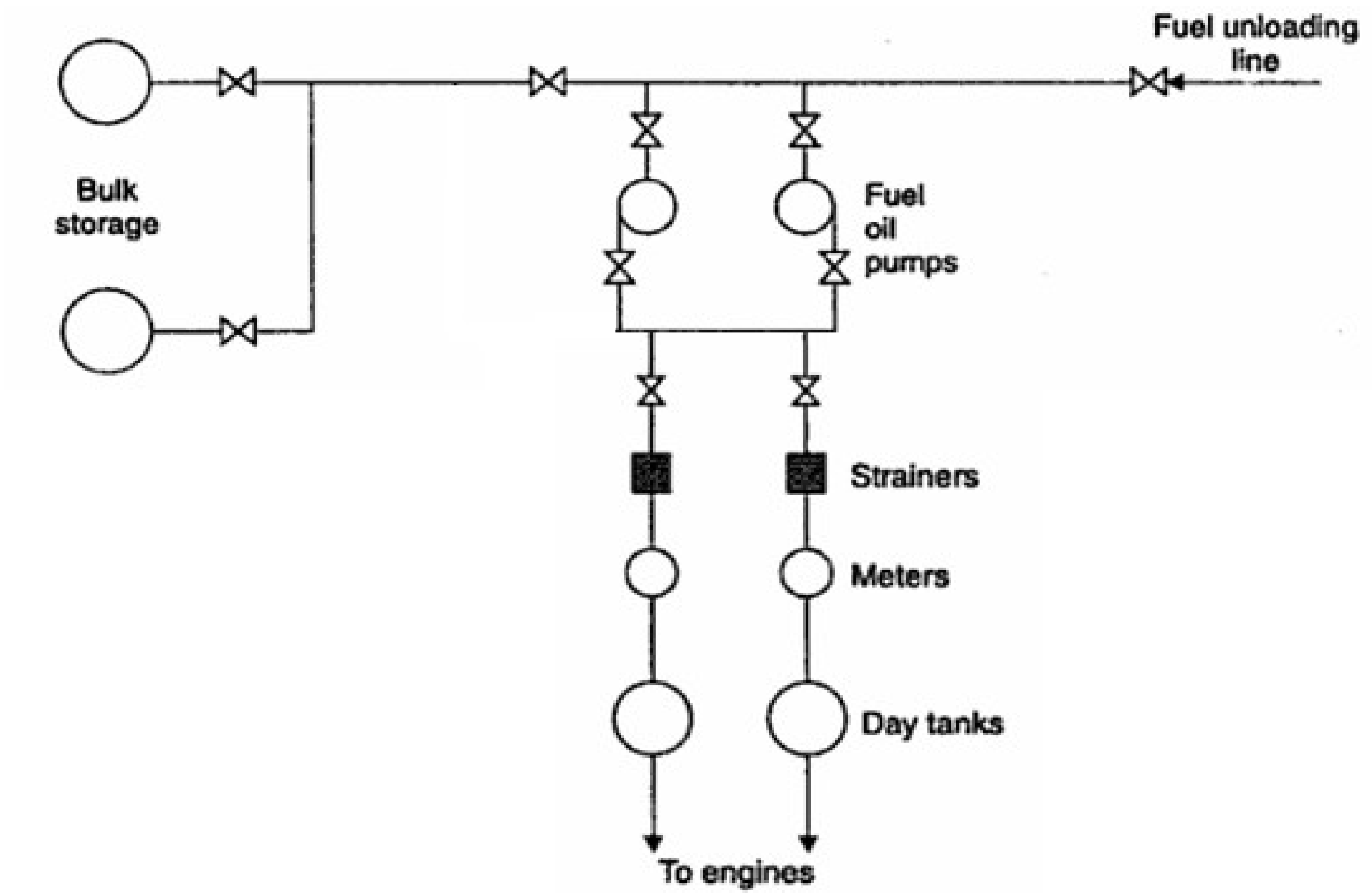
Engine exhaust system

- The exhaust manifold connects the engine cylinder exhausts to the exhaust pipe.
- A muffler in the exhaust pipe reduces the pressure in the line and eliminates most of the noise that may result if exhaust gases are directly discharged to atmosphere.
- Exhaust pipe leading out of the building should be short in length with minimum number of bends to provide as low a pressure loss as possible.
- Flexible tubings may be added in exhaust pipe to take care of misalignments and expansion/contraction and also to isolate the system from engine vibrations.
- Each engine should have its independent exhaust system.
- Where possible, exhaust heat recovery should be made to improve plant thermal efficiency. E.g., air heating, low pressure steam generation in diesel-steam power plant etc.

Fuel system

Fuel system

The fuel system stores and distributes fuel to engines on demand. A generic schematic of fuel system is shown below

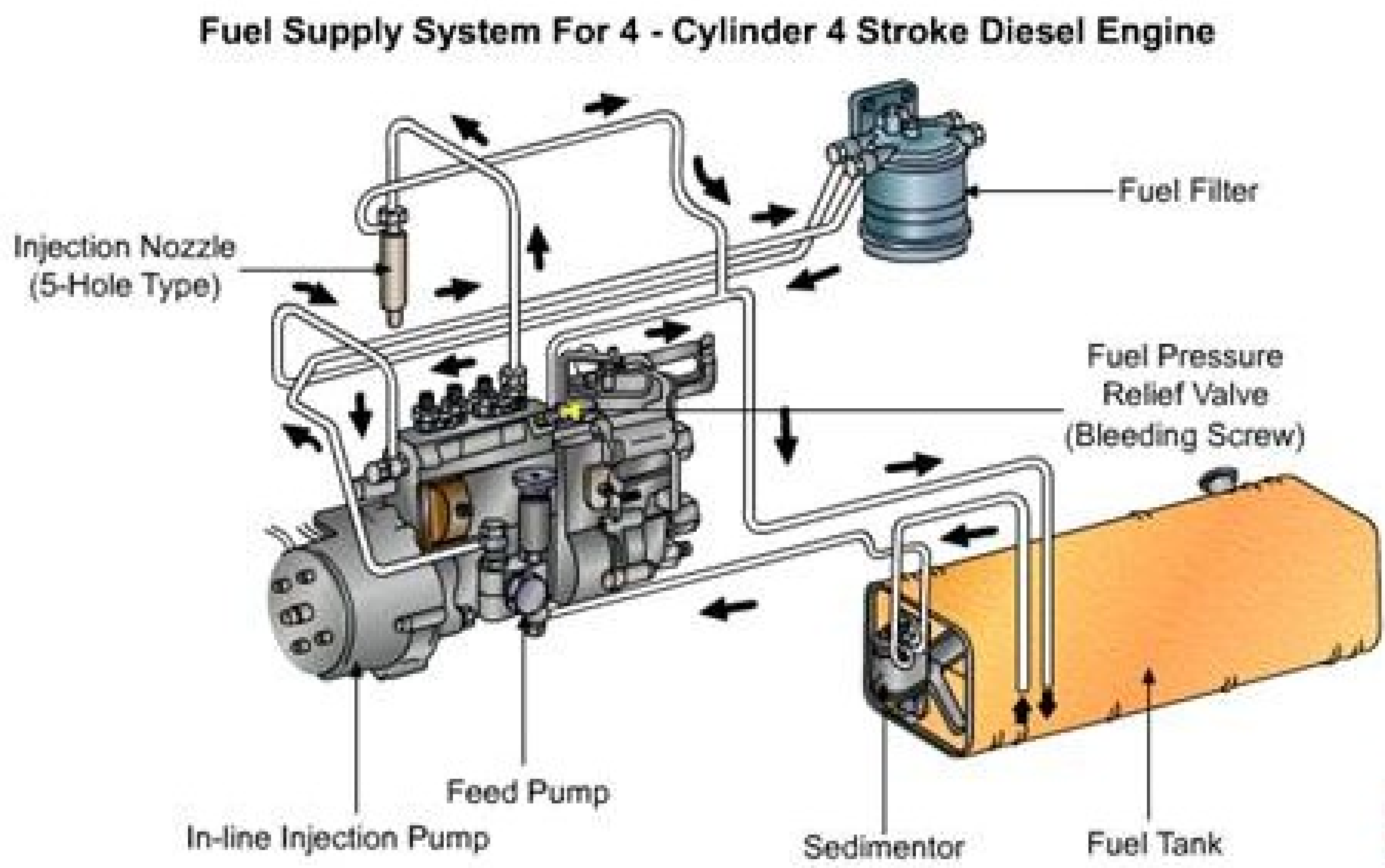


Fuel system

For satisfactory operation of a fuel supply system, following points must be considered:

- **System should be capable of supplying clean and measurable quantity of fuel to engines.**
- **All pipe joints should be pressure tested and leak tight.**
- **Filters should be easily accessible for periodic cleaning.**
- **Safety interlocks should be available to take care of fuel leaks, overpressure and low fuel situations.**
- **Adequate back up components should be available to take care of system failure modes.**

Fuel system



Fuel Supply System For 4 - Cylinder 4 Stroke Diesel Engine
Fuel Filter
Injection Nozzle
(5-Hole Type)
Fuel Pressure
Relief Valve
(Bleeding Screw)
Feed Pump
In-line Injection Pump
Sedimentor
Fuel Tank

Fuel injection systems

Fuel injection systems

Fuel injection system is the heart of the Diesel engine and the performance of the engine is controlled by the efficiency of fuel injection into the cylinder.

The problem of metering, injecting, atomizing and mixing with air for combustion becomes acute with high speed engines. However, engines driving electrical generators are low speed engines and they have simple combustion chambers.

Functions of a fuel injection system

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

Fuel injection systems

Types of fuel injection systems

Following fuel injection systems are commonly used in Diesel power stations.

- **Common-rail injection system**
- **Individual pump injection system**
- **Distributor injection system**

Atomisation of fuel can be accomplished in two ways:

- **Air blast**
- **Pressure spray**

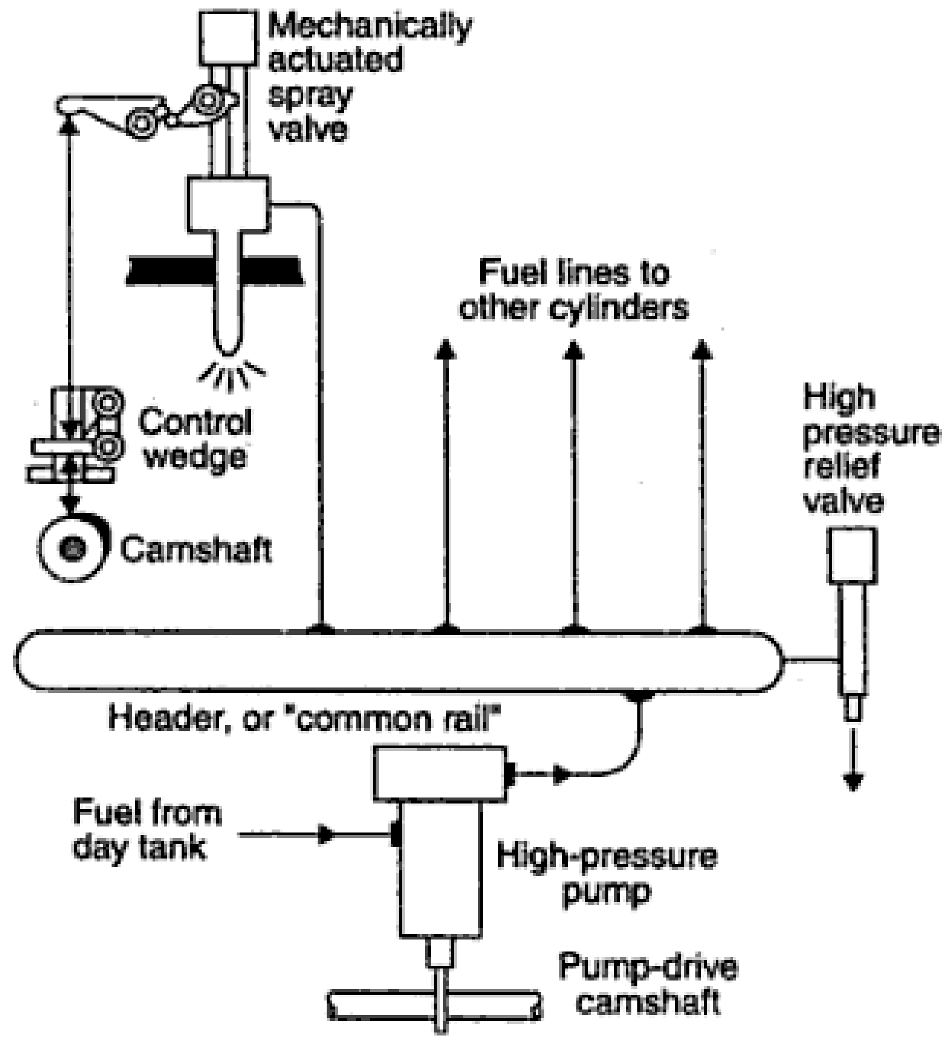
Early diesel engines used air-fuel injection at about 70 bar pressure. But it called for a separate compressor for air supply. Present day practice is to use a fuel pressure between 100 and 200 bar to atomise the fuel as it flows through the spray nozzles.

Fuel injection systems

Common Rail Injection System (Type-1)

One type of common rail fuel injection system is shown here.

- A single pump supplies high pressure (100 – 200 bar) fuel to a header
- A relief valve on header maintains constant pressure
- Quantity of fuel injected and time of injection are dictated by a control wedge that adjusts the lift of a mechanically operated valve.

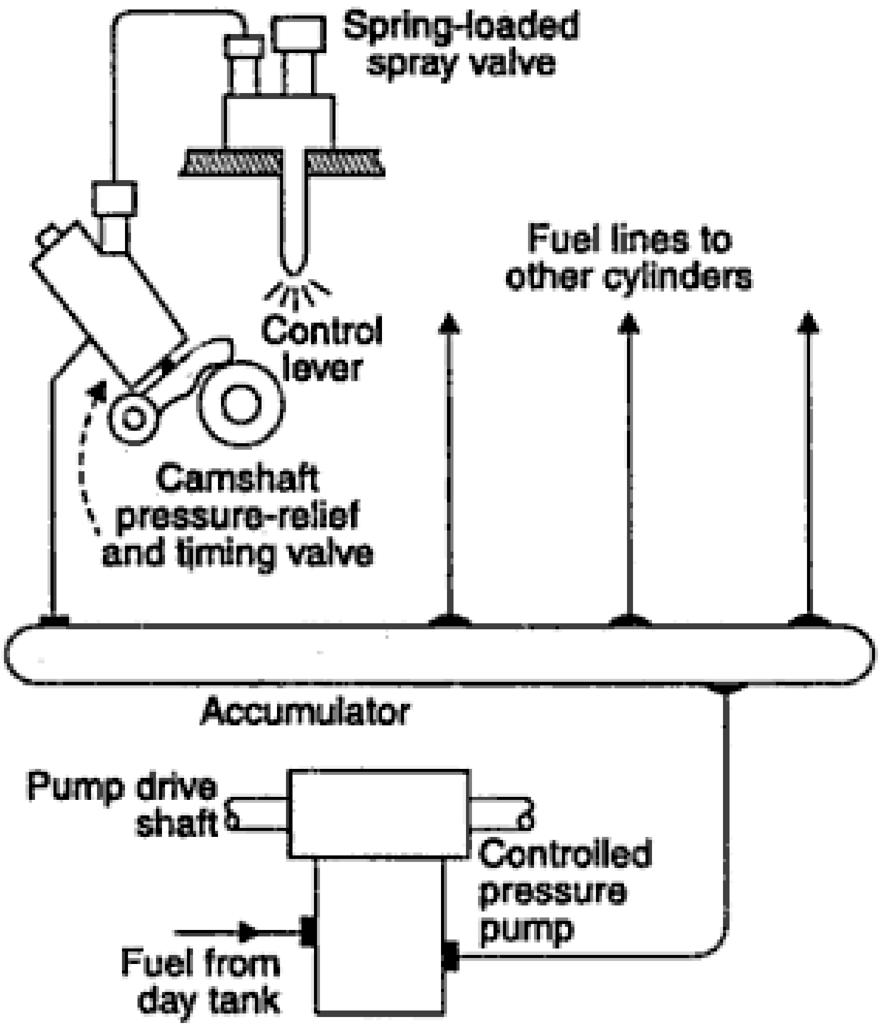


Fuel injection systems

Common Rail Injection System (Type-2)

A second type of common rail fuel injection system is shown here.

- **A single pump supplies high pressure (100 – 200 bar) fuel to an accumulator**
- **Pressure relief and timing valves regulate injection time and amount**
- **Spring loaded spray valves merely act as check valves**

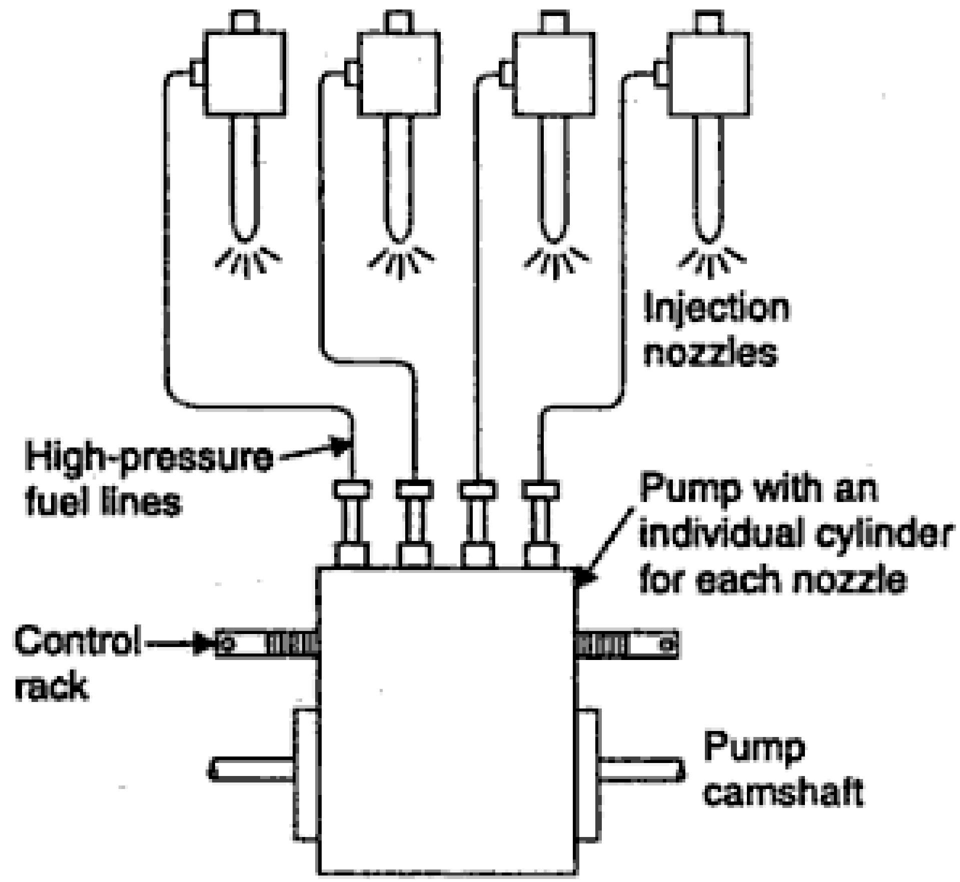


Fuel injection systems

Individual pump Injection System

The schematic is shown here.

- An individual pump or pump cylinder connects directly to each fuel nozzle.
- Metering and injection timing controlled by individual pumps
- Nozzle contains a delivery valve actuated by the fuel pressure

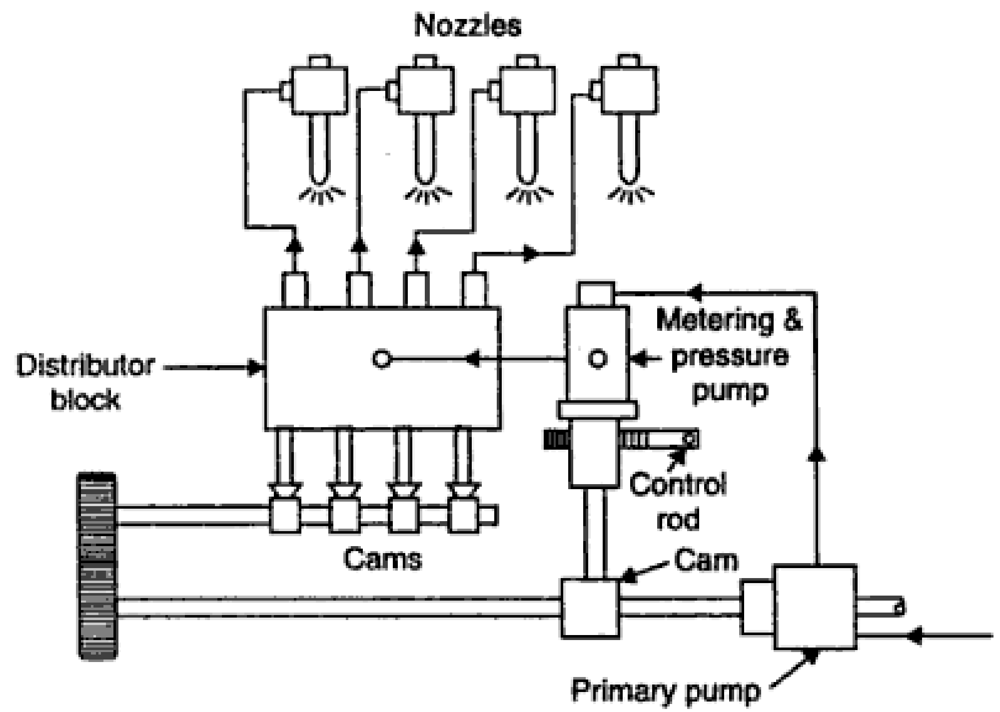


Fuel injection systems

Distributor System

The schematic is shown here.

- **The fuel is metered at a central point**
- **A pump meters, pressurises and times the fuel injection**
- **Fuel is distributed to cylinders in correct firing order by cam operated poppet valves which admit fuel to nozzles**



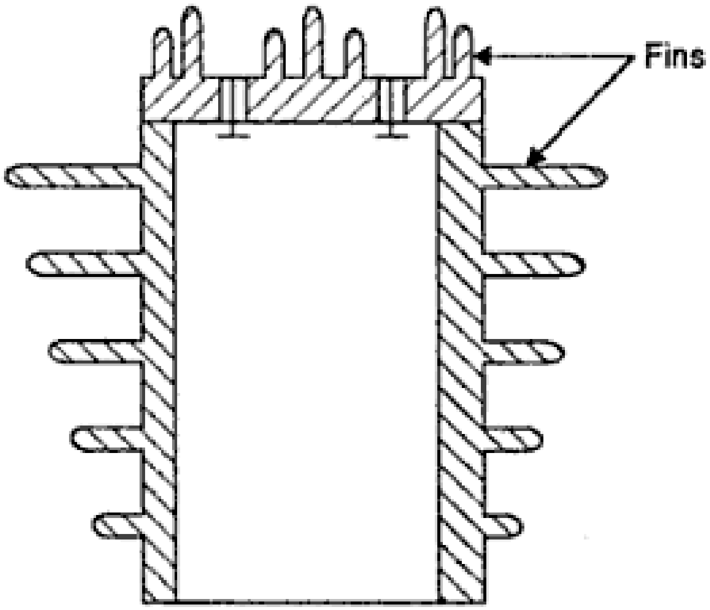
Cooling systems

Engine cooling is necessary for the following reasons:

- **The temperature of combustion gases inside the cylinder can reach 2750℃. If there is no external cooling, average temperature of cylinder and piston can be as high as 1000° to 1500℃ which may melt them.**
- **Lubricating oils have an operating temperature range of 160° to 200℃. Above these temperatures, oil will burn and carbon deposition will occur. In other words, lubrication will no longer be effective.**
- **Strength of materials of construction decreases with increase in temperature and there is a limiting temperature for every material beyond which the material becomes too weak for the intended application.**
- **Hot exhaust valves can result in pre-ignition and detonation or knocking.**
- **High cylinder head temperature can reduce volumetric efficiency and hence the power output.**

Cooling systems

- Almost 25% to 35% of total heat supplied in the engine is removed by the cooling medium. An additional 3% to 5% heat loss occurs through lubricating oil and radiation.
- There are two methods of cooling I.C. engines:
    1. Air cooling
    2. Liquid cooling



Air cooling : In this method, heat is carried away by the air flowing over and around the cylinder. Fins are added on the cylinder which provide additional mass of material for conduction as well as additional area for convection and radiative modes of heat transfer.

Advantages of air cooling

- Simpler engine design as no liquid coolant jackets are needed.
- Absence of cooling pipes and radiator makes cooling system simpler.
- No danger of coolant leakage etc.
- Engine is not subjected to problems associated with frozen coolant during winter as is the case with water cooled engines.
- For a given power, the weight of an air cooled engine is less than that of a liquid cooled engine.
- Engine is self contained and easier to install.

Disadvantages of air cooling

- Noisy movement
- Non uniform cooling
- Output of an air cooled engine is less than that of a liquid cooled engine.
- Smaller useful compression ratio
- Maintenance is not easy
- Not practical for diesel engines

Cooling systems

Liquid cooling : In this method, the cylinder walls and head are provided with jackets through which the cooling liquid can circulate.

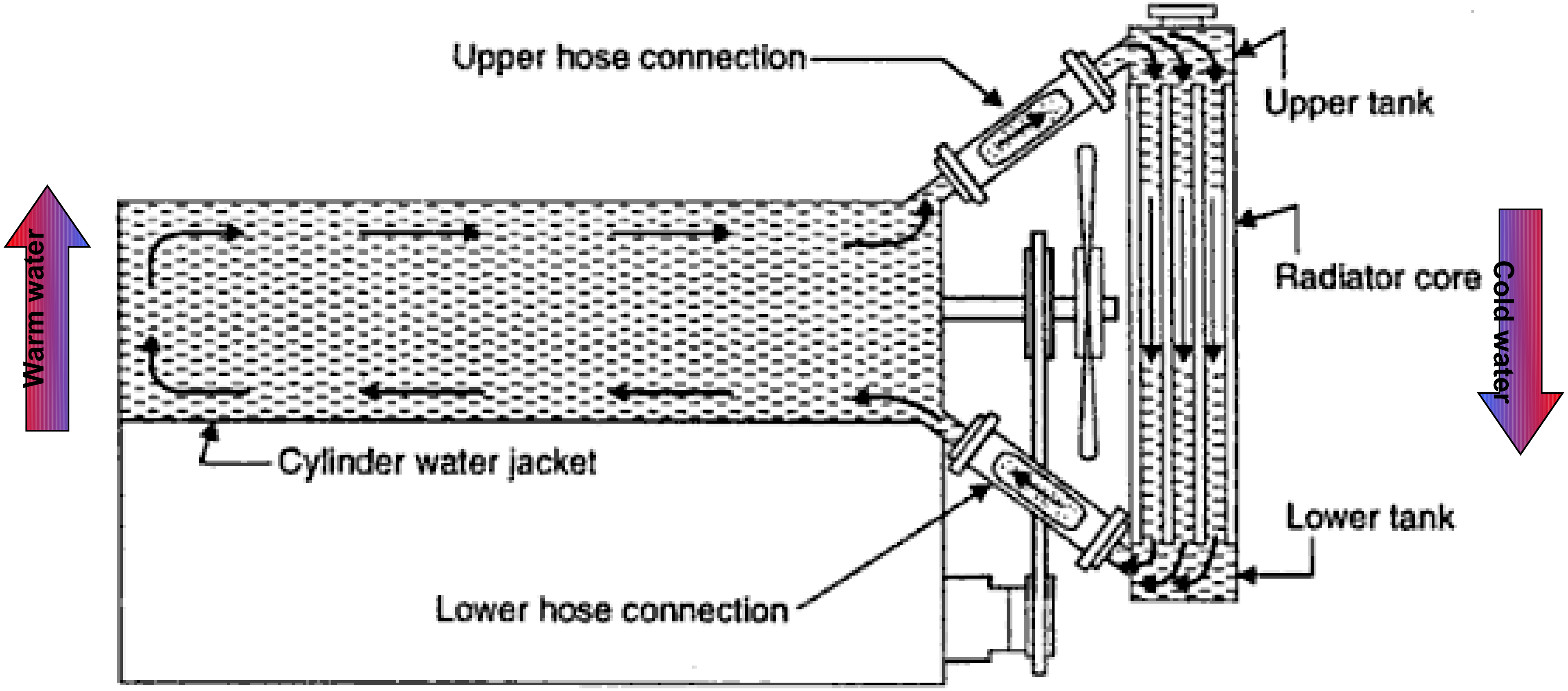
- **The heat is transferred from the cylinder walls to the liquid by convection and conduction.**
- **The liquid gets heated during its passage through the cooling jackets and is itself cooled by means of an air cooled radiator system. The heat from liquid in turn is transferred to air.**

There are several methods of circulating coolant liquid around the cylinder walls and head:

- **Thermo-syphon cooling**
- **Forced or pump cooling**
- **Cooling with thermostatic regulator**
- **Pressurised cooling**
- **Evaporative cooling**

Cooling systems

Thermo-syphon cooling : In this method works on the fact that water becomes lighter with increase in temperature.



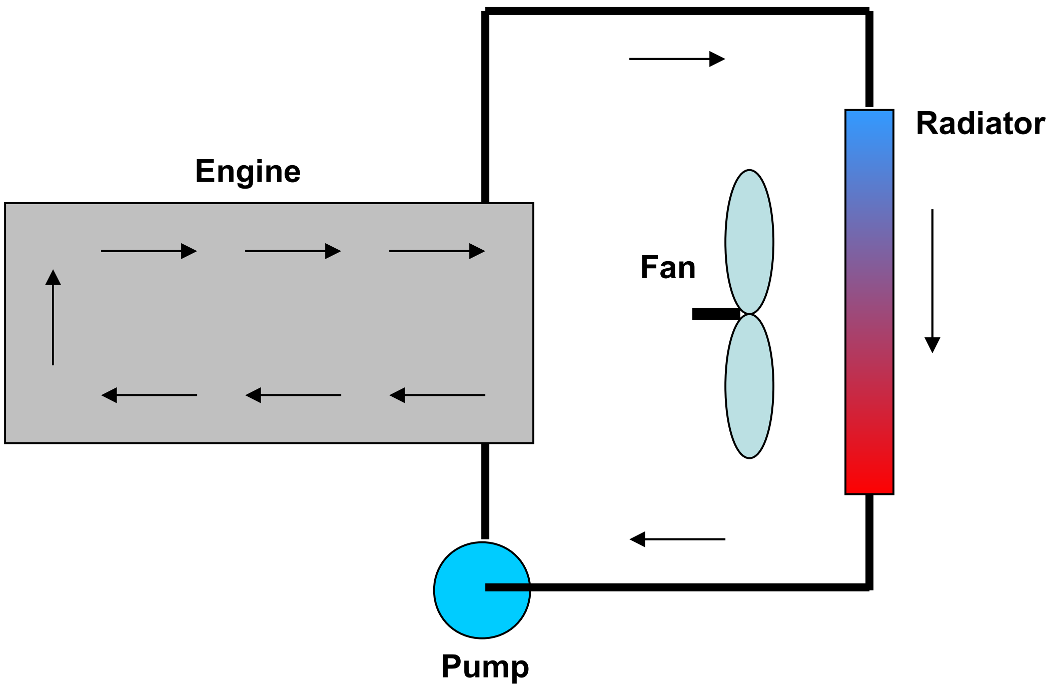
Cooling systems

Thermo-syphon cooling : Schematic of a thermo-syphon cooling system is shown in the previous slide.

- **Top and bottom ends of radiator are connected to the top and bottom water jackets of the engine.**
- **Water travels down the radiator across which air is passed to cool it.**
- **Air flow across the radiator can be due to the motion of the vehicle or by a fan.**
- **The system is simple and works on the basis of convective currents of water – hot water raises within the engine water jacket due to reduction of density and cold water drops down in the radiator due to increase in density.**
- **Disadvantage is that the cooling depends only on temperature differences and not on engine speed.**
- **Circulation of water starts only after the engine begins to work**

Cooling systems

Forced or Pump cooling : In this method, a pump is used to cause circulation of coolant in the water jacket of the engine. The pump is usually belt driven from the engine.



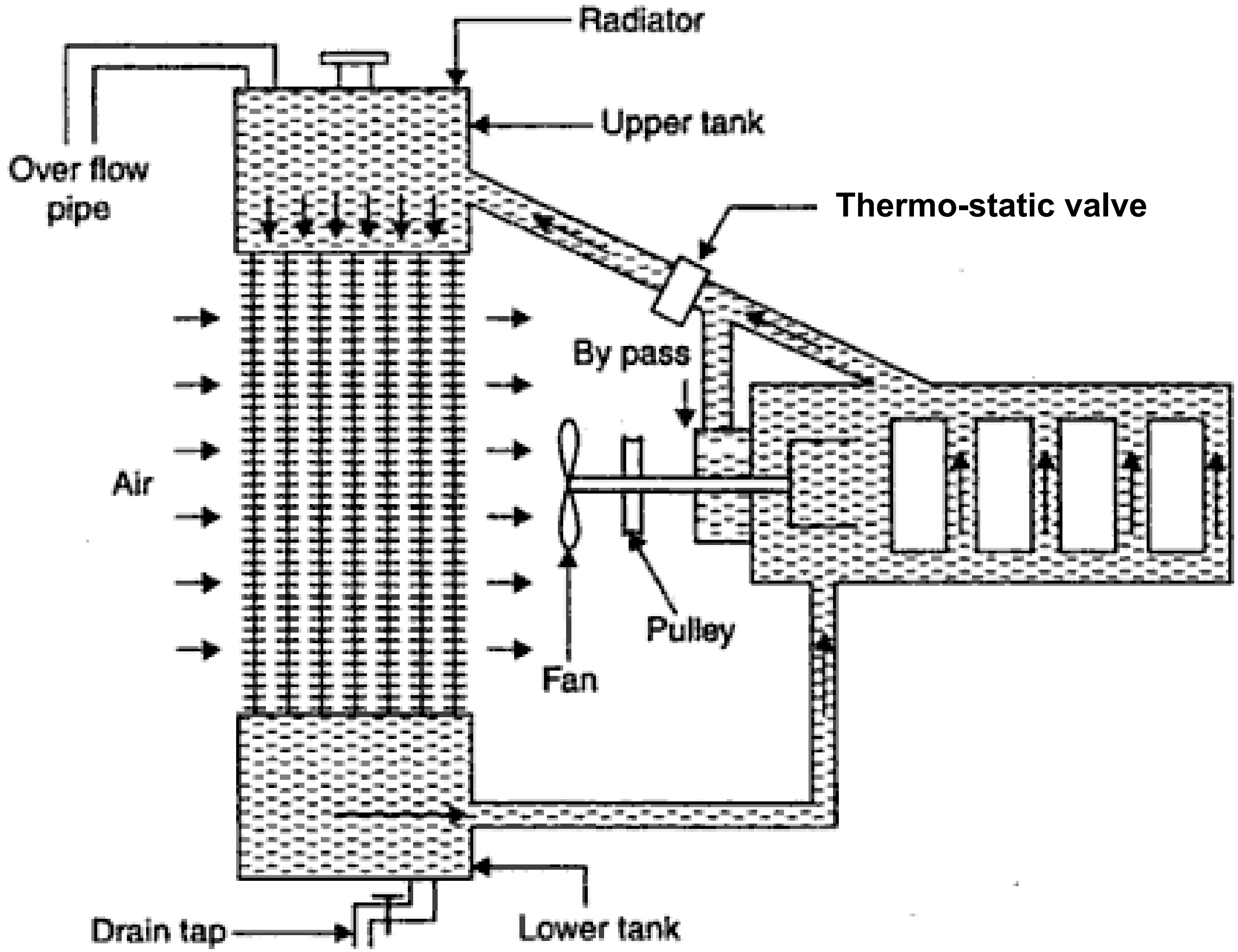
Cooling systems

Forced or Pump cooling : Schematic of a forced pump cooling system is shown in the previous slide.

- **Advantage of this system is that cooling is ensured under all conditions of operation.**
- **The system has following disadvantages:**
  - **Cooling is independent of temperature. This may result overcooling the engine.**
  - **While moving uphill, cooling requirement is more but the coolant circulation may reduce because of reduced engine speed. This may result in overheating of engine.**
  - **Cooling stops as soon as engine stops. Residual heat in engine can cause overheating. This is undesirable as cooling should continue until engine reaches normal temperature.**

Cooling systems

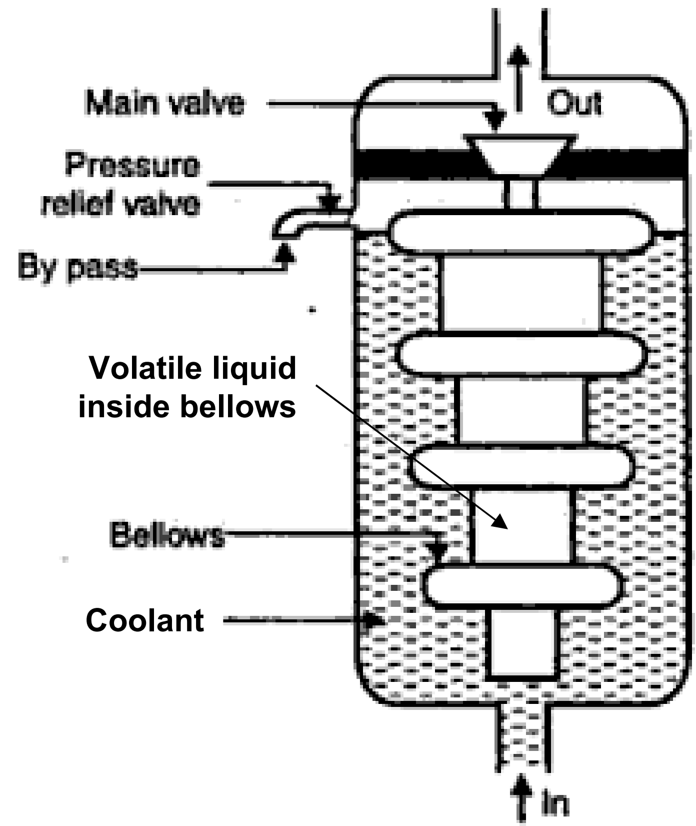
Cooling with thermostatic regulator :A thermostat is a temperature controlling device used to stop flow of coolant below a preset cylinder barrel temperature.



Cooling systems

Cooling with thermostatic regulator :

- Modern cooling systems employ thermostatic valves to prevent coolant in the engine jacket from circulating through radiator for cooling until its temperature has reached a value suitable for efficient engine operation.
- A thermostat consists of thin copper bellows filled with volatile liquid like ether or ethyl alcohol.
- The volatile liquid changes to vapour at the correct working temperature, thus creating enough pressure to expand the bellows.
- The movement of the bellows opens the main valve in proportion to the temperature, thus increasing or decreasing the flow of coolant from engine to radiator
- When the thermostat valve is not open, engine operation raises the coolant pressure. This opens the bypass pressure relief valve to maintain coolant circulation within the engine block.



Cooling systems

Pressurised cooling : This system employs high pressure coolant to increase its boiling point and thereby increased heat transfer.

- The boiling point of the coolant can be increased by increasing its pressure. This allows a greater heat transfer to occur in the radiator due to larger temperature differential between radiator and ambient.

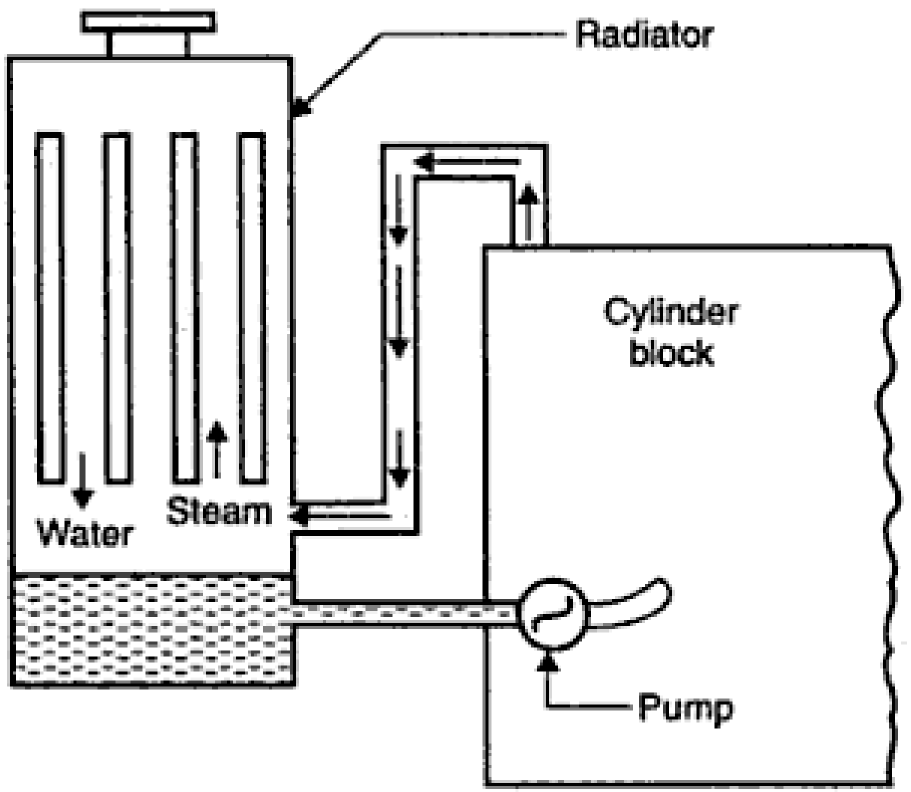
- Usually the coolant pressure is maintained between 1.5 and 2 bar.

- Pressurised cooling system requires an additional valve called “vacuum valve” to avoid formation of vacuum when the coolant temperature drops on shutting down the engine.

- A safety valve in the form of pressure relief valve is provided on the radiator top tank so that whenever the radiator cap is opened, the pressure is immediately relieved.

Cooling systems

Evaporative cooling : In this system, also called steam or vapour cooling, the temperature of cooling water is allowed to reach 100°C. This type of cooling utilises the high latent heat of vapourisation of water to obtain cooling with minimum water. In this system, the coolant is always liquid but the steam formed is flashed off in a separate vessel to condense.



Advantages of liquid cooling

- Compact design of engine with minimal frontal area.
- Fuel consumption of a high compression liquid cooled engine is lower than that for an air cooled engine.
- Uniform cooling of cylinder barrels and heads due to jacketing. Easier to reduce temperatures of cylinder head and valve seating.
- Cooling system can be conveniently located anywhere, while for air cooled engines, installation is necessarily at the front end of mobile vehicles.
- Very effective for high horse power engines compared to air cooled systems which need large quantity of air for cooling.

Disadvantages of liquid cooling

- A dependent system which requires water / coolant for circulation in the jacket.
- Power absorbed by coolant pumps is considerably higher than that for cooling fans.
- In the event of failure of cooling system, serious damage may be caused to the engine.
- System is complex due to coolant jackets, pump, pipes, radiator etc.
- Cost of the system is considerably high compared to air cooled systems.
- Requires periodic maintenance.

Lubrication systems

Lubrication is the admittance of oil or grease between two surfaces having relative motion to reduce friction. The purpose of lubrication may be one or more of the following:

- **To reduce friction and wear between parts having relative motion.**
- **To cool the surfaces by carrying away heat generated due to friction.**
- **To seal a space against leakage, such as space between piston rings and cylinder liner.**
- **To clean the surfaces by carrying away carbon and metal particles caused by wear.**
- **To absorb shock between bearings and other parts, consequently reduce noise.**

Lubrication systems

Main parts of an engine requiring lubrication are:

1. Main crankshaft bearings
2. Connecting rod big end bearing
3. Connecting rod small end or gudgeon pin bearing
4. Piston rings and cylinder walls
5. Timing gears
6. Valve mechanism
7. Valve guides, valve tappets and rocker arms

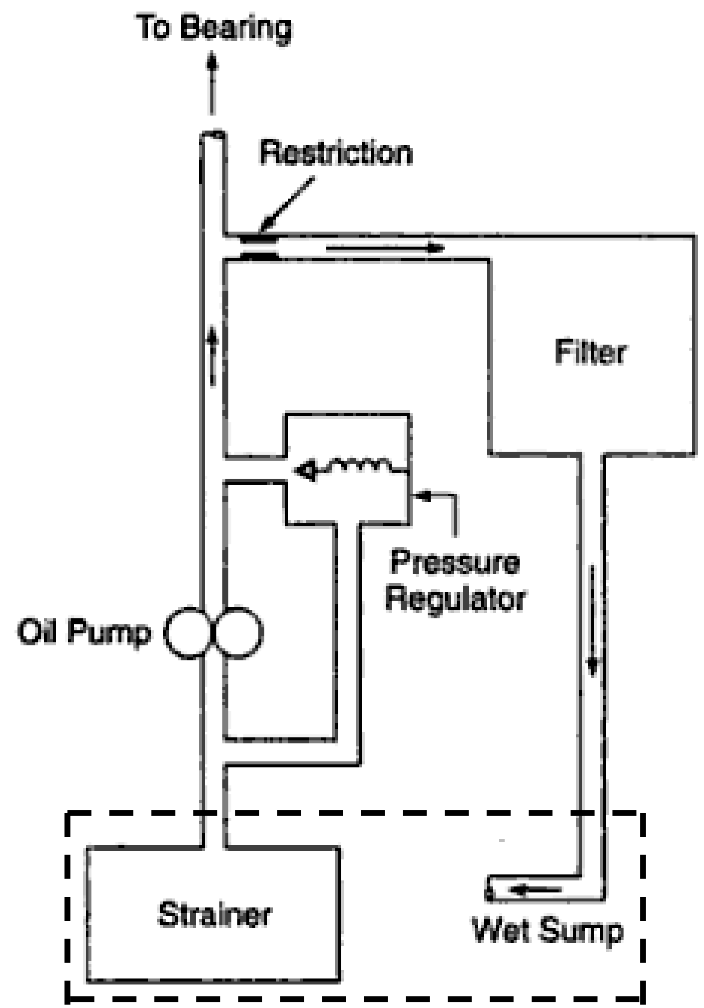
Classification of lubrication systems

Lubrication systems used for I.C. engines may be classified as follows:

1. Wet sump lubrication system
2. Dry sump lubrication system
3. Mist lubrication system

Wet sump lubrication system:

This system uses a large capacity oil sump at the base of crank chamber, from which the oil is drawn by a low pressure oil pump and delivered to various parts. Oil then returns back to the sump after serving the purpose.

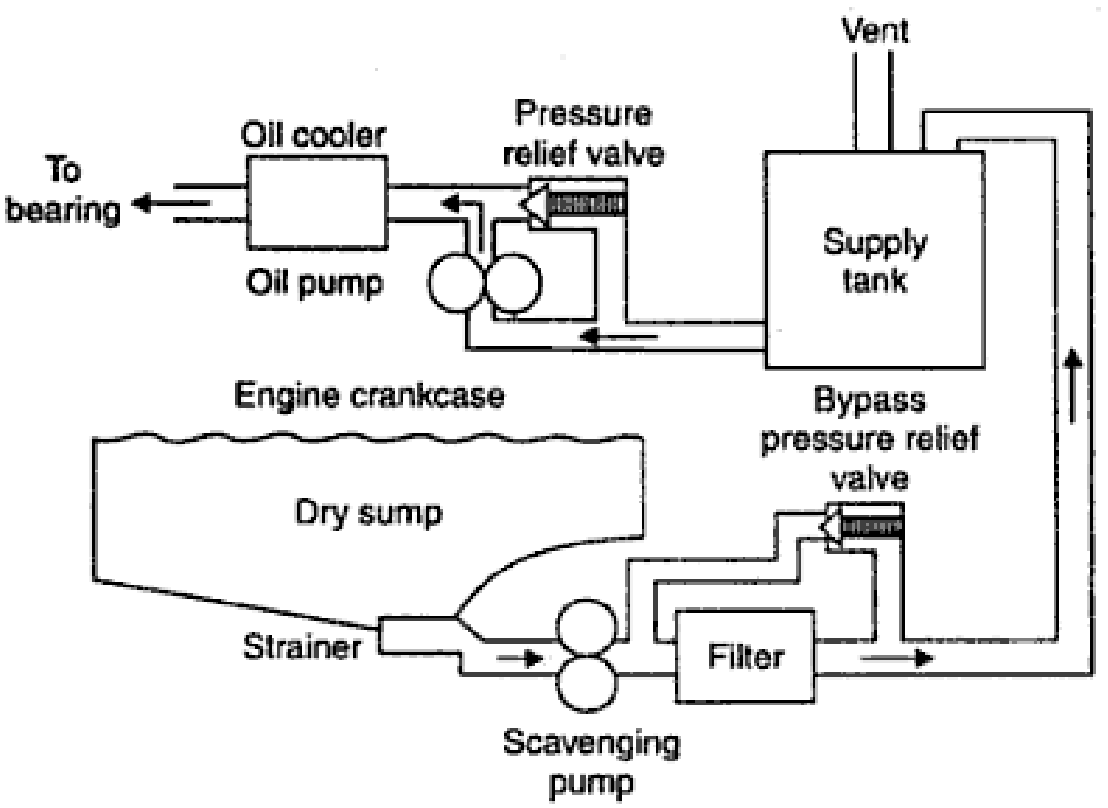


Wet sump lubrication system

Classification of lubrication systems

Dry pump lubrication system:

Oil from the sump is carried to a separate storage tank outside the cylinder block. Oil from the sump is pumped to storage tank by a scavenging pump. Oil from the storage tank is pumped to the engine cylinder through another pump and oil cooler. Oil pressure varies from 3 to 8 bar. This type of lubrication is generally adopted for high capacity engines.



Classification of lubrication systems

Mist lubrication system:

- This system is used for 2-stroke engines.
- Most of these engines are crank charged i.e., they employ crank case compression and therefore, are not suitable for crank case lubrication.
- These engines are lubricated by adding 2 to 3% lubricating oil in the fuel tank.
- The oil and fuel mixture is induced through the carburettor.
- The gasoline is vapourised and the oil in the form of mist, goes via crank case into the cylinder.
- The oil, which impinges on the crank case walls, lubricates the main and connecting rod bearings, and the rest of the oil which passes in to the cylinder during charging and scavenging periods, lubricates the piston, piston rings and the cylinder.

Mist Lubrication systems

Advantages:

- System is simple
- Low cost because of absence of pumps, filters etc.

Disadvantages:

- A portion of the lubricating oil invariably burns in the combustion chamber. This results in smoky exhaust, carbon deposits on piston crown, ring grooves and exhaust port, reducing engine efficiency.
- Since the oil comes in contact with acidic vapours produced during combustion, it loses its anti corrosion property and can lead to corrosion of bearings.
- For effective lubrication, oil and fuel must be thoroughly mixed. This requires separate mixing prior to use or special additives to give good mixing characteristics.
- Unless there is a good control on the lubricating oil, 2-stroke engines may run “over oiled”.

Engine starting systems

There are three common methods of starting I.C. engines:

1. Starting by an auxiliary engine
2. Use of electric motors or self starters
3. Compressed air system

Starting by an auxiliary engine (normally petrol driven):

- An auxiliary engine is closely mounted to the main engine and connected through clutch and gears.
- At first, the clutch is disengaged and the auxiliary engine is started (by hand or via self starter).
- After auxiliary engine warms up, the drive gear is engaged through the clutch and the main engine is cranked for starting.
- An overrunning clutch is used to avoid damage to auxiliary engine after the main engine starts.

Engine starting systems

Use of electric motors or self starters:

- Used for small Diesel or Petrol engines
- A storage battery of 12V to 36V is used to drive an electric motor.
- The electric motor is geared to the flywheel with a provision for automatic disengagement after the engine has started.
- The motor draws heavy current and is designed to work continuously for a short period of time (typically 30 seconds).
- When the engine is running normally, a small d.c. generator on the engine serves to charge the battery.

Engine starting systems

Use of compressed air system:

- Compressed air system is commonly used for starting large diesel engines employed for stationary power plants.
- Compressed air is stored at about 17 bar pressure in separate air tanks.
- This compressed air is initially supplied to a few of the engine cylinders, making them work like reciprocating air motors to run the engine shaft.
- Fuel is admitted to the remaining cylinders and ignition takes place in the normal way causing the engine to start.
- The air tank is charged by a separate or engine driven compressor.
- The system includes air storage tank, safety valves and interconnecting pipes.

Method of starting and stopping engines

Starting of engines:

- In case of an electric motor starting, check the condition of battery. If compressed air is used, check the air system for any possible leaks.
- Check the engine fuel system, lubrication system and cooling system for their proper functions.
- Crank the engine after ensuring that all load is pit off and the decompression (if available) device is engaged.
- Once the engine starts, run the engine at low speed for a few minutes and observe the working of fuel, lubrication and cooling systems.
- Increase the speed gradually till it synchronises with the station bus bar.
- Connect the generator to the bus bar when it is in synchronisation and increase the engine speed till it begins to share the desired load.

Method of starting and stopping engines

Stopping of engines:

- **Reduce the speed of the engine gradually until practically no power is delivered by the generator.**
- **Disconnect the unit from the bus and allow the engine to idle for a few minutes and stop it in conformity with manufacturer's instructions.**

Governing system:

- **The function of the governing system is to maintain the speed of the engine constant irrespective of the load on the plant. This is generally done by gradually decreasing the fuel supply to the engine.**