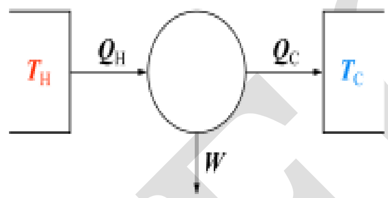
***Syllabus:- Module-IV (EST120 Part-2 BASICS OF MECHANICAL ENGINEERING)***

*Analysis of thermodynamic cycles: Carnot, Otto, Diesel cycles, Derivation of efficiency of these cycles, Problems to calculate heat added, heat rejected, net work and efficiency. IC Engines: CI, SI, 2- Stroke, 4-Stroke engines. Listing the parts of different types of IC Engines. Efficiencies of IC Engines (Definitions only), Air, Fuel, cooling and lubricating systems in SI and CI Engines, CRDI, MPFI. Concept of hybrid engines.*

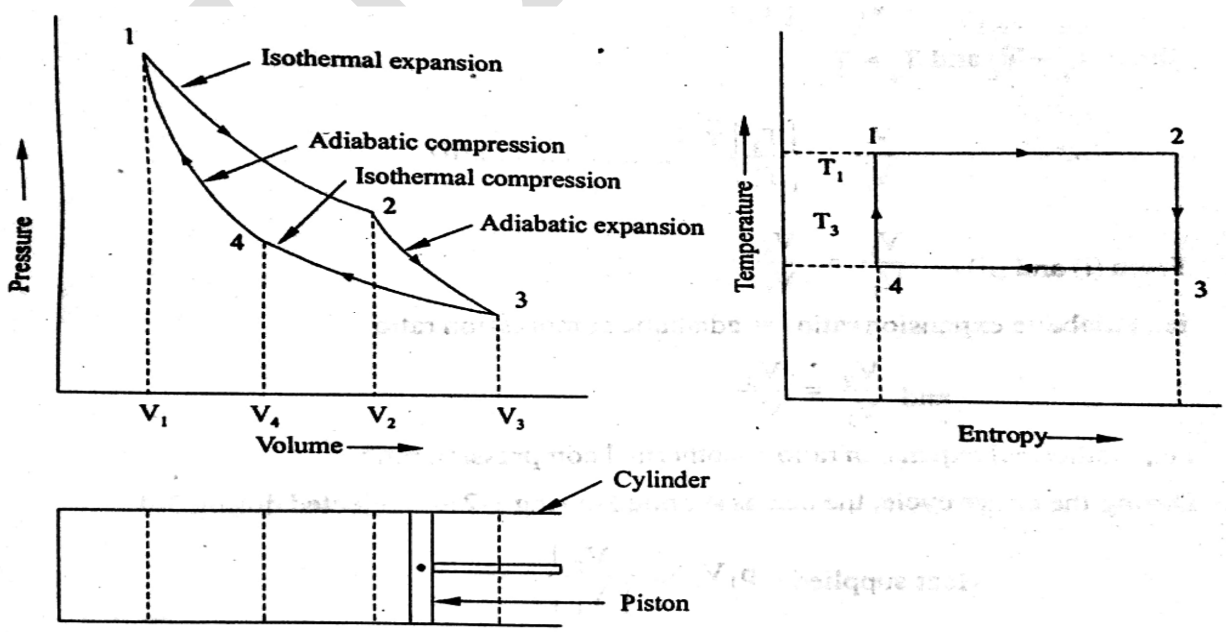
**AIR STANDARD CARNOT CYCLE**

The Carnot cycle is a theoretical thermodynamic cycle proposed by French physicist Sadi Carnot in 1824.




The Carnot cycle when acting as a heat engine consists of the following steps

- Reversible isothermal expansion
- Isentropic (reversible adiabatic) expansion
- Reversible isothermal compression
- Isentropic compression



For the adiabatic expansion process 2-3,

$$\frac{V_3}{V_2} = \left\{\frac{T_2}{T_3}\right\}^{\frac{1}{\gamma-1}} \quad \text{.......................(i)}$$

For the adiabatic compression process 4-1,

$$\frac{V_4}{V_1} = \left\{\frac{T_1}{T_4}\right\}^{\frac{1}{\gamma-1}}$$

Since $T_1 = T_2$ and $T_4 = T_3$

$$\frac{V_4}{V_1} = \left\{\frac{T_2}{T_3}\right\}^{\frac{1}{\gamma-1}} \quad \text{........................(ii)}$$

From (i) and (ii) $\quad \dfrac{V_3}{V_2} = \dfrac{V_4}{V_1}$

ie., adiabatic expansion ratio = adiabatic compression ratio

and $\dfrac{V_2}{V_1} = \dfrac{V_3}{V_4}$

i.e., isothermal expansion ratio = isothermal compression ratio.

During the entire cycle, the heat is supplied during 1-2 and rejected during 3-4

$$\text{Heat supplied} = p_1 V_1 \ln\left\{\frac{V_2}{V_1}\right\}$$

$$= mRT_1 \ln\left\{\frac{V_2}{V_1}\right\}$$

$$\text{Heat rejected} = p_3 V_3 \ln\left\{\frac{V_3}{V_4}\right\}$$

$$= mRT_3 \ln\left\{\frac{V_3}{V_4}\right\}$$

Air standard efficiency, $\quad \eta = \dfrac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}}$

$$= \frac{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\} - mRT_3 \ln\left\{\frac{V_3}{V_4}\right\}}{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\}}$$

$$\eta = \frac{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\} - mRT_3 \ln\left\{\frac{V_2}{V_1}\right\}}{mRT_1 \ln\left\{\frac{V_2}{V_1}\right\}}$$

$$= \frac{mR \ln\left\{\frac{V_2}{V_1}\right\}(T_1 - T_3)}{mR \ln\left\{\frac{V_2}{V_1}\right\} \times T_1}$$

$$= \frac{(T_1 - T_3)}{T_1}$$

$$\text{or} \quad \eta = 1 - \frac{T_3}{T_1} = 1 - \frac{\text{Temperature of cold body}}{\text{Temperature of hot body}}$$

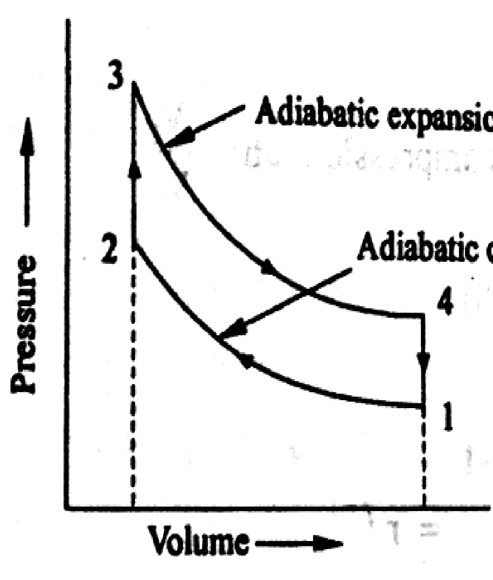
**Generally the temperature of hot body is taken as $T_1$ and that of cold body is taken as $T_2$.**

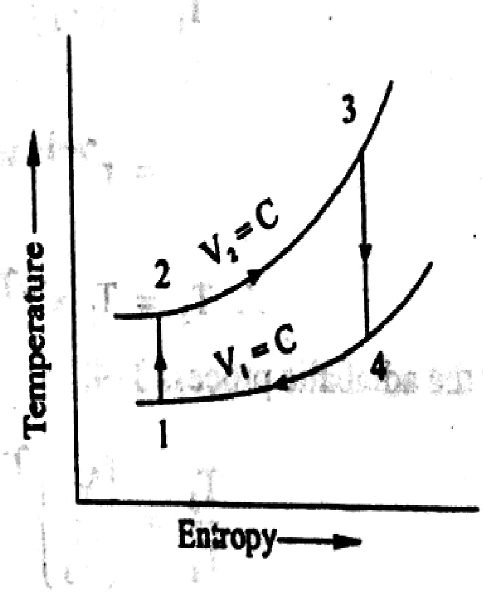
$$\text{Then,} \quad \eta = 1 - \frac{T_2}{T_1}$$

**OTTO CYCLE**

The Otto cycle is a set of processes used by spark ignition internal combustion engines (2-stroke or 4-stroke cycles).

These engines a) ingest a mixture of fuel and air, b) compress it, c) cause it to react, thus effectively adding heat through converting chemical energy into thermal energy, d) expand the combustion products, and then e) eject the combustion products and replace them with a new charge of fuel and air.



**Heat supplied during constant volume process, 2 - 3 = $mC_v(T_3 - T_2)$**

**Heat rejected during constant volume process, 4 - 1 = $mC_v(T_4 - T_1)$**

**Air standard efficiency,**

$$\eta = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

$$= 1 - \frac{mC_V(T_4 - T_1)}{mC_V(T_3 - T_2)}$$

$$= 1 - \left\{\frac{T_4 - T_1}{T_3 - T_2}\right\} \text{.................(i)}$$

**For the adiabatic process 1-2,**

$$\frac{T_2}{T_1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1}$$

$$= r^{\gamma-1}, \text{ where r is the compression ratio, } \frac{V_1}{V_2}$$

$$\therefore\ T_2 = T_1 \times r^{\gamma-1} \text{.................(ii)}$$

**For the adiabatic process 3- 4,**

$$\frac{T_3}{T_4} = \left\{\frac{V_4}{V_3}\right\}^{\gamma-1} = \left\{\frac{V_1}{V_2}\right\}^{\gamma-1} = r^{\gamma-1}$$

$$\therefore T_3 = T_4 \times r^{\gamma-1} \text{...........(iii)}$$

**Substituting equations (ii) and (iii) in the expression for efficiency, equation (i),**

$$\eta = 1 - \frac{(T_4 - T_1)}{T_4 r^{\gamma-1} - T_1 r^{\gamma-1}}$$

$$= 1 - \frac{(T_4 - T_1)}{(T_4 - T_1) r^{\gamma-1}}$$

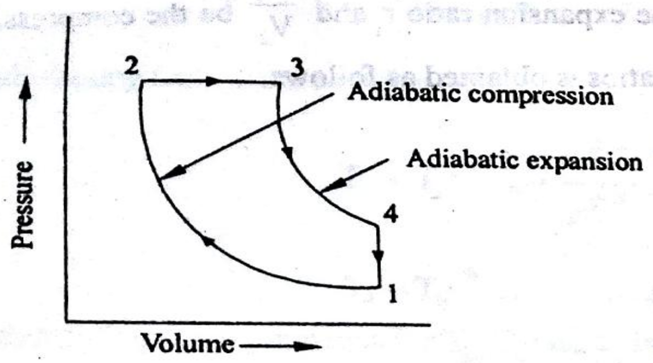
$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

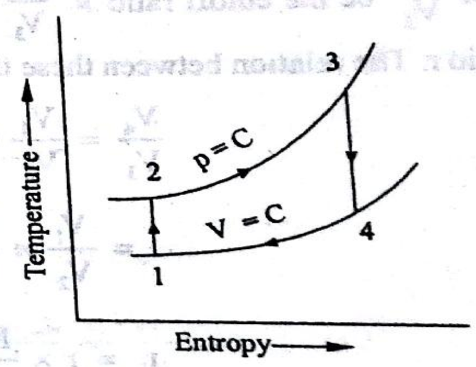
**The above expression shows that the efficiency of Otto cycle increases with increases of the compression ratio.**

**DIESEL CYCLE**

The Diesel cycle is a compression ignition (rather than spark ignition) engine. Fuel is sprayed into the cylinder at (high pressure) when the compression is complete, and there is ignition without a spark.

This cycle can operate with a higher compression ratio than the Otto cycle because only air is compressed and there is no risk of auto-ignition of the fuel. Although for a given compression ratio the Otto cycle has higher efficiency, because the Diesel engine can be operated to higher compression ratio, the engine can actually have higher efficiency than an Otto cycle when both are operated at compression ratios that might be achieved in practice.




**Heat supplied during constant Pressure process 2-3 = m $C_p$ ($T_3$ - $T_2$).**

**Heat rejected during constant volume process 4-1 = m $C_v$ ($T_4$ - $T_1$).**

**Air Standard efficiency,**

$$\eta = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$$

$$= 1 - \frac{mC_V(T_4 - T_1)}{mC_P(T_3 - T_2)}$$

$$= 1 - \frac{C_V}{C_P}\frac{(T_4 - T_1)}{(T_3 - T_2)}$$

$$= 1 - \frac{1}{\gamma} \times \frac{(T_4 - T_1)}{(T_3 - T_2)} \text{ ..................(i)}$$

Let $\frac{V_3}{V_2}$ be the cutoff ratio $\rho$, $\frac{V_4}{V_3}$ be the expansion ratio $r_1$ and $\frac{V_1}{V_2}$ be the compression ratio r.

**Substituting the expressions for $T_2$, $T_3$ and $T_4$ in equation (i),**

$$\eta = 1 - \frac{1}{\gamma}\frac{T_1\rho^{\gamma} - T_1}{\left(T_1 r^{\gamma-1}\rho - T_1 r^{\gamma-1}\right)}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}} \times \frac{1}{\gamma}\left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right]$$

**The above expression shows that the air standard efficiency of Diesel cycle is a function of compression ratio, cutoff ratio and the ratio of specific heats.**

**INTERNAL COMBUSTION ENGINES (IC ENGINES)**

An Engine is a device which transforms one form of energy into another form. Normally, most of the engines convert thermal energy into mechanical work and therefore they are called as Heat Engines.

**Heat Engine:**

Heat engine is a device which transforms the chemical energy of fuel into thermal energy and utilizes this thermal energy to perform useful mechanical work. Thus thermal energy is converted to mechanical energy in a heat engine.

Heat engines are broadly classified into two types;

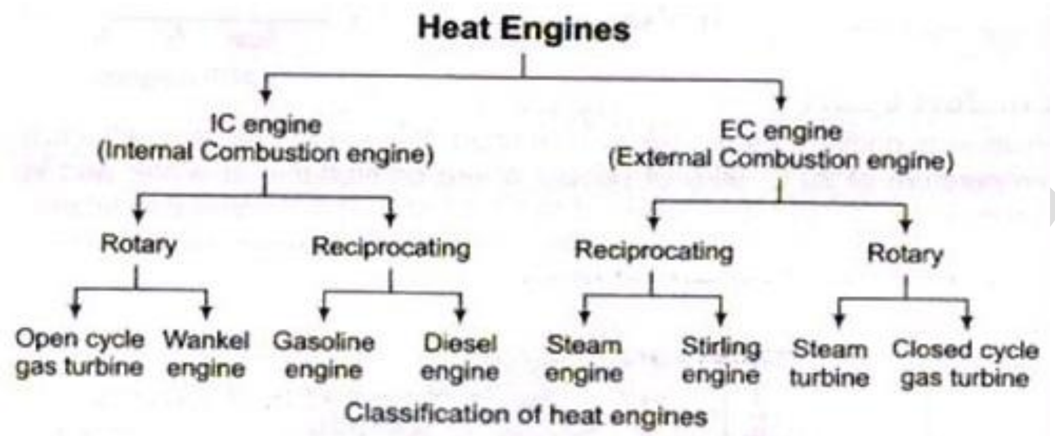
- Internal Combustion Engines (IC Engines)
- External Combustion Engines (EC Engines)

**Internal Combustion Engines (IC Engines):**

In internal combustion engines combustion takes place within the engine. Example: Petrol Engine, Diesel Engine.

**External Combustion Engines (EC Engines):**

In external combustion engines combustion takes place outside the engine. Example: Steam Engine.




Classification of Heat Engines

**CLASSIFICATION OF IC ENGINES**

IC Engines are classified in many ways based on the criterion selected for classification.

1. **Based on the Ignition System:-**

   According to the ignition system employed for igniting the charge in the engine cylinder IC engines are classified as (i) Spark Ignition (SI) engines & (ii) Compression Ignition (CI) engines.

   (i) Spark Ignition (SI) Engine:- In SI engine an electric spark is used for igniting the fuel air mixture. Petrol & gaseous fuel engines are SI engines.

   (ii) Compression Ignition (CI) Engine:- In CI engine, air is compressed to very high temperature and pressure and fuel is injected to it in the form of fine spray. The fuel gets ignited due to the high temperature of the compressed air. Diesel engines are CI engines.

2. **Based on the type of fuel used:-**

   (i) Petrol engine:- In petrol engine highly volatile liquid fuel such as petrol is used.

   (ii) Diesel engine:- In diesel engine less volatile liquid fuel such as diesel is used.

   (iii) Gas engine:- In gas engine gaseous fuel such as methane is used.

3. **Based on the working cycle:-**

   (i) Otto engine:- Otto engine works on the Otto cycle (constant volume cycle). Petrol & gaseous fuel engines works on Otto cycle.

   (ii) Diesel engine:- Diesel engine works on the diesel cycle. Diesel engines works on diesel cycle.

4. **Based on the number of strokes per cycle:-**

   (i) Four stroke engine:- In four stroke engine one cycle of operation is completed in four strokes of the piston. One power stroke is obtained in four strokes of the piston that is in two revolutions of the crank shaft.

(ii) Two stroke engine:- In two stroke engine one cycle of operation is completed in two strokes of the piston. One power stroke is obtained per two strokes of the piston that is in each revolution of the crank shaft.

5. **Based on the application of the engine:-**
   (i) Stationary engines:- Stationary engines are used in power plants.
   (ii) Mobile engines:- Mobile engines are used in automobiles, aircrafts etc.
6. **Based on the cooling system:-**
   (i) Air-cooled engines:- In air-cooled engine, heat is directly dissipated into the air around the cylinder.
   (ii) Water-cooled engines:- In water-cooled engine excess heat is removed from the engine cylinder and cylinder head by circulating water through the jackets provided in the engine cylinder and cylinder head.
7. **Based on the speed of the engine:-**
   (i) Low speed engines:- Engine speed upto 350 rpm.
   (ii) Medium speed engines:- Engine speed between 350 rpm & 1000 rpm.
   (iii) High speed engines:- Engine speed above 1000 rpm.
8. **Based on the number of cylinders:-**
   (i) Single cylinder engine:- In single cylinder engine there is only one cylinder in the engine.
   (ii) Multi cylinder engines:- In multi cylinder engine there are more than one cylinder in the engine.
9. **Based on the cylinder arrangement:-**
   (i) Vertical engines:- In vertical engine the axis of the engine is vertical.
   (ii) Horizontal engines:- In horizontal engine the axis of the engine is horizontal.

**ENGINE COMPONENTS AND NOMENCLATURE**

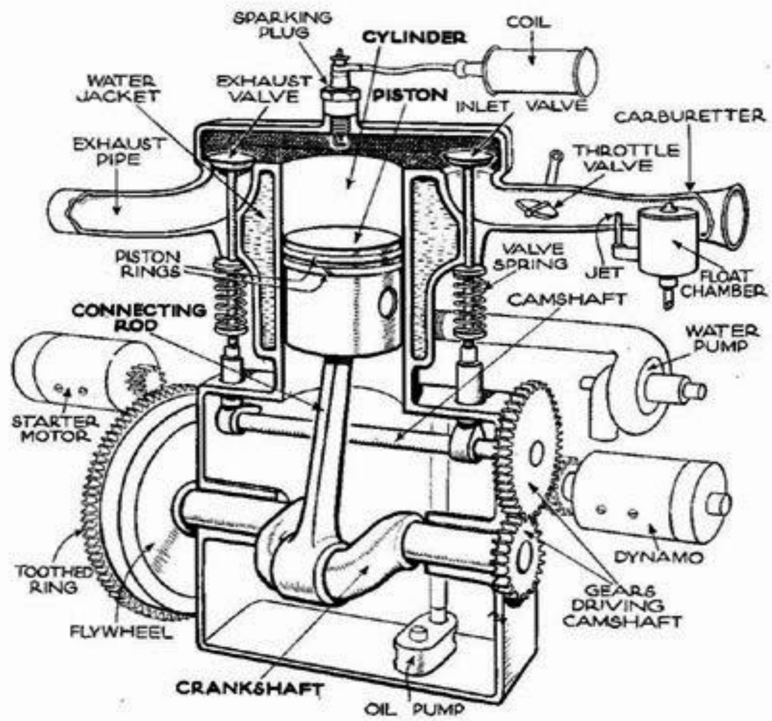
There are two types of IC engines; Spark Ignition (SI) engines and Compression Ignition (CI) engines.

**Engine components:-**

The following are the major engine components of internal combustion engine.

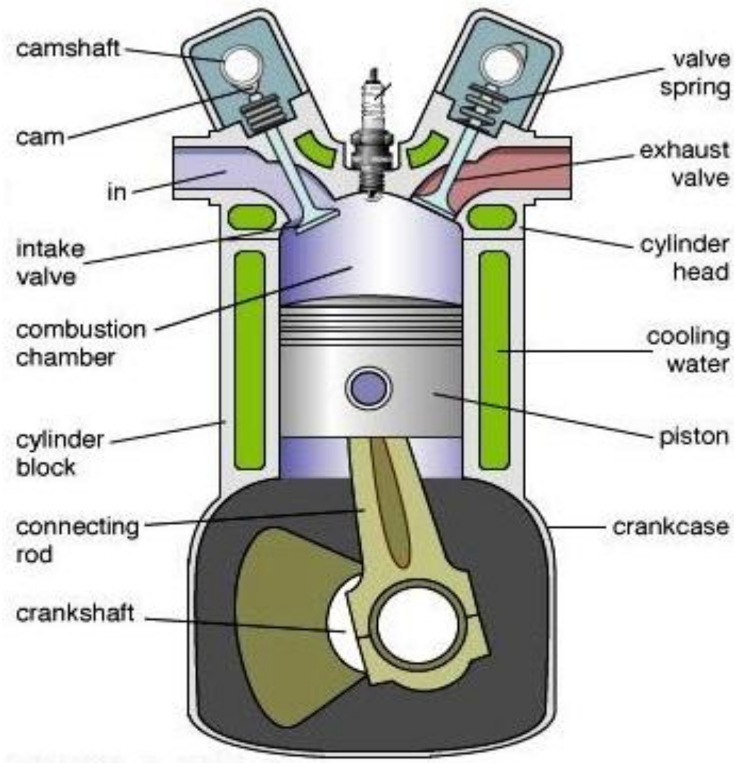
1. **Cylinder block**:- The cylinder block is the main supporting structure of the IC engine. The cylinder head is mounted on the cylinder block. The cylinder head and cylinder block are provided with water jackets in the case of water cooling or with cooling fins in the case of air cooling. The cylinder head is held tight to the cylinder block by a number of bolts or studs. The bottom portion of the cylinder block is called the crankcase.
2. **Cylinder**:- It is a cylindrical vessel or space in which the piston makes a reciprocating motion. The cylinder is closed by the cylinder head at one end and the other end is covered by the moving piston. The combustion of fuel takes place inside the cylinder and power is developed. The cylinder is supported in the cylinder block.
3. **Cylinder head**:- It is a cast iron piece bolted to one end of the cylinder. It acts as a cover to close the cylinder. It contains provisions for placing inlet and exhaust valve. In petrol engines, it houses a spark plug for igniting fuel+air mixture. In diesel engines, it houses a fuel injector for injecting the fuel into the cylinder.
4. **Piston**:- It is a cylindrical component fitted into the cylinder and which reciprocates inside the engine cylinder. The combustion chamber is formed between the cylinder head and piston. The

main function of the piston is to transmit the force exerted by the high pressure gas to the connecting rod. It is made of aluminium alloy.




main parts of engine

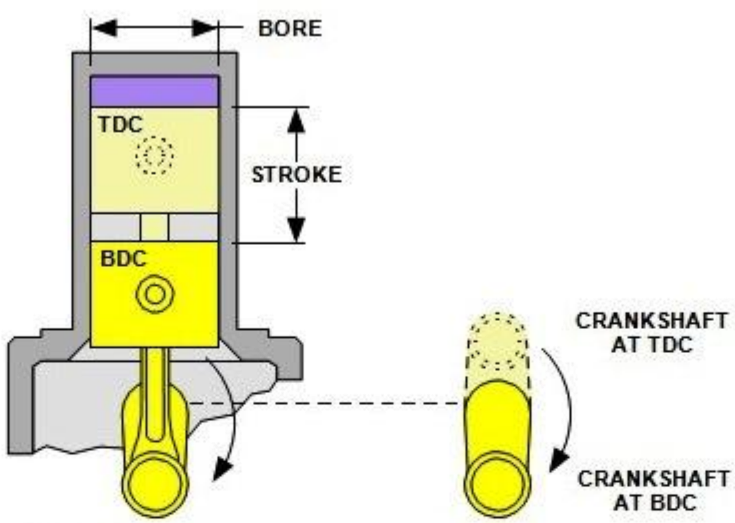
5. **Combustion chamber**:- The space enclosed between the cylinder head and the piston during combustion process is called the combustion chamber.
6. **Inlet manifold**:- It is the pipe which connect the intake system to the inlet valve of the engine and through which air or fuel+air mixture is drawn into the cylinder is called the inlet manifold.
7. **Exhaust manifold**:- It is the pipe which connect the exhaust system to the exhaust valve of the engine and through which the products of combustion escape into the atmosphere is called the exhaust manifold.
8. **Inlet valve and Exhaust valve:-** Inlet and exhaust valve are provided on the cylinder head for regulating the charge into the cylinder (inlet valve) and for discharging the products of combustion (exhaust valve ) from the cylinder.
9. **Spark plug:-** It is a component to initiate the combustion process in spark ignition (SI) engines and is usually located on the cylinder head.
10. **Connecting rod:-**It is the element which interconnects the piston and the crankshaft and transmits the gas force from the piston to the crankshaft.
11. **Crankshaft:-** It converts the reciprocating motion of the piston into useful rotary motion of the output shaft .The crankshaft is enclosed in the crankcase.
12. **Camshaft:-** It controls the opening and closing of the inlet & exhaust valves.
13. **Cam:-** It is an integral part of the cam shaft, it is designed in such a way as to open the valves at the correct timing and to keep them open for the necessary duration.
14. **Flywheel:-** It is a heavy wheel mounted on the crankshaft. Its main function is to maintain the angular velocity of crankshaft fairly constant.




Engine components and nomenclature

**Engine nomenclature:-**

1. **Top dead centre (TDC):-**It is the dead centre when the piston is farthest from the crankshaft. The extreme position of the piston at the top of the cylinder is the top dead centre (TDC).
2. **Bottom dead centre (BDC):-**It is the dead centre when the piston is nearest from the crankshaft. The position of the piston when it is farthest from the top of the cylinder is the bottom dead centre (BDC).




Top and Bottom Dead centre

3. **Clearance volume ($V_C$):-** The volume of the combustion chamber between the piston and the cylinder head, when the piston is at the top dead centre is called the clearance volume ($V_C$).

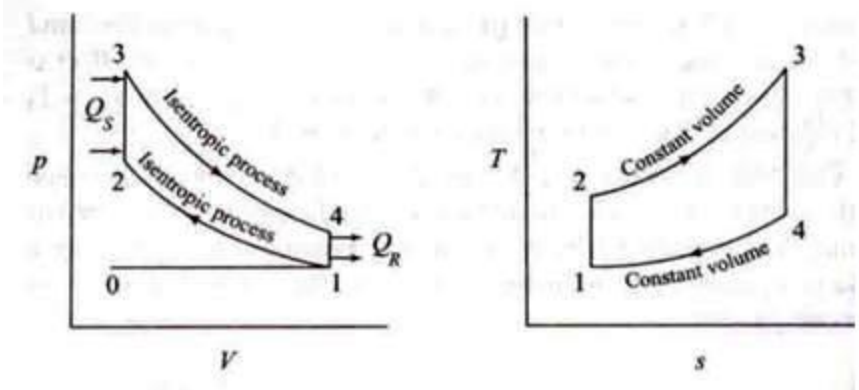
4. **Compression ratio (r):-** It is the ratio of the total cylinder volume when the piston is at the bottom dead centre, $V_T$, to the clearance volume, $V_C$,. It is designated by the letter (r).

$$r = V_T/V_C$$

**WORKING PRINCIPLE OF PETROL ENGINES [SPARK IGNITION (SI) ENGINES]**

Petrol engine is invented by Nicolaus A. Otto (1876). Petrol engines operate on Otto cycle. Petrol engines operate on four stroke or two stroke cycle.

**Otto cycle (constant volume heat addition cycle):-** In Otto cycle, heat is supplied and rejected at constant volume. A homogeneous mixture of petrol + air is supplied to the engine cylinder during the suction stroke. A carburetor provides a mixture of petrol + air in the required proportion. The fuel + air mixture gets compressed during the compression stroke.

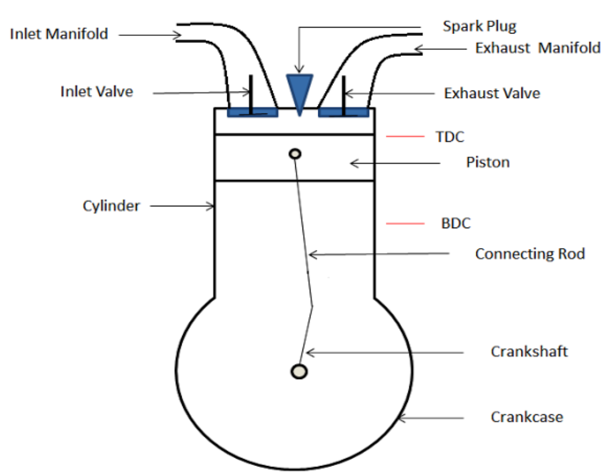



Otto cycle

At the end of the compression stroke the mixture is ignited with the help of a spark plug located on the cylinder head and combustion occurs at constant volume, thus heat is supplied at constant volume. The gas expands and moves the piston downwards, doing work. The product of combustion is exhausted at constant volume.

**Working of Four Stroke Petrol Engine:-**

In a four stroke engine, the cycle of operation is completed in four strokes of the piston or two revolutions of the crank shaft. During the four strokes, there are five events to be completed; namely suction compression, combustion, expansion and exhaust. The cycle of operation for an SI engine consists of the following four strokes: (i) Suction or Intake stroke; (ii) Compression stroke; (iii) Expansion or power stroke (iv) Exhaust stroke.



**(i) Suction or Intake stroke**

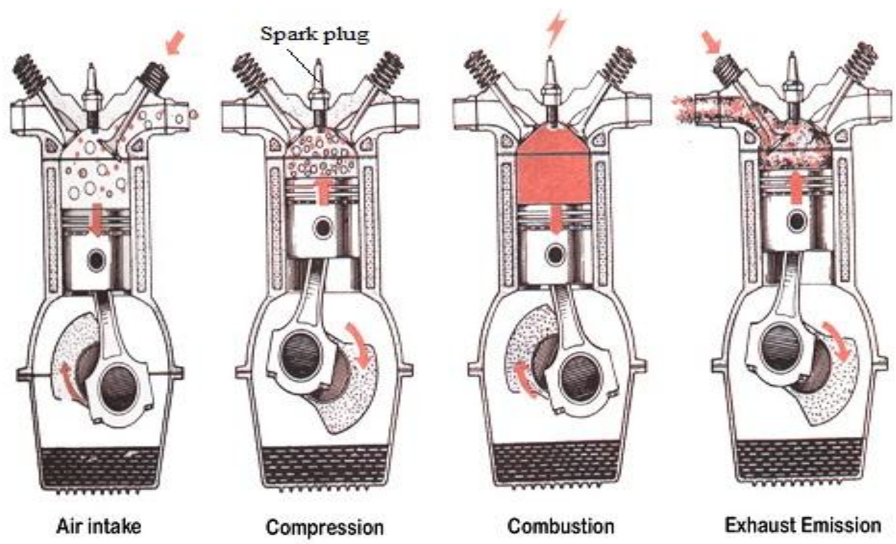
Suction stroke ($0 \rightarrow 1$), starts when the piston is at top dead centre (TDC) and about to move downwards to bottom dead centre (BDC). The inlet valve is open at this time and the exhaust valve is closed. Due to the suction created by the motion of the piston towards the bottom dead centre, the charge (fuel+air mixture) is drawn into the cylinder. A carburettor provides a mixture of petrol+air in the required proportion. When the piston reaches the BDC the suction stroke ends and the inlet valve closes.

**(ii) Compression stroke**

Compression stroke ($1 \rightarrow 2$), the charge taken into the cylinder during the suction stroke is compressed in the return stroke of the piston. During the compression stroke both inlet & exhaust valve are in closed position. At the end of the compression stroke the mixture is ignited with the help of spark plug located on the cylinder head. During the burning process the chemical energy of the fuel is converted into heat energy producing a temperature rise of about 2000ºC ($2 \rightarrow 3$).

**(iii) Expansion or power stroke**

The high pressure of the burnt gases forces the piston towards the BDC ($3\rightarrow 4$). Both the inlet & exhaust valves are in closed position. Only during the expansion or power stroke, power is produced. Both pressure and temperature decreases during expansion.




Working principle of a Four Stroke Petrol Engine (SI engine)

**(iv) Exhaust stroke**

At the end of the expansion stroke the exhaust valve opens and the inlet valve remains closed. The piston starts moving from the BDC to TDC ($5\rightarrow 0$) and sweeps the burnt gases out from the cylinder at atmospheric pressure. The exhaust valve closes when the piston reaches TDC at the end of the exhaust stroke. By this one cycle is completed.

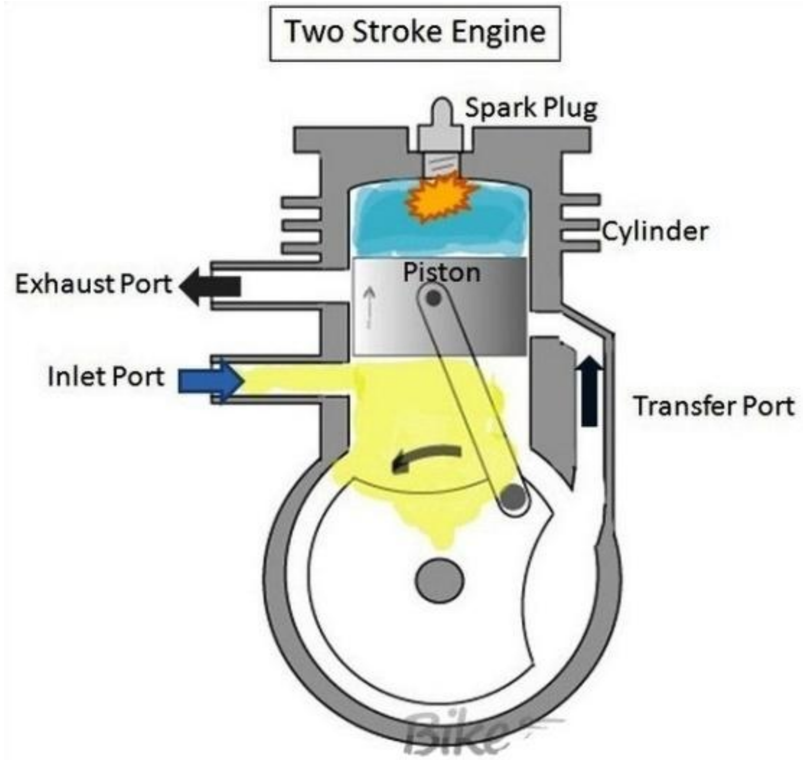
**TWO STROKE ENGINE:-**

Dugald Clark (1878) invented the two stroke engine. In a two stroke engine, one cycle of operation is completed in two strokes of the piston or one revolution of the crank shaft. Two strokes are sufficient to complete the cycle, one for compressing the fresh charge and other for expansion or power stroke. Here ports are provided in place of valves.

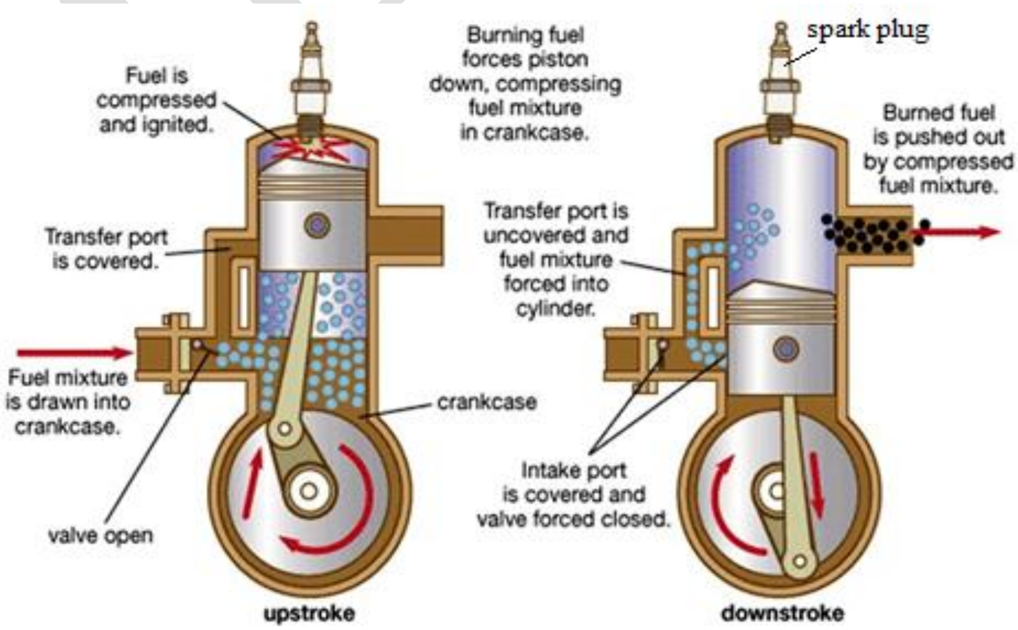
**Working of Two Stroke Petrol Engine:-**

The cylinder is connected to a closed crankcase. The fresh petrol+ air is inducted into the crankcase through the spring loaded inlet port when the pressure in the crankcase is reduced due to upward motion of the piston during compression stroke. After the compression and ignition using an electric spark from the spark plug, expansion takes place in the usual way.

During the expansion stroke the charge in the crankcase is compressed. Near the end of the expansion stroke, the piston uncovers the exhaust port and the cylinder pressure drops to atmospheric pressure as the combustion products leave the cylinder.




Further movement of the piston uncovers the transfer port, permitting the slightly compressed charge in the crankcase to enter the engine cylinder. The top of the piston is having a deflector to deflect the fresh charge towards the top of the cylinder before flowing to the exhaust port. During the upward motion of the piston from BDC the transfer port closes first and then the exhaust port close when compression of the charge begins and the cycle is repeated.



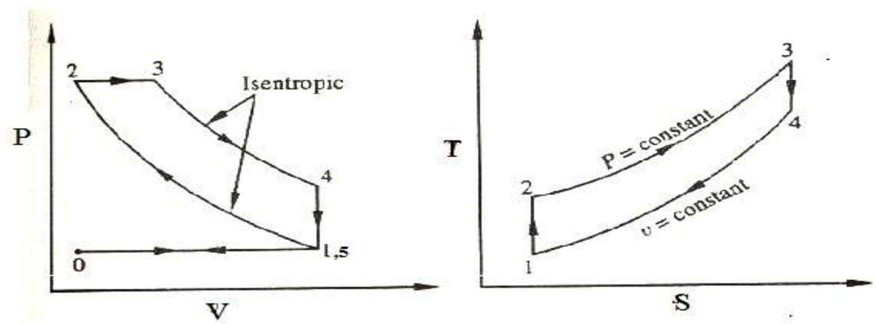

Working principle of a Two Stroke Petrol Engine (SI engine)

In two stroke petrol engine, the fuel + air mixture is admitted into the crankcase and compressed. A carburetor is used for mixing the fuel and air in the correct proportion. For the ignition of the fuel+air mixture at the end of the compression in the engine cylinder, a spark plug is provided.

**WORKING PRINCIPLE OF DIESEL ENGINES (COMPRESSION IGNITION (CI) ENGINES**

Diesel engine is invented by Rudolf Diesel (1892). Diesel engines operate on Diesel cycle. Diesel engines operate on four stroke or two stroke cycle.

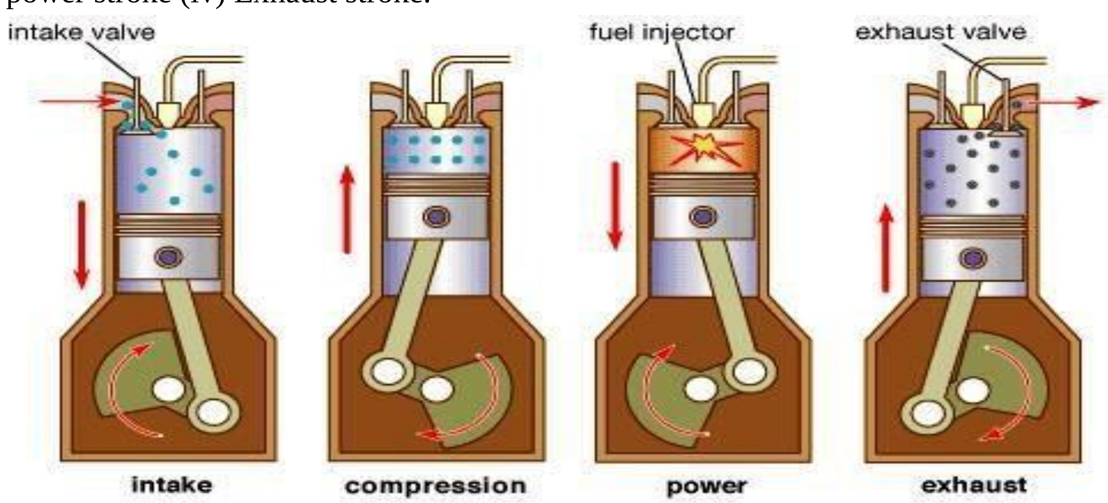
**Diesel cycle (constant pressure heat addition cycle):-** In diesel cycle, heat is supplied at constant pressure and is rejected at constant volume. Atmospheric air is drawn into the engine cylinder during the compression stroke and is compressed to high pressure and temperature. The temperature of compressed air will be above the ignition temperature of diesel. Just before the end of the compression stroke a measured quantity of fuel under pressure is injected in the form of fine spray by means of a fuel pump and fuel injector. Due to very high pressure and temperature of the air the fuel ignites and the gases expand displacing the piston. After doing the work on the piston the burnt gases escape from the engine cylinder through the exhaust valve. As the ignition takes place due to heat of compressed air; it is called compression ignition engine (CI engine).




CI engine operates at a higher compression ratio. The compression ratio of CI engine is from 16 to 20. The compression ratio of SI engine is from 6 to 10. In CI engine, a high pressure fuel pump and a fuel injector are provided to inject the fuel into the combustion chamber.

**Working of Four Stroke Diesel Engine:-**

In a four stroke engine, the cycle of operation is completed in four strokes of the piston or two revolutions of the crank shaft. During the four strokes, there are five events to be completed; namely suction compression, combustion, expansion and exhaust. The cycle of operation for a CI engine consists of the following four strokes: (i) Suction or Intake stroke; (ii) Compression stroke; (iii) Expansion or power stroke (iv) Exhaust stroke.




Working of Four Stroke Diesel Engine

**(i) Suction or Intake stroke**

Suction stroke (0 → 1), air alone is inducted during the suction stroke. During this stroke the piston moves from TDC to BDC. The inlet valve opens and air at atmospheric pressure is drawn into the engine cylinder. During the suction stroke intake valve is open and exhaust valve is closed.

**(ii) Compression stroke**

Compression stroke (1 → 2), air inducted during the suction stroke is compressed. In this stroke the piston moves towards TDC and compresses the enclosed air to high pressure and temperature. Both inlet and exhaust valves remain closed during this stroke.

**(iii) Expansion or power stroke**

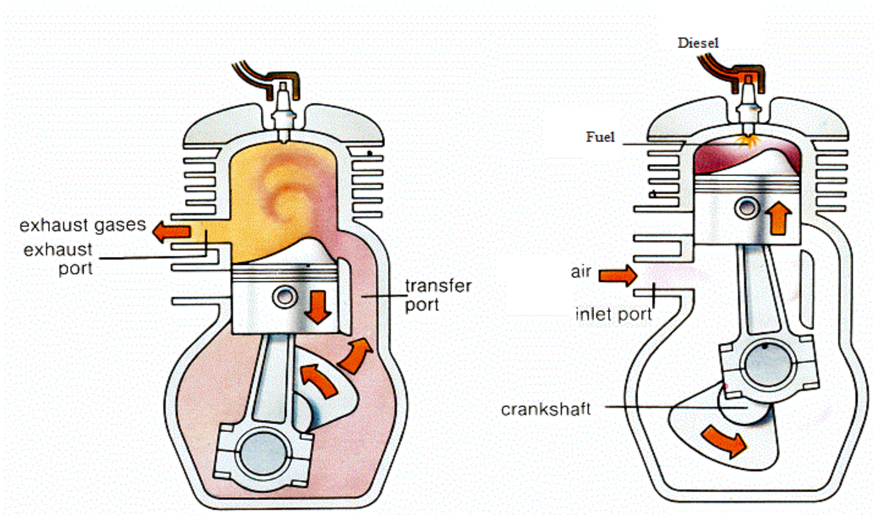
Fuel injection starts nearly at the end of the compression stroke. Fuel is injected into the hot compressed air in the form of fine spray by means of a fuel pump and fuel injector. The fuel starts burning at constant pressure and pushes the piston from TDC (2→3). At point 3 the fuel supply is cut off. The high pressure gas in the cylinder expands doing the work on the piston (3→4). The inlet and exhaust valves remain closed during this stroke.

**(iv) Exhaust stroke**

The piston moves from BDC to TDC pushes out the product of combustion through the exhaust valve. During this stroke exhaust valve remains opened and inlet valve remains closed (4→5). By this one cycle is completed.

## Working of Two Stroke Diesel Engine:-

In a two stroke diesel engine, one cycle of operation is completed in two strokes of the piston or one revolution of the crank shaft. Two strokes are sufficient to complete the cycle, one for compressing the fresh charge and other for expansion or power stroke. Here ports are provided in place of valves.




Working of Two Stroke Diesel Engine

The cylinder is connected to a closed crankcase. During the upward stroke of the piston, the air in the cylinder is compressed. At the same time fresh air enters the crankcase through the air inlet port. Towards the end of the compression stroke diesel is introduced in the form of fine spray by the fuel pump and fuel injector and due to the high pressure and temperature of the air, the fuel will start burning. The piston the travels downward from BDC to TDC due to the expansion of the gases and near the end of the expansion stroke the piston uncovers the exhaust port and the burnt gases escape through this port. The transfer port is then uncovered and the compressed air from the crankcase flows into the cylinder. The incoming fresh air helps to remove the burnt gases from the engine cylinder.

## COMPARISON OF FOUR STROKE AND TWO STROKE ENGINE

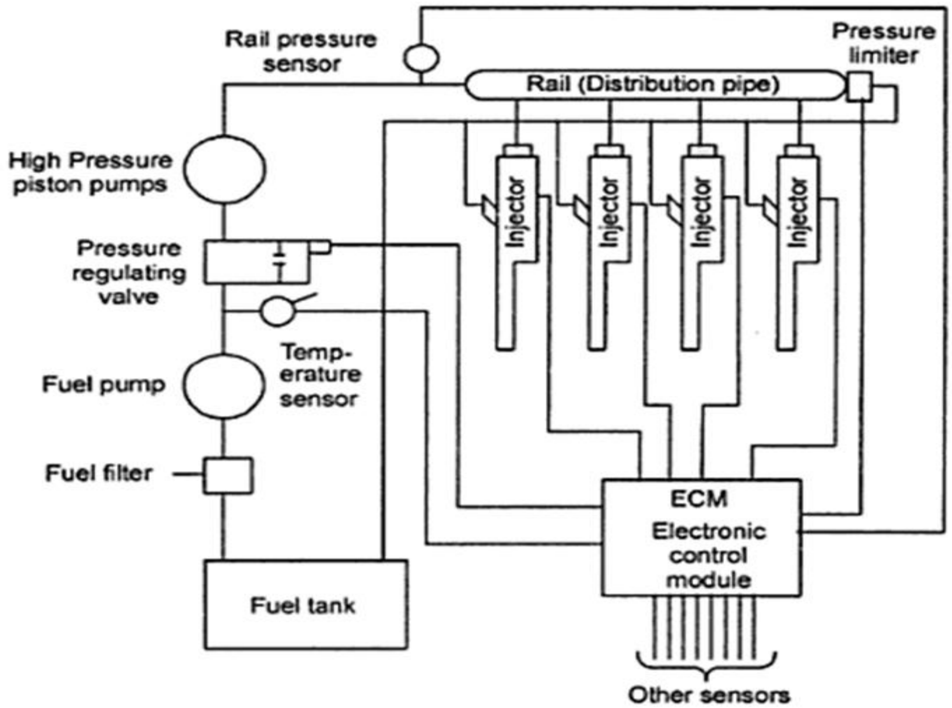
| FOUR STROKE ENGINE | TWO STROKE ENGINE |
|---|---|
| In four stroke engine one cycle of operation is completed in four strokes of the piston. One power stroke is obtained in four strokes of the piston that is in two revolutions of the crank shaft. | In two stroke engine one cycle of operation is completed in two strokes of the piston. One power stroke is obtained per two strokes of the piston that is in each revolution of the crank shaft. |
| Turning moment is not uniform, hence a heavier flywheel is needed. | Turning moment is uniform, hence a lighter flywheel can be used. |
| Less cooling & lubrication are required. | Greater cooling & lubrication are required |
| Four stroke engines are having inlet & exhaust valves. | Two stroke engines are having no valves but only ports. |
| Initial cost of the engine is more. | Initial cost of the engine is less. |
| Thermal efficiency is higher. | Thermal efficiency is lower. |
| Lower rate of wear & tear. | Higher rate of wear & tear. |
| Power produced for same size of engine less. | Power produced for same size of engine is twice. |
| Engine is heavier & bulkier | Engine is lighter & more compact |
| Used where efficiency is important; namely in cars, buses, trucks, ,tractors, aeroplanes etc. | Used where low cost, compactness and light weight are important; namely in mopeds, scooters, motor cycles etc. |

## COMPARISON OF SI AND CI ENGINE

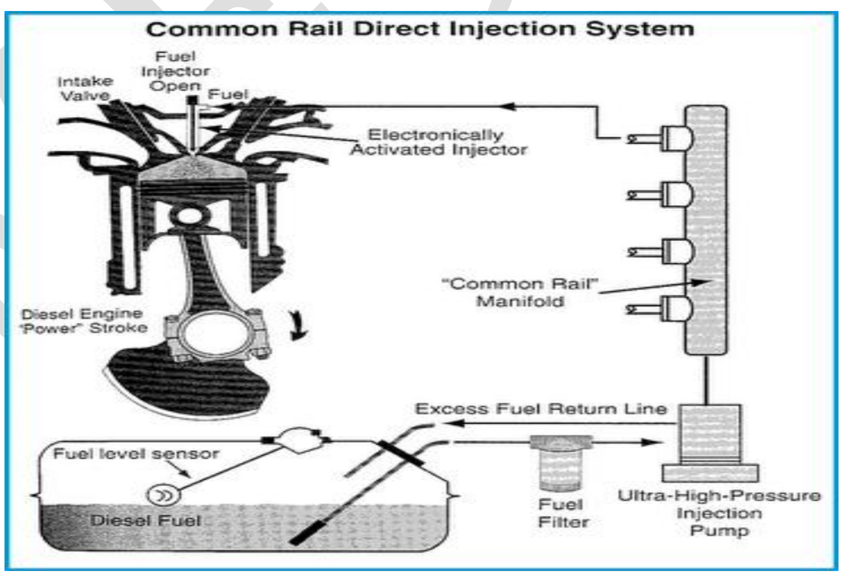
| SPARK IGNITION (SI) ENGINE | COMPRESSION IGNITION (CI) ENGINE |
|---|---|
| Works on otto cycle (constant volume heat addition cycle). | Works on diesel cycle (constant pressure heat addition cycle). |
| Highly volatile liquid fuel such as Petrol is used as fuel. | Less volatile liquid fuel such as Diesel is used as fuel. |
| Gaseous mixture of fuel + air is introduced during the suction stroke. A carburetor and an ignition system are necessary. | Fuel is directly injected into the combustion chamber at high pressure and at the end of the compression stroke. A fuel pump and injector are necessary. |
| Ignition system & spark plug are necessary. | Ignition system & spark plug are not necessary. |
| Compression ratio is between 6 to 10. | Compression ratio is between 16 to 20. |
| Light weight & High speed engines. | Heavy weight & Low speed engines. |
| Thermal efficiency is lower. | Thermal efficiency is higher. |
| Initial cost is less. | Initial cost is more. |
| Maintenance cost is less. | Maintenance cost is more. |

## COMMON RAIL DIRECT INJECTION (CRDI)

- It is a modern variant of direct injection system
- Common rail is a large manifold and continuously fed by fuel under pressure.
- Injectors are fed by pipes connected to rail.




- Injector is opened electronically.
- Pulverisation-not proper combustion-low efficiency -improved by CRDI
- High pressure fuel fed into injectors by the common rail.
- Pressure of fuel is maintained about 1500 bar.




**Advantages**

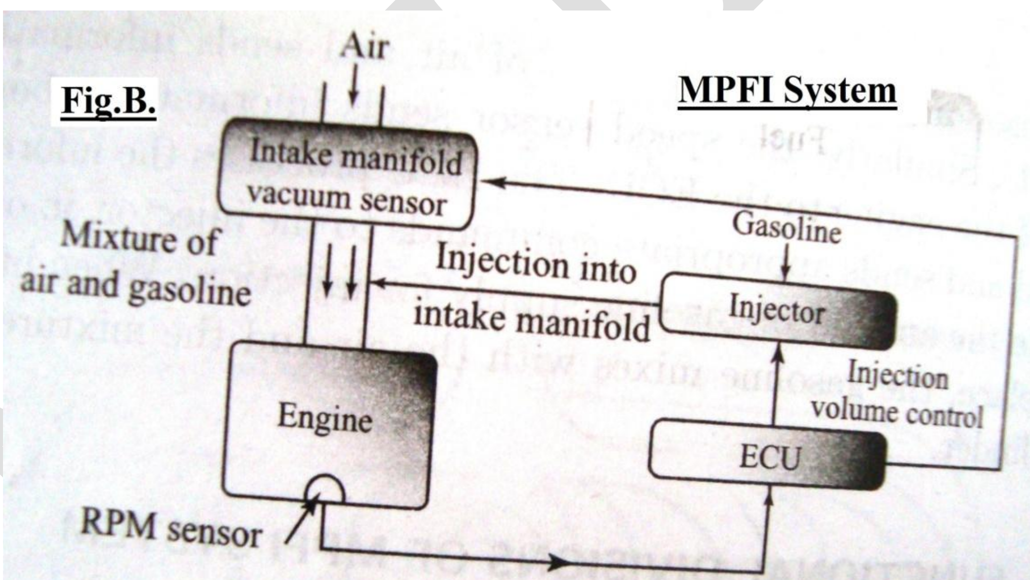
- higher efficiency
- Better combustion
- Better power balance
- Reduced noise levels

**Manufacturers of CRDI engine**

- Mahindra CRDE
- Tata DICOR
- Bmw-d engines
- Hyundai CRDI engines

**MULTI POINT FUEL INJECTION (MPFI)**

- It is an improvement over carburetors.
- It allows more efficient combustion of fuel, there by producing more power with lesser emissions.
- It is a technology similar to what CRDI is in diesel engines.
- In carburetor, air and fuel are mixed in a fixed ratio and sent to the cylinders for combustion.
- This is a purely mechanical system with negligible flexibility.
- It often sends more fuel into the cylinder than the available air, thereby leading to incomplete combustion, high fuel consumption and excess emissions.
- This also leads to carbon deposits inside the combustion chamber and reduces engine life.
- MPFI is an intelligent way of doing what a carburetor does.
- In this system each cylinder has injectors to spray the fuel/air charge into the cylinders.
- The fuel and air are mixed in what is called the intake manifold.




- In MPFI, each injector in controlled by the ECU (engine control unit).
- The ECU monitors various engine parameters and accordingly decides just how much fuel is to be injected into the cylinder and at precisely what time .
- This system also allows each cylinder to be controlled independently.
- Injectors are precision built solenoid valves.
  They have single or multiple orifices which spray fuel into the intake manifold.
- The fuel is taken from a common rail/header, pressurized to around 3 bar, fed by a high pressure fuel pump.
- ECU or the Electronic Control Unit is the brain behind the MPFI system.

- It is a computer chip which receives input on various engine parameters, compares them against preloaded engine and throttle maps and accordingly decides exactly how much fuel is to be injected into which cylinder and at what time
- Because of this, the engine becomes cleaner, more responsive and uses lesser fuel.
- Modern ECUs have memory by which they can learn the user's driving style.
- For e.g., if someone has a habit of speedy pick up, the ECU will remember that and give more power at lower rpm by injecting in more fuel.
- It will judge by the amount of pressure being put of the throttle.

**Advantages of MPFI**

- More uniform A/F mixture will be supplied to each cylinder, hence the difference in power developed in each cylinder is minimum.
- Vibration from the engine equipped with this system is less, due to this the life of engine components is improved.
- Immediate response, in case of sudden acceleration / deceleration.
- Since the engine is controlled by ECU, more accurate amount of A/F mixture will be supplied and as a result complete combustion will take place. This leads to effective utilization of fuel supplied and hence low emission level.
- The mileage of the vehicle will be improved.

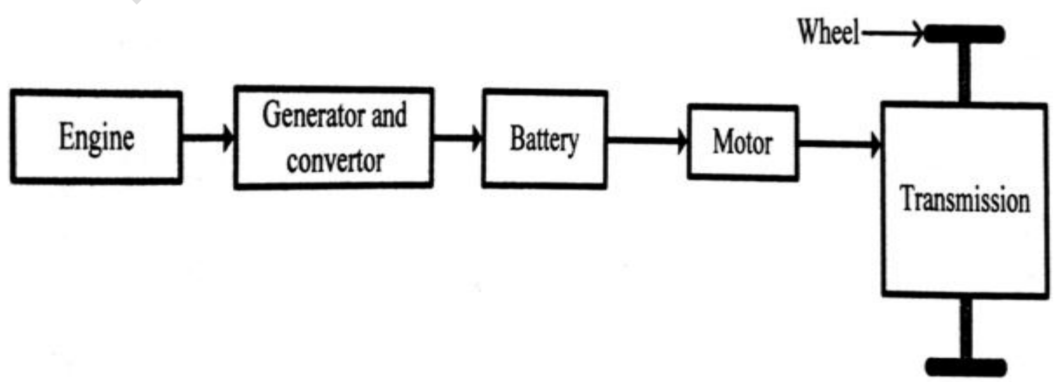
## HYBRID VEHICLES

Hybrid cars are becoming more popular and more common. Basically, a hybrid car is one that uses two or more engines i.e. an electric motor and a conventional engine (either petrol or diesel). The electric engine powers the car at lower speeds and gas engine powers it at higher speeds. A hybrid car like Toyota Prius and Civic Hybrid not only conserves fuel but also produce less $CO_2$ emissions.

- Uses two or more distinct power sources to move vehicle.
- Usually an IC engine along with high voltage Electric motor with battery is used.
- IC engines have lower efficiency & high fuel consumption at lower rpm.
- At lower speeds, Hybrid vehicles uses electric motor as power source & from medium to higher speed, motor is replaced by IC engine.
- Thus it improves overall fuel consumption & reduces emission.

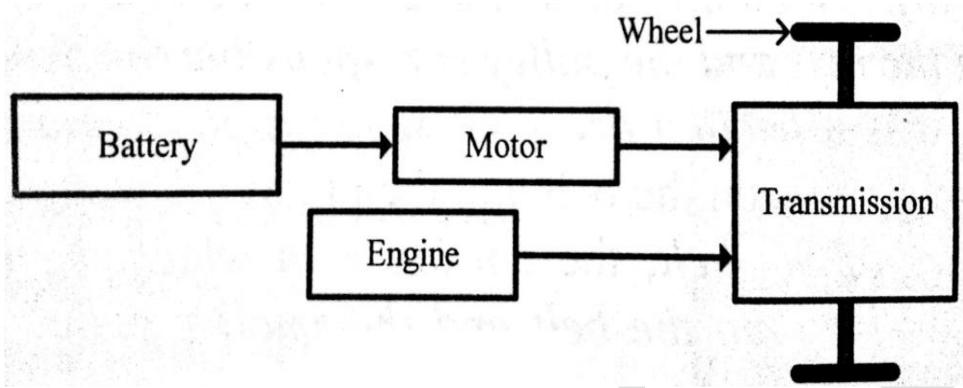
**(a)SERIES HYBRID**

- Engines turns a generator, producing current, which is used to charge batteries
- Batteries run the electric motor that drives transmission.
- Thus engine never directly powers the vehicle.



**(b)PARALLEL HYBRID**

- Electric motor as well as Engine is engaged to the transmission.
- So any of the two power plants can be used to drive the transmission.
- Battery for the electric motor is charged during the running time by utilising engine power.
- New technology uses Regenerative braking for charging batteries.
- This converts kinetic energy lost during braking into electric energy for charging batteries.




## ***Questions***

1. Write notes on hybrid engines. (5)
2. Explain the working of a 4 stroke SI engine with neat sketches' (10)
3. Discuss briefly about MPFI engine.(5)
4. Explain the term CRDI. (5)
5. With a neat sketch explain the working of a2 stroke petrol engine. (8)
6. Sketch the P-v and T-s diagram of a Carnot cycle and List the processes. (4)
7. In an air standard Otto cycle the compression ratio is 7 and compression begins at 35$^o$C, 0.1MPa. The maximum temperature of the cycle is 1100$^o$C. Find
   i) Heat supplied per kg of air,
   ii) Work done per kg of air,
   iii)Cycle efficiency
   Take Cp = 1.005 kJ/kgK and Cv=0.718 kJ/kgK (10)
8. Explain the working of a 4 stroke SI engine with neat sketches. (7)
9. Explain the fuel system of a petrol engine. (3)