Module 4

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 CYCLES

The working fluid in an I.C Engine doesn't operate on a cycle. In the accurate study and analysis of Internal combustion engine, processes are very complicated. To simplify the theoretical study "Standard Air Cycles" are introduced, these cycles are similar to the open cycles, but some simplifying assumptions are made.

An air standard cycle is an idealized cycle in which air is taken as the working fluid. The actual combustion process is replaced by a heat transfer process and exhaust process is replaced by a heat rejection process. Air standard cycle refers to thermodynamic cycle being studied with certain assumptions, so as to use the principles of thermodynamics conveniently. It is the most simplified form of thermodynamic cycle under consideration. General assumptions made for a cycle to be air-standard cycle are as follows:

i. Air is the working fluid and behaves as a perfect gas.
ii. Working fluid does not get changed in its mass and composition.
iii. Thermodynamic processes constituting cycle are reversible.
iv. There is no heat loss from system to surrounding and vice-versa.
v. During heat addition process, heat is assumed to be supplied from a high temperature source.
vi. During heat rejection process, heat is assumed to be rejected to a low temperature sink.
vii. Specific heats of working fluid do not change throughout the cycle.

In air standard cycle, a part of the heat transferred to air is converted into useful work and the remainder is rejected. Therefore the work done by the air is equal to the difference between the heat supplied and heat rejected, if there is no mechanical loss.

Therefore, **Work done during a cycle = Heat supplied – Heat rejected.**

Air standard efficiency

- **Thermal efficiency**

Thermal efficiency of a process is defined as the ratio of the work done to the heat supplied during the cycle.

Thermal efficiency = Work done / Heat supplied

- **Air standard efficiency**

Air standard efficiency is the thermal efficiency obtained with air as the working fluid. i.e. It is the ratio of work done to the heat supplied during a cycle with air is used as the working fluid.

Air standard efficiency = Work done / Heat supplied

Work Done WD = Heat Supplied (H.S) – Heat Rejected (H.R)

Air standard efficiency = (H.S – H.R)/H.S

= 1 – (H.R / H.S)

$$\eta_{air} = 1 - \frac{\text{heat rejected}}{\text{heat supplied}}$$

CARNOT CYCLE

Probably the best known reversible cycle is the Carnot cycle, which was first proposed in 1824 by French engineer Sadi Carnot. **The theoretical heat engine that operates on the Carnot cycle is called the Carnot heat engine.** Carnot cycle is a reversible thermodynamic cycle comprising of four reversible processes **(two isothermal processes and two adiabatic processes).** (refer figure 1.1)

Thermodynamic processes constituting Carnot cycle are;

- **Process 1-2, Isothermal expansion process**
- **Process 2-3, Isentropic expansion process**
- **Process 3-4, Isothermal compression process**

- **Process 4-1, Isentropic compression process**

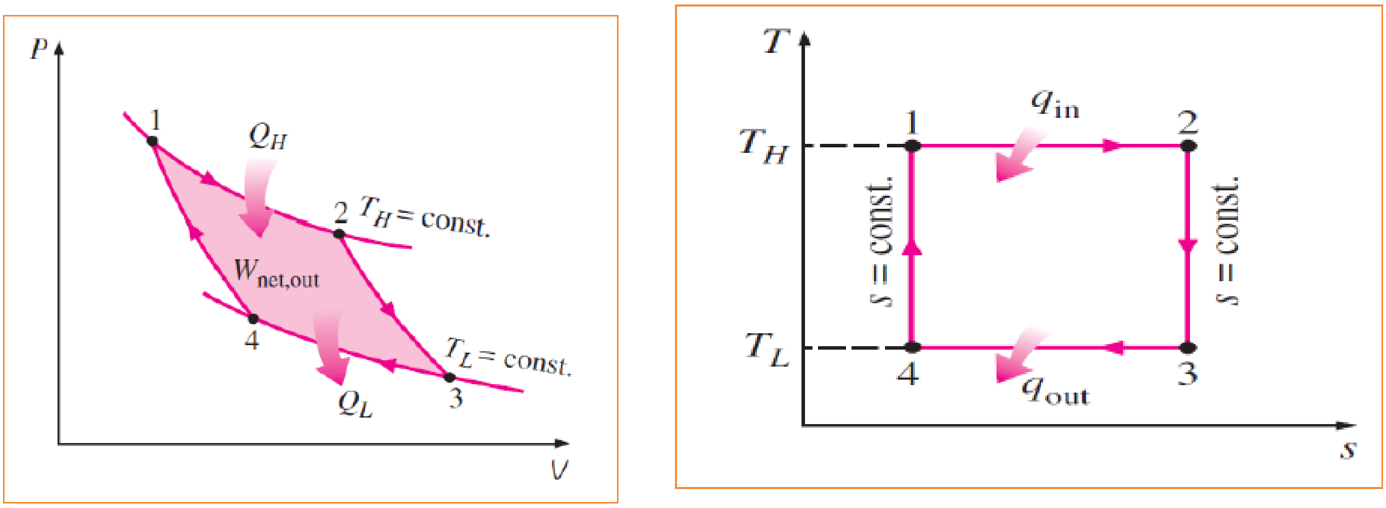
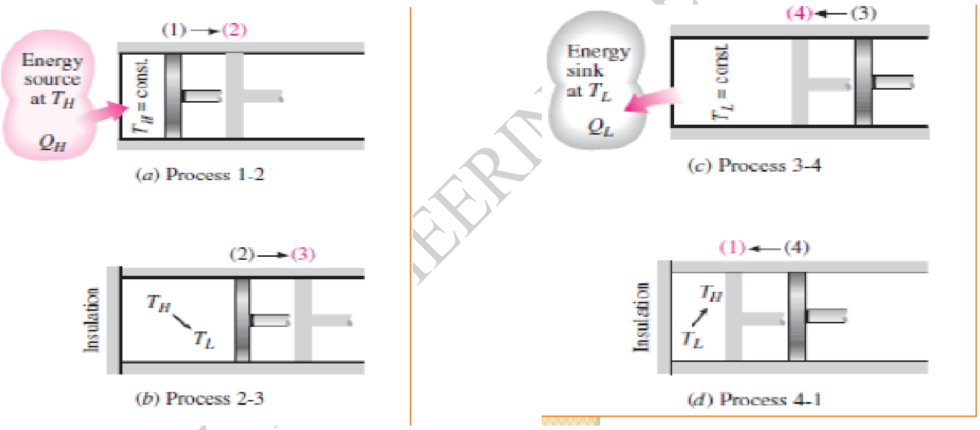


Fig 1.1 Carnot cycle P-V Diagram and T-S diagram



Consider a given mass of air in the cylinder, inside which a frictionless piston slides. Let the pressure, volume and temperature of air at state 1 be P_1,V_1 and T_1 respectively

Process 1-2 Reversible isothermal expansion

Heat is supplied to this air isothermally from an external hot body. The air expands at constant temperature T_1 till the state 2 is reached. This process is represented by curve 1-2 in the P-V diagram and a horizontal line in T-S diagram. During this process heat is absorbed from the heat source and an equal amount of work is done by the air (pushes the piston and expands). At point 2 source of heat is removed.

Process 2-3 Isentropic expansion (reversible adiabatic expansion)

The air is allowed to expand adiabatically till state 3. This is represented by curve 2-3 in the p-V diagram and a vertical line 2-3 in the T-S diagram. Let the pressure, volume and temperature of the air at state 3 be p_3,V_3 and T_3 respectively. During the process 2-3 work is done by the air utilizing its internal energy.

Process 3-4 Reversible isothermal compression

At state 3, an external cold body is brought in contact with the cylinder and heat is rejected isothermally to the cold body at constant temperature T_3. This isothermal compression is represented by the curve 3-4 in the p- V diagram and a horizontal line 3-4 in the T-S diagram. During this process work is done on the air and an equal amount of heat is rejected to the cold body.

Process 4-1 Isentropic compression

At state 4, the cold body is removed and the air is compressed adiabatically to the initial state 1. In the p-V diagram this adiabatic compression process is represented by curve 4-1 and in the T-S diagram by a vertical line 4-1. During this process work is done on the air to bring it to the original state.

Area under curve 1-2-3 is the work done by the gas during the expansion part of the cycle, and the area under curve 3-4-1 is the work done on the gas during the compression part of the cycle. The area enclosed by the path of the cycle (area 1-2-3-4-1) is the difference between these two and represents the net work done during the cycle

Why Carnot engine is not possible?

Although Carnot cycle gives maximum possible efficiency, yet no engine can be made to work on this cycle due to the following reasons.
The Carnot cycle consists of Isothermal and adiabatic processes.

The expansion and compression processes are adiabatic and hence the two operations should be carried out as quickly as possible, so that there is hardly any time for the heat exchange to take place. i.e., in order to achieve adiabatic process, the piston has to move very fast, so that there is no heat exchange with the surroundings.

On the other hand, heat supply and heat rejection takes place isothermally, which means the operations must be slow to maintain the constant temperature. i.e., In order to achieve isothermal process, the piston has to move very slowly, so that the temperature remains constant during heat exchange. It is obvious that such sudden change in the speed of an engine in one cycle is not possible in actual practice.

OTTO CYCLE

This is a modified form of Carnot cycle in order to make it a realistic cycle. **The Otto cycle is the ideal cycle for spark-ignition reciprocating (Petrol) engines.** It is named after Nikolaus A. Otto, who built a successful four-stroke engine in 1876. **Otto cycle has two constant volume and two adiabatic processes. Heat is supplied and rejected at constant volume. Expansion and compression of air takes place adiabatically.**

It consists of two isentropic (constant entropy) processes and 2 isochoric (constant volume) processes.

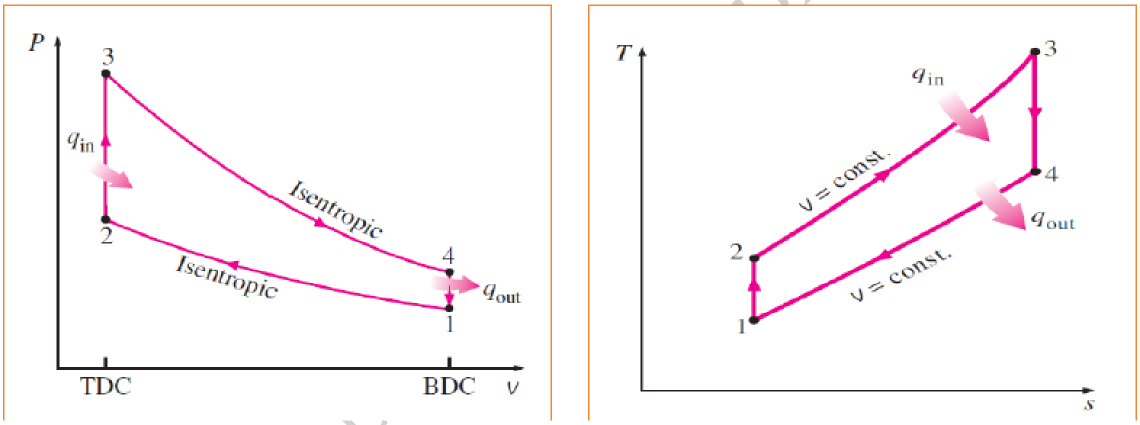


Fig 1.2 Otto cycle – P-V Diagram and T-S diagram

The processes are,

- **Process 1-2 Isentropic compression**
- **Process 2-3 Isochoric heat addition**
- **Process 3-4 Isentropic expansion**
- **Process 4-1 Isochoric heat rejection**

Consider a cylinder containing 'm' kg of air. Let P_1, V_1 and T_1 be the pressure, volume and temperature of air inside the cylinder, at state 1.

Process 1-2 Isentropic compression

This air is compressed adiabatically to state 2, doing work on the air. Curve 1-2 in the p-V diagram and the line 1-2 in the T-S diagram represents this process.

Process 2-3 Isochoric heat addition

Now heat is supplied to this compressed air at constant volume from an external hot body till state 3 is reached. This process is represented by a vertical line 2-3 in the p-V diagram and curve 2-3 in the T-S diagram.

Process 3-4 Isentropic expansion

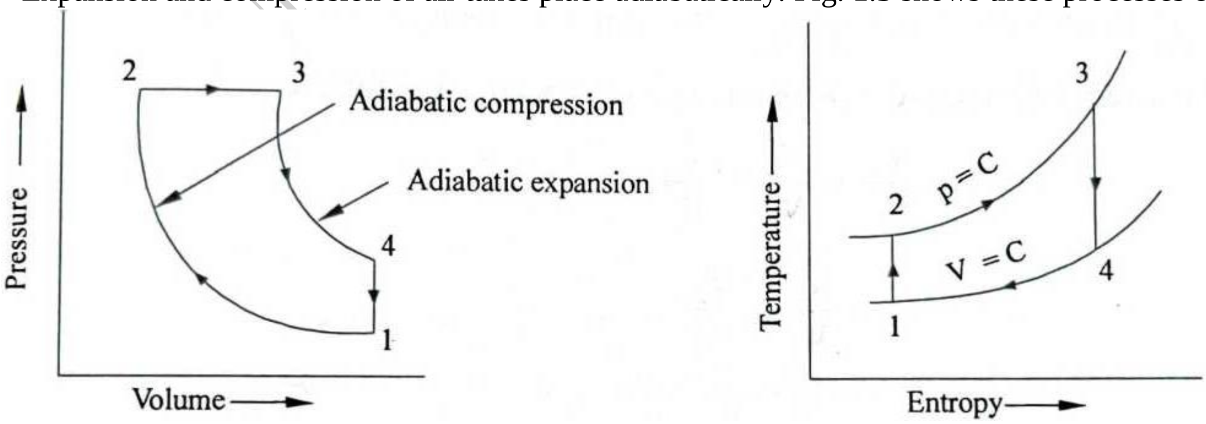
At state 3 the hot body is removed and the air is allowed to expand adiabatically to state 4, doing external work. This process is represented by curve 3-4 in the p-V diagram and a vertical line 3-4 in the T-S diagram.

Process 4-1 Isochoric heat rejection

Heat is rejected at constant volume to an external cold body till state 1 is reached. This process is represented by vertical line 4-1 in the p-V diagram and curve 4-1 in the T-S diagram. Thus the air finally returns to its original state after completing a cycle.

DIESEL CYCLE

Diesel cycle is the cycle on which the diesel engine works. Diesel cycle consists of four reversible processes. Heat is supplied at constant pressure and rejected at constant volume. Expansion and compression of air takes place adiabatically. Fig. 1.3 shows these processes on



P-V and T-S diagrams.

Fig 1.3 Diesel cycle – P-V diagram and T-S diagram

Diesel cycle consists of 2 isentropic processes and an isochoric process and isobaric process.

The processes in Diesel cycle are,

- **1-2 Isentropic compression (reversible adiabatic compression)**
- **2-3 Isobaric heat addition (constant pressure heat addition)**
- **3-4 Isentropic expansion (reversible adiabatic expansion)**
- **4-1 Isochoric heat rejection (constant volume heat addition)**

Consider a cylinder containing 'm' kg of air. Let P_1 , V_1 and T_1 be the pressure, volume and temperature of air inside the cylinder at state 1.

1-2 Isentropic compression (reversible adiabatic compression)

This air is compressed adiabatically to state 2, doing work on the air. Curve 1-2 in the p-V diagram and line 1-2 in the T-S diagram represents this process.

2-3 Isobaric heat addition (constant pressure heat addition)

Now heat is supplied to the air at constant pressure from an external hot body till state 3 is reached. This process is represented by a horizontal line 2-3 in the P-V diagram and a curve 2-3 in the T-S diagram.

3-4 Isentropic expansion (reversible adiabatic expansion)

At state 3, the hot body is removed and the air is allowed to expand adiabatically to state 4, doing external work. This process is represented by curve 3-4 in the P-V diagram and a vertical line 3-4 in the T-S diagram.

4-1 Isochoric heat rejection (constant volume heat addition)

At point 4 an external cold body is brought in contact with cylinder. Heat is rejected at constant volume to an external cold body till state 1 is reached. This process is represented by a vertical line 4-1 in the p-V diagram and curve 4-1 in the T-S diagram. Thus the air finally returns to its original state after completing a cycle.

INTERNAL COMBUSTION ENGINE

A device which transforms one form of energy into another form is called an engine. **An engine which converts thermal energy into mechanical energy is called heat engine.** Heat engine transforms the chemical energy of a fuel into thermal energy and this thermal energy is converted into mechanical energy to perform useful work. Heat engines can be broadly classified into two categories.

(i) External combustion engines (EC engines)

(ii) Internal combustion engines (IC engines)

In an external combustion engine, a working fluid is used for transferring the heat of combustion to the engine where the heat of combustion is converted into mechanical energy. Steam engines and steam turbines are common examples of this category.

In an internal combustion engine air is taken from the atmosphere and the combustion of fuel and air occurs in the engine (inside the cylinder) which converts thermal energy into mechanical energy. This eliminates the need for heavy and bulky devices such as boilers and heat exchangers. Also high thermal efficiencies can be achieved in internal combustion engines. These factors give rise to the wide use of internal combustion engines for mobile power plants such as those used in automobiles, ships and slow speed aircrafts.

Engine components

The following are the major components of internal combustion engine. Refer fig. 2.1.

1. **Cylinder**

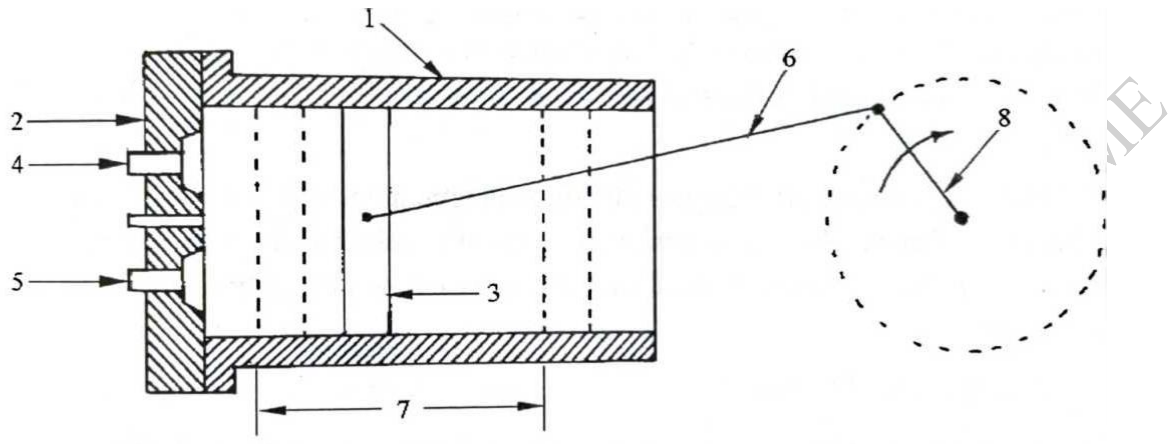
It is a cylindrically shaped container within which the piston reciprocates. The cylinder is closed by the cylinder head at one end and the other end is covered by the moving piston. Combustion of fuel takes place inside the cylinder and power is developed.

2. **Cylinder head**

It acts as a cover to close the cylinder. It contains provisions for placing inlet and exhaust valves. 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.

3. Piston

It is a close fitting member which reciprocates inside the engine cylinder. The main function of the piston is to transmit the force exerted by the high pressure gas to the connecting rod. It is shaped like an inverted cup and is generally made of aluminium alloy.



1. Cylinder 2. Cylinder head 3. Piston 4. Inlet valve 5. Exhaust valve 6. Connecting road 7. Stroke length 8. Crank

Fig. 2.1. Engine components and nomenclature

4. Inlet and exhaust valves

These are valves provided in the cylinder head for the admission of fresh air into the engine cylinder and for the rejection of burnt gases from the engine cylinder. These valves are usually kept closed by valve springs. Openings of these valves are made mechanically by means of a device called cam.

5. Inlet manifold

The metal tube which connects the intake system to the inlet valve of the engine and through which air or air fuel mixture is drawn into the cylinder is called inlet manifold.

6. Exhaust manifold

The metal tube which connects the exhaust system to the exhaust valve of the engine and through which the product of combustion escape is called exhaust manifold.

7. **Connecting rod**

It is the element which interconnects the piston and the crank. Connecting rod transmits the gas force from the piston to the crank shaft and transforms the reciprocating motion of piston inside the cylinder into rotary motion of the crank.

8. **Crank**

It is a rotating member which receives power from the connecting rod and transmits to the crank shaft.

9. **Flywheel**

It is a heavy wheel mounted on the crank shaft. Its main function is to maintain the angular velocity of crank shaft fairly constant.

10. **Crankshaft**

It is the shaft at which useful positive work is available from the piston-cylinder arrangement. Reciprocating motion of piston gets converted into rotary motion of crankshaft.

11. **Cams and Camshafts**

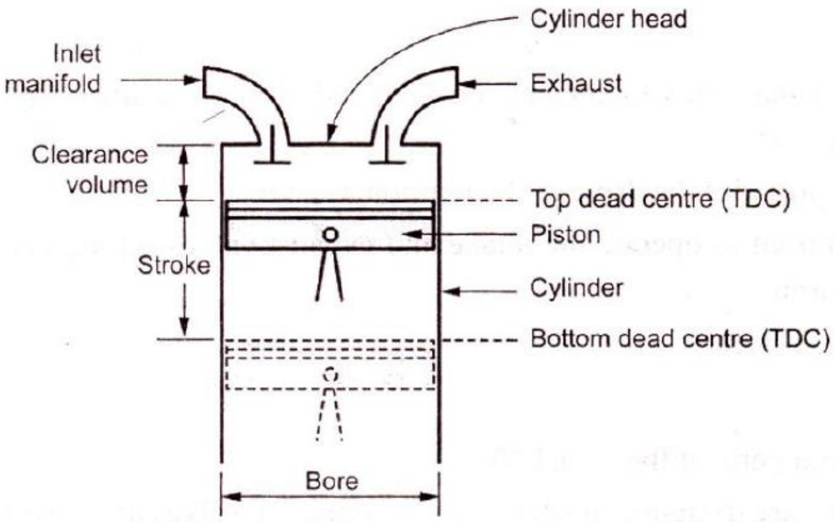
Cams are mounted upon camshaft for opening and closing the valves at right timings and for correct duration. Camshaft gets motion from crankshaft through timing gears.

Nomenclatures used in IC Engines

The following are the various nomenclatures used in internal combustion engines

1. **Cylindrical Bore:** The inside diameter of cylinder is called cylinder bore.
2. **Top Dead Centre (TDC) or Inner Dead Centre (IDC):** The extreme position of the piston at the top of the cylinder is the top dead centre (TDC). In the case of horizontal engines it is known as inner dead centre (IDC).
3. **Bottom Dead Centre (BDC) or Outer Dead Centre (ODC):** The position of the piston when it is farthest from the top of the cylinder is the bottom dead centre (BDC). In horizontal engines, it is known as outer dead centre (ODC)
4. **Stroke:** The travel of the piston from one dead centre to the other is called stroke. The distance between the two dead centres is called the stroke length.

5. **Swept volume:** The volume of the cylinder in between the two dead centres is the swept volume. It is denoted by Vs.
6. **Clearance volume:** The volume of the cylinder in between the top dead centre and the cylinder head is the clearance volume. It is denoted by Vc.



7. **Compression ratio:** The ratio of the volume of the cylinder between the bottom dead centre and the cylinder head to the clearance volume is the compression ratio of the engine. It is denoted by 'r'.

Classification of IC engines

IC engines may be classified in many ways based on the criterion selected for classification.

A. 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:** in which an electric spark is used for igniting the fuel air mixture. Most of the engines using petrol or gaseous fuel belong to this category.

ii) **Compression Ignition (CI) engines:** in which air is compressed to a very high temperature and pressure and fuel is injected to it in the form of a spray. The fuel gets ignited due to the high temperature of the compressed air. Most of the engines using diesel as fuel belong to this category.

B. Based on the number of strokes per cycle

i) **Four stroke engines:** in which one cycle of operation is completed in four strokes of the piston, ie., one power stroke is obtained in four strokes of the piston ie., in two revolutions of the crank shaft.

ii) **Two stroke engines:** in which one cycle of operation is completed in two strokes of the piston, giving one power stroke per two strokes of the piston ie., in each revolution of the crank shaft.

C. Based on the type of fuel used

i) **Gas engines:** in which gaseous fuel such as methane is used as the main fuel.

ii) **Petrol engines:** in which highly volatile liquid fuel such as petrol is used.

iii) **Diesel engines:** in which less volatile liquid fuel such as diesel oil is used.

iv) **Dual - fuel engines:** in which a gaseous fuel or a highly volatile liquid fuel is supplied along with air during the suction stroke and a viscous liquid fuel is injected into the combustion space near the end of the compression stroke.

D. Based on the working cycle.

i) **Otto engine:** in which the engine works based on the Otto cycle (constant volume cycle). Most of the petrol and gas engines work on this cycle.
ii) **Diesel engine:** in which the engine works based on the diesel cycle. Most of the low speed oil engines work on this cycle.
iii) **Dual combustion engine:** in which the engine works on the dual combustion cycle. Most of the high speed oil engines work on this cycle.

E. Based on the application of the engine

i) **Stationary engines** **ii) Mobile engines**

F. Based on the cooling system

i) **Air cooled engines:** **ii) Water cooled engines:**

G. Based on the speed of the engine

i) Low speed engines (up to 350 rpm) ii) Medium speed engines (350 - 1000 rpm) (iii) High speed engines (above 1000 rpm)

H. Based on the number of cylinders

i) Single cylinder engines ii) Multi cylinder engines

I. Based on the cylinder arrangement

i) **Vertical engine ii) Horizontal engine iii)** In - line engine: iv) V- engine:

v) Radial engine: vi) Opposed cylinder engine:

Spark Ignition (SI) Engine

Spark ignition (SI) engines employ external ignition system for initiating the combustion process. **In these engines, fuel is ignited by an electric spark.** Electrical discharge produced between the spark plug electrodes by the ignition system starts the combustion process close to the end of compression stroke. Most of the engines using petrol or gaseous fuel belong to this category. **Spark plug is the most commonly used ignition method used in spark ignition engines**. ***Petrol engines operate on the so called Otto cycle.***

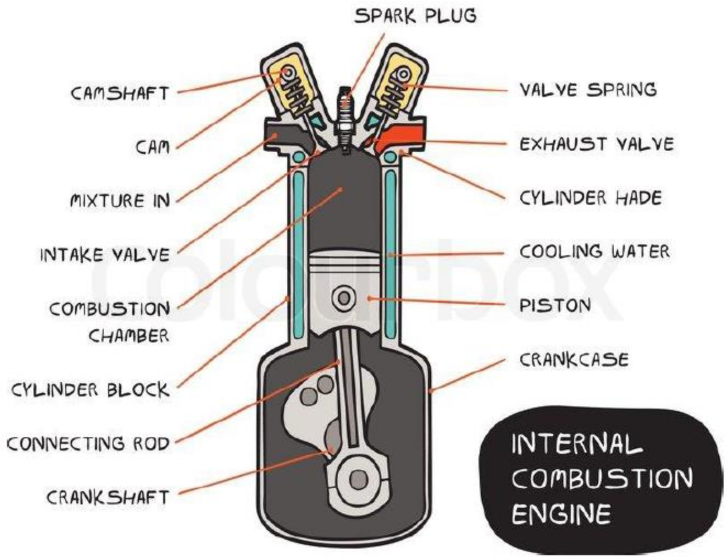


Fig 2.3 SI Engine

In this cycle, heat is supplied and rejected at constant volume. A **homogeneous mixture of air and petrol is supplied to the engine cylinder during the suction stroke.** The fuel air mixture (charge) gets compressed during the compression stroke. At the end of this stroke, fuel is ignited 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.

Four stroke SI Engine (Petrol Engine)

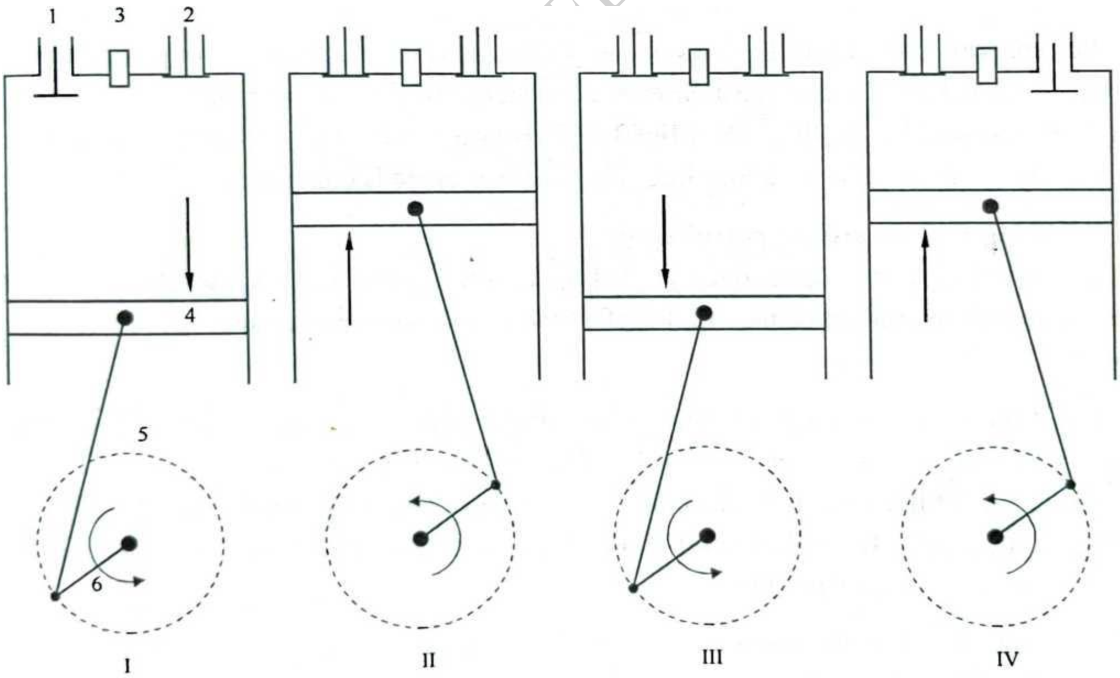
Four stroke petrol engines require 4 strokes of piston or 2 revolution of crank shaft to complete 1 cycle of operation. One power stroke is obtained in four strokes of the piston. A stroke refers to the full travel of the piston along the cylinder from one dead centre to the other. The four-stroke cycle engine is the most common type of small engine.

Working Principle of Four stroke petrol engine

Working Principle of Petrol Engine can be explained by 4 processes or strokes. They are

1) Suction stroke (intake stroke / Induction stroke)
2) Compression stroke
3) Power stroke (Working stroke / Expansion stroke)
4) Exhaust stroke

Refer the figure given below



I. Suction stroke II. Compression stroke III. Working stroke IV. Exhaust stroke

1. Inlet valve 2. Exhaust valve 3. Spark plug 4. Piston 5. Connecting rod 6. Crank

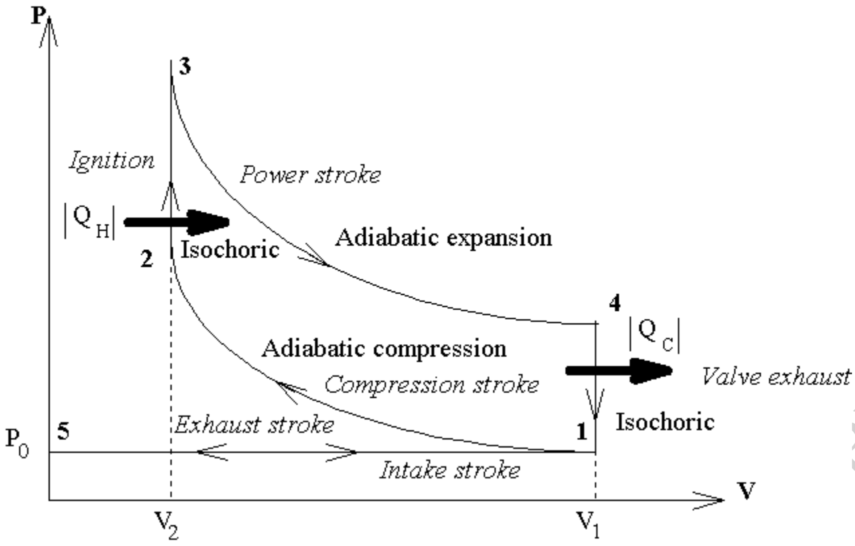


Fig 2.5 P-V diagram for a four stroke petrol (SI) engine

1) Suction stroke (Process 5-1)

During this stroke the **piston moves from top dead centre (TDC) to bottom dead centre (BDC)**. The ***inlet valve opens*** and the **air-fuel mixture** is drawn into the engine cylinder. The ***exhaust valve remains closed*** throughout this stroke. The pressure inside the cylinder is lower than the ambient pressure by an amount that depends upon the speed of engine. This is represented by the ***line 5-1*** in fig-2.5.

2) Compression stroke (Process 1-2)

During compression stroke, the air-fuel mixture is compressed as the ***piston moves from BDC to TDC***. During this stroke ***both inlet and outlet valve remains closed***. The air-fuel mixture is compressed to a high pressure and the pressure at the end of compression process depends upon the compression ratio. This stroke is represented by the ***curve 1-2*** in fig-2.5.

3) Power stroke (Process 3-4)

Ignition Process (Process 2-3) :*Just before the end of this stroke, the spark plug initiates a spark* which ignites the mixture and combustion takes place at constant volume (***line 2-3*** in fig.3.5). ***Both the inlet and exhaust valves remains closed*** throughout this process.

As the fuel air mixture bums, hot gases are produced which drive the piston towards BDC and thus work is done (***Piston moves from TDC to BDC***). This expansion process is shown by the ***line 3-4*** in fig. 2.5. ***Both the valves remain closed*** during this stroke.

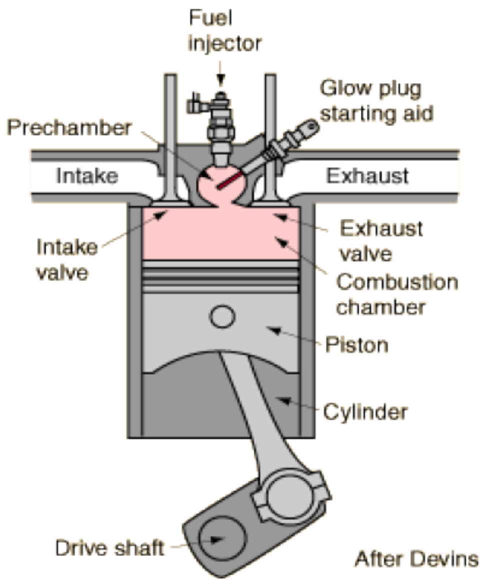
At the end of power stroke exhaust valve opens and exhaust gas flow outside through exhaust valve ***((4-1) Constant volume heat rejection)***.

4) Exhaust stroke (Process 1-5)

The removal of the burnt gases is accomplished during this stroke. ***The piston moves from BDC to TDC*** and the exhaust gases are driven out of the engine cylinder. This operation is represented by the **line 1-5** in fig. 2.5. During this stroke the ***exhaust valve remain opened and the inlet valve remains closed***. By this one cycle is completed and the engine is ready to suck the charge again.

COMPRESSION IGNITION (CI) ENGINE

In Compression Ignition (CI) engines, air is drawn inside the cylinder and compressed to a very high temperature & pressure. The fuel is injected to it in the form of a spray. The fuel gets ignited due to the high temperature of the compressed air. Most of the engines using diesel as fuel belong to this category. ***CI Engines works on the basis of diesel cycle***.



CI Engine

Diesel engine is based on the work of Rudolph Diesel. It operates based on the theoretical air cycle known as Diesel cycle. These engines operate on four stroke or two stroke cycle.

Atmospheric air is drawn into the engine cylinder during the suction stroke and is compressed by the piston during the compression stroke to high pressure and temperature. The temperature of compressed air will be above the ignition temperature of fuel. Just before the end of the compression stroke a metered quantity of fuel under pressure is injected in the form of fine spray by means o of a fuel injector. Due to very high pressure and temperature of the air the fuel ignites and the gases expand displacing the cu piston. After doing 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).

Four Stroke CI Engine (Four Stroke Diesel engine)

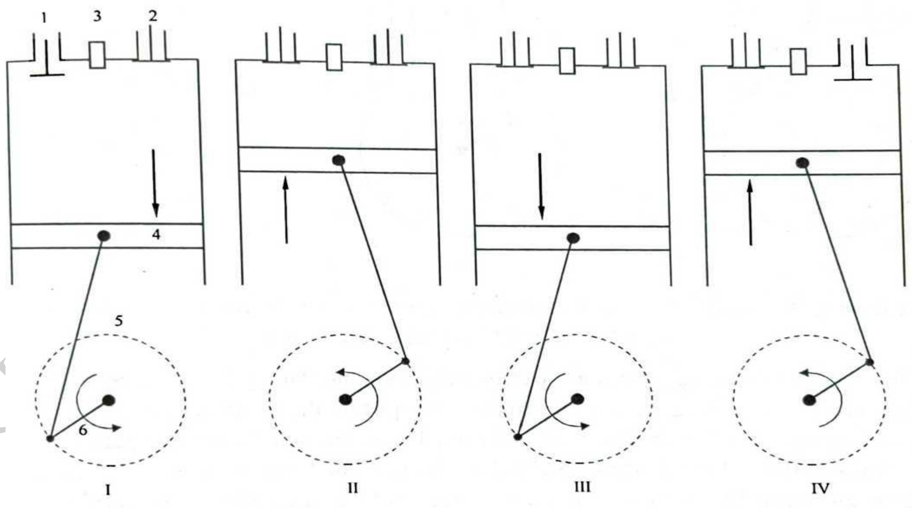
Four stroke diesel engines require 4 strokes of piston or 2 revolution of crank shaft to complete 1 cycle of operation. The operation of C.I. engines (or diesel engines) is practically the same as those of S.I. engines. The cycle in both the types, consists of suction, compression, ignition, expansion and exhaust.

Working principle of diesel engines (Compression Ignition engines)

Working Principle of diesel Engine can be explained by 4 processes or strokes. They are

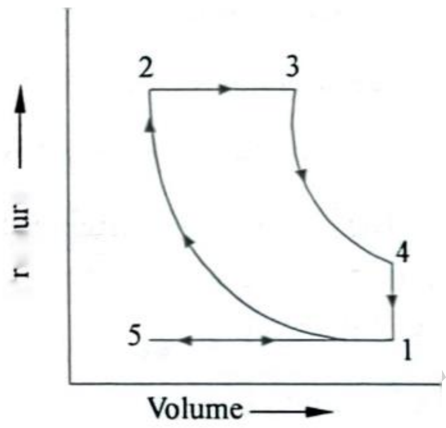
1) Suction stroke (intake stroke / Induction stroke)
2) Compression stroke
3) Power stroke (Working stroke / Expansion stroke)
4) Exhaust stroke

Refer the figure below



I. Suction stroke II. Compression stroke III. Working stroke IV. Exhaust stroke
1. Inlet valve 2. Exhaust valve 3. Fuel Injector 4. Piston 5. Connecting rod 6. Crank
Fig. 3.3 Working of four stroke diesel engine

Fig 2.6 Diesel cycle for four stroke diesel engine



1) Suction stroke (Process 5-1)

During this stroke the ***piston moves from top dead centre (TDC) to bottom dead centre (BDC). The inlet valve opens*** and ***air*** at atmospheric pressure is drawn into the engine cylinder. The exhaust valve remains closed. This operation is represented by the **line 5-1** in fig. 2.6

2) Compression stroke (Process 1-2)

In this stroke the ***piston moves towards TDC to BDC*** and ***compresses the enclosed air*** to high temperature and pressure. This operation is represented by **curve 1-2** in fig.2.6. ***Both the inlet and exhaust valves remains closed*** during this stroke.

3) Power stroke (Process 3-4)

Ignition process (Process 2-3): Towards the ***end of compression stroke a metered quantity of fuel is injected into the hot compressed air in the form of fine spray*** by means of a ***fuel injector***. The fuel starts burning, theoretically, at constant pressure and pushes the piston from TDC. This is shown by line 2-3 in fig.2.6.

At point 3, fuel supply is cut off. The high pressure gas in the cylinder expand upto point 4, doing work on the piston ***(Piston moves from TDC to BDC)***. The **inlet and exhaust valves remain closed** during this stroke. ***At the end of this stroke the exhaust valve opens.***

Process 4-1; Constant volume hear rejection

At the end of stroke exhaust valve opens and exhaust gas flow outside through exhaust valve

4) Exhaust stroke (Process 1-5)

The piston moves from BDC to TDC and the burnt gases escape through the exhaust valve. During this stroke the ***inlet valve remains closed***. This stroke is represented by the line 1-5 in Fig 2.6. During this stroke the ***exhaust valve remains opened*** and the inlet valve remains closed. This completes the cycle and the engine is ready to suck air again.

<u>Two Stroke Petrol (SI) Engine</u>

<u>Two stroke petrol engines require 2 strokes of piston or 1 revolution of crank shaft to complete 1 cycle of operation.</u> In two stroke engines one cycle of operation is completed in two strokes of the piston by eliminating separate suction and exhaust stroke. **One power stroke is obtained in two strokes of the piston**. **Here ports are provided instead of valves.**

Working of Two stroke petrol engine

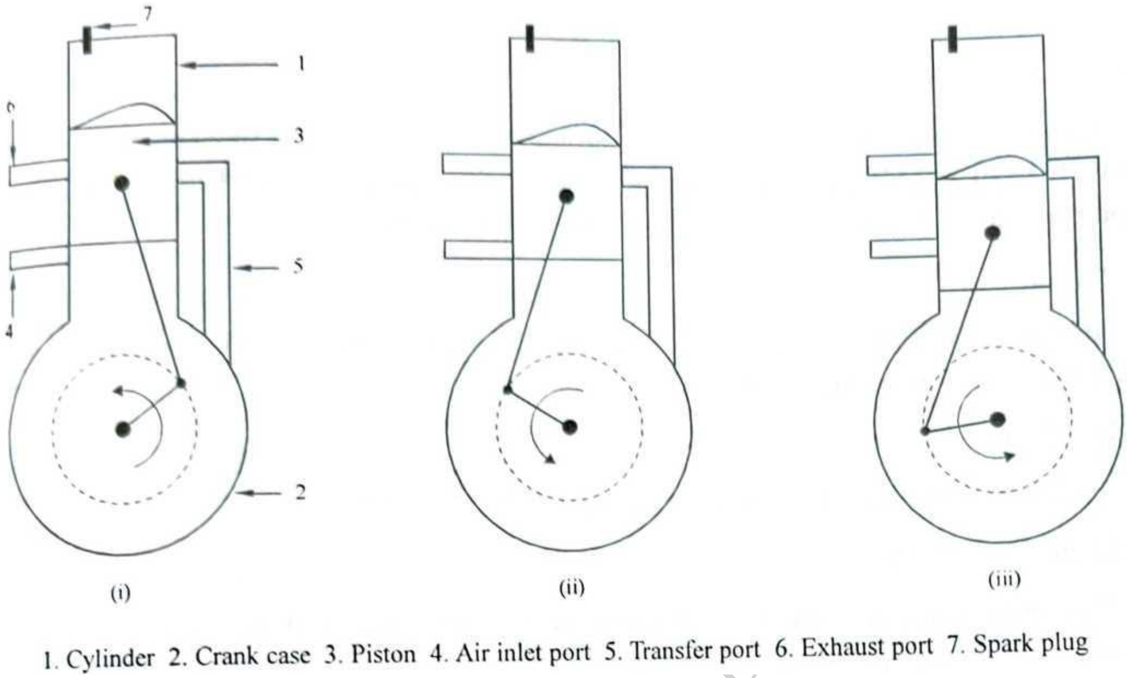


Fig 2.7 Working of Two stroke petrol engine

Fig.2.7 shows the working of a two stroke petrol engine. The cylinder is connected to a closed crankcase.

During the upward stroke of the piston, the air fuel mixture in the cylinder is compressed. At the same time fresh air - fuel mixture enters the crank case through the inlet port. Fig.2.7 (i).

Towards the end of this stroke, the fuel air mixture is ignited using an electric spark from the spark plug. In this case, combustion process is assumed to take place at constant volume.

The piston, then travels downwards due to the expansion of the gases (fig.2.7 (ii)) and near the end of this stroke the piston uncovers the exhaust port and the burnt gases escape through this port.

The transfer port is then uncovered (fig.2.7 (iii)) and the compressed air fuel mixture from the crankcase flows into the cylinder. The incoming fresh air fuel mixture helps to remove the burnt gases from the engine cylinder. Refer fig.2.7.

NOTE

Remember – For Two stroke engines, suction process is happening when the air and fuel mixture is taken from crank case to the cylinder through transfer port (not when the air and fuel mixture enters the crank case through inlet port).

Two Stroke Diesel (CI) Engine

Two stroke diesel engines require 2 strokes of piston or 1 revolution of crank shaft to complete 1 cycle of operation. In two stroke engines one cycle of operation is completed in two strokes of the piston by eliminating separate suction and exhaust stroke. One power stroke is obtained in two strokes of the piston.

Working of Two stroke diesel engine

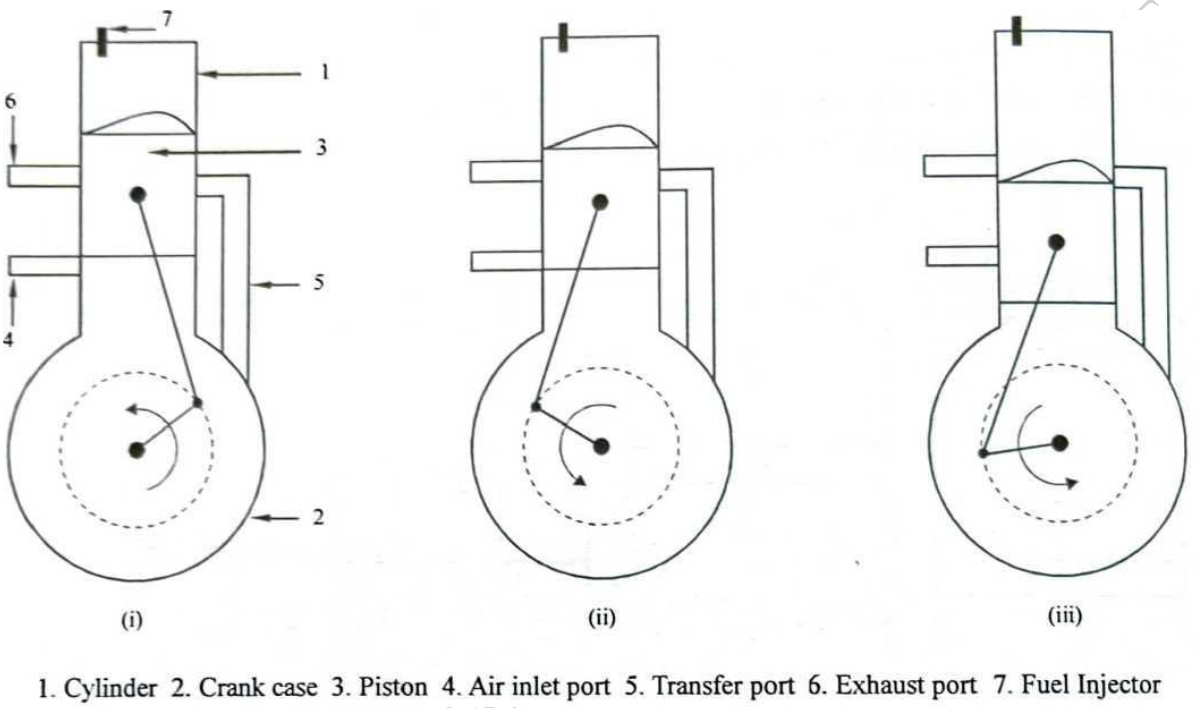


Fig 2.8 Working of two stroke diesel engine

Fig.2.8. shows the working of a 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 crank case through the air inlet port. Fig.2.8.(i).

Towards the end of this stroke fuel is introduced in the form of fine spray by the fuel injector and due to the high pressure and temperature of the air, the fuel starts burning.

The piston, then travels downwards due to the expansion of the gases (fig.2.8.(ii)) and near the end of this stroke the piston uncovers the exhaust port and the burnt gases escape through this port.

The transfer port is then uncovered (fig.2.8(iii)) 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 Engines

Criteria	Four Stroke Engine	Two Stroke Engine
Thermodynamic cycle	Cycle is completed in 4 strokes. One power stroke in 2 revolutions of crankshaft.	Cycle is completed in 2 strokes. One power stroke in 1 revolutions of crankshaft.
Thermal efficiency	Higher at normal and partial loads	Lower at normal and partial loads
Volumetric efficiency	Higher due to more time for suction	Lower due to less time for suction
Power output by weight ratio	Lower, a heavier engine is required to produce a given output because of one power stroke in two revolutions	Higher, a lighter and compact engine produces the given output because of one power stroke in each revolution
Cooling & Lubrication	Normally water cooled, Except in 2 or 3- wheelers. Less wear and tear, less lubricant required	Normally air cooled, wear and tear is more. Usually oil is mixed with fuel, more lubrication is required
Valve mechanism	Required, design gets complicated	Not required, design is simplified
Initial cost	High	Low
Use	Heavy duty vehicles where efficiency is more important	Light vehicles where compactness and weight are more important.
Effect on environment	Low	More polluting gases
Turning moment diagram	Less uniform and heavier flywheel is required.	More uniform and lighter fly wheel is required.

Efficiencies of IC Engines

1. **Mechanical Efficiency**

It is defined as the ratio of brake power to the indicated power.

i.e, $\eta_{mech} = BP/IP$;where, BP is the brake power and IP is the indicated power

Mechanical efficiency is thus indicator of how efficiently indicated power is converted into brake power.

2. Volumetric Efficiency

It is defined as the ratio of the volume of air sucked inside per cycle per cylinder at the ambient condition to the stroke volume of the cylinder.

η_{vol} = (Volume of air inducted at ambient condition) / (Stroke volume)

= (mass of air inducted at per cycle) / (Mass of air occupying the stroke volume at ambient condition)

$$= \frac{\dot{m}_a \text{kg/min}}{\rho_a \times V_s \times \left(N \text{ or } \frac{N}{2}\right)}$$

where V_s is the stroke volume.

$$\dot{m}_a = \eta_{vol} \times \rho_a \times \frac{\pi}{4} D^2 L \left(N \text{ or } \frac{N}{2}\right)$$

3. Thermal Efficiency

Thermal efficiency of an IC engine is expressed as the ratio of power output and the rate of energy input in the form of fuel. It can be defined on the basis of indicated or brake power output.

3a) Indicated thermal efficiency

- It is defined as the ratio of indicated power output and the rate of energy input in the form of fuel.

$$\eta_{i.th} = \frac{IP}{\dot{m}_f \times HV}$$

3b) Brake Thermal Efficiency

- It is defined as the ratio of brake power output and the rate of energy input in the form of fuel.

$$\eta_{br.th} = \frac{BP}{\dot{m}_f \times HV}$$

Relation between efficiencies

$$\eta_{mech} = \frac{BP}{IP} = \frac{BMEP}{IMEP} = \frac{\eta_{i.th}}{\eta_{br.th}}$$

Air and Fuel system

Air system for petrol engine

Air system for petrol engine essentially consists of air filter and carburetor. For burning of fuel, oxygen is required . In Internal combustion engine oxygen is obtained from the atmospheric air. Air after cleaning in the air filter is mixed with fuel in correct ratio using a carburetor . For complete combustion, the air - fuel ratio must be about 15:1 by weight. There is a range of air - fuel ratio within which combustion of fuel can occur. This range of air-fuel ratio is approximately 8:1 to 20:1 by weight. Outside this range the mixture is either too rich or too lean.

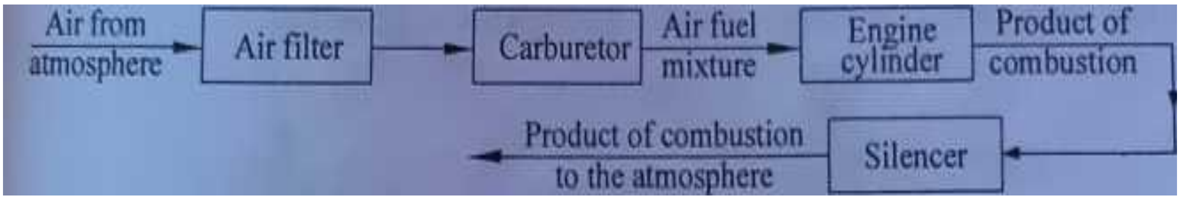


Fig.3.8. Air system for petrol engine.

The carburetor provides air fuel mixture in the required ratio in accordance with the requirements of the engine. At the time of starting of the engine a rich mixture, about 10:1 is required. During normal running a comparatively lean mixture, 15:1, serves the purpose. During acceleration period a rich mixture is needed. This air fuel mixture is supplied to the engine cylinder through the inlet valve. Inside the cylinder, the mixture is burned and there by the chemical energy of fuel is converted into thermal energy. The product of combustion, after expanding, is discharged to the atmosphere. Generally a silencer or muffler is used to reduce the noise.

Fuel system for petrol engine

Fuel supply system for a petrol engine consists of a fuel storage tank, fuel pump, filter, carburetor, and inlet manifold from where the fuel enters the engine cylinder through inlet valve.

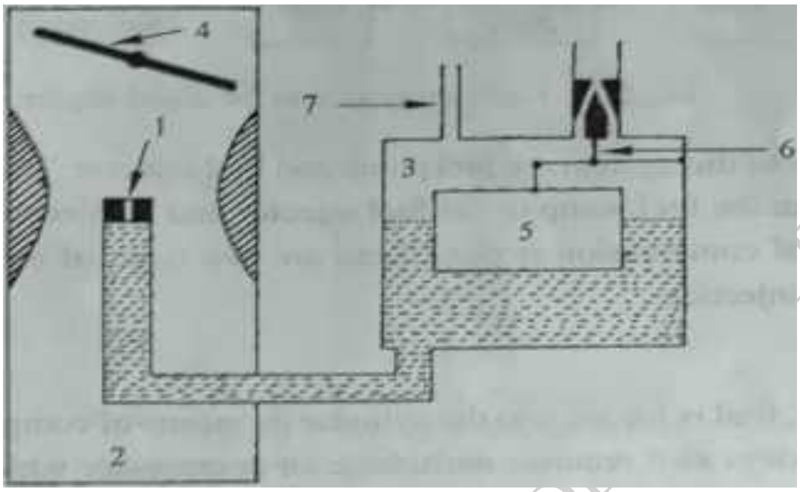
Fig.3.9. Fuel supply system for petrol engine.

The fuel can be supplied to the engine either under gravity or using a pump. In the gravity system, the fuel storage tank is placed at a higher level than the carburetor so that the fuel flows to the carburetor under gravity. When storage tank is kept below the level of carburetor fuel pump is required to force the fuel to the carburetor. The fuel pump and the carburetor are the main components of the fuel supply system.

Carburetor

Carburetor is used to discharge into the air stream the desired quantity of liquid fuel to produce a homogeneous air - fuel mixture, A good carburetor must produce automatically the desired air-fuel ratio at all speeds and loads of the engine. The basic principle used in carburetor is that when a volatile fuel is placed in the passage of high velocity air, the fuel gets vapourised at a faster rate.

Fig. 3,11 illustrates a simple carburetor . It consists of a jet situated at the centre of a venturi tube. Petrol is supplied to the venturi from a float chamber. A throttle valve controls the amount of air fuel mixture delivered to the engine.



l.Jet 2, Venturi tube 3, Float.chamber 4,Throttle valve 5, Float 6. Float needle 7. Air vent

Fig, 3.11. Simple carburetor

Petrol is pumped into the float chamber by means of a fuel pump. The level of petrol in the float chamber is maintained constant at a correct height by a float. When the fuel level is below normal, the float needle gets lowered and fuel enters the float chamber. When the fuel level attains its normal level, the float needle closes the fuel supply line. This mechanism maintains constant fuel level in the float chamber.

When the engine is running, the suction of engine causes air to run through the venturi tube. The diameter of venturi tube surrounding the tip of the fuel nozzle (fuel jet) is reduced (known as venturi throat). This will increase the velocity of air at the throat and reduce the pressure. The pressure at this point is less than atmospheric . In the float chamber the pressure is atmospheric. Due to this pressure difference , fuel will flow into the air stream at the venturi throat and gets vapourised.

The function of the throttle is to Control the speed and power of the engine. The more the throttle is closed, the greater will be the obstacle to the flow of air and legs will be the quantity of mixture delivered to the cylinder. As the throttle is opened, more air flows through the venturi tube, and consequently the power of the engine increases.

Fuel system for diesel engines

Fuel supply system for diesel engine consists of a fuel storage tank, filter, low pressure or transfer pump, high pressure fuel pump and fuel injector.

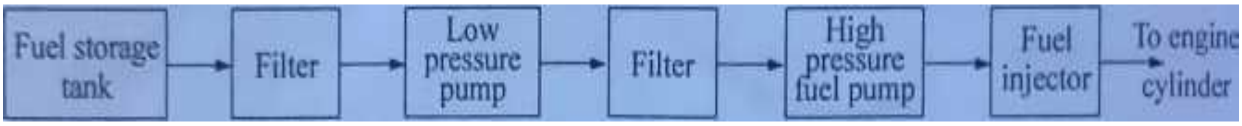


Fig. 3.12. Fuel supply system for diesel engine

The main parts of this system are fuel pump and fuel injector. The fuel is supplied at very high pressure from the fuel pump to the fuel injector and is injected to the engine cylinder towards the end of compression stroke. There are two types of injection systems. (i) Air injection (ii) Solid injection

Air injection

In this method, fuel is forced into the cylinder by means of compressed air. This method is obsolete these days as it requires multistage air compressor which increases the engine weight and cost. Moreover the compressor consumes about 10 % of the power developed by the engine and hence the output of the engine is reduced.

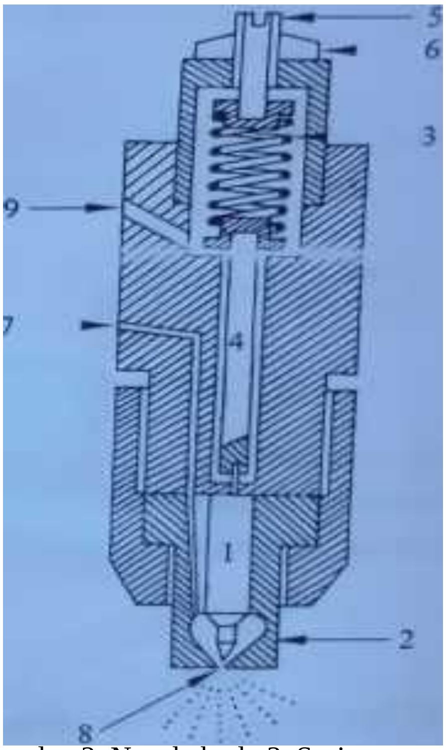
Solid injection (Mechanical injection)

In this method a fuel pump is used to supply measured quantity of fuel at high pressure to the injector. The injector injects the fuel at a very high velocity into the engine cylinder in the form of fine spray.

Fuel injector

Fig. 3.14. shows a typical fuel injector. It consists of a nozzle valve fitted in a nozzle body

The nozzle valve is held on its seat by a spring which exerts pressure through a spindle. An adjusting screw and a lock nut are provided in order to adjust the lift of the nozzle valve. The fuel oil under pressure from fuel pump enters the injector through the passage and lift the nozzle valve. The fuel travels down the nozzle and is injected into the engine cylinder in the form of fine spray. When the fuel pressure falls, the nozzle valve occupies its seat under the spring force and fuel supply is cut off. Any leakage of fuel oil at the end of compression is fed back to the fuel pump suction chamber by a leak off pipe.



1. Nozzle valve 2. Nozzle body 3. Spring 4. Spindle 5. Adjusting screw 6. Locknut 7. Passage 8. Nozzle 9. Leak off connection

Fig. 3.14. Fuel injector

Cooling systems in IC Engines

The combustion of air and fuel takes place inside the engine cylinder and hot gases are generated. An IC engine at the best can convert only about 30% of the heat into work. The temperature of gases will be around 2300-2500°C.**If the heat absorbed by the engine parts is not removed it will cause excessive rise in temperature of these parts. This high temperature may result into burning of oil film between the moving parts and may result into seizing or welding of the same.** So, this temperature must be reduced to about 150-200°C at which the engine will work most efficiently. **Too much cooling is also not desirable since it reduces the thermal efficiency.** So, the object of cooling system is to keep the engine running at its most efficient operating temperature. **So the purpose of cooling system is to keep the engine parts from getting too hot and not to keep the engine parts cool.**

The two types of cooling systems normally used in IC engines are

1) Air cooling
2) Liquid cooling (water cooling)

Air cooling

The cooling method in which heat is directly dissipated into the air around the cylinder is called air cooling. The basic principle involved in this type of cooling system is to have a current of air flowing continuously over the heated surface from where the heat is to be removed. It is used in motor cycles, airplane engines and small stationary engines. In this type, heat is dissipated directly to the air after being conducted through the cylinder walls. Usually, fins are provided on the outer surface of the cylinder and cylinder head to increase the area exposed to the cooling air.

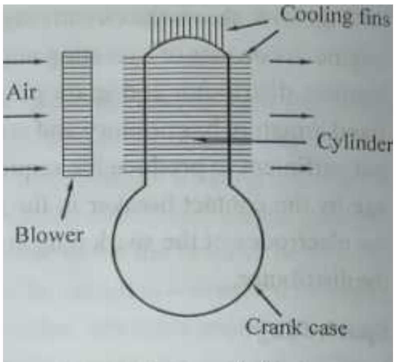


Fig. 3.18. Air cooled engine

In some cases, a blower is fitted which throwsair on these fins to increase the heat transfer rate. This is shown in fig. 3.18. In mobile engines, the forward velocity of the engine helps in increasing the air velocity.

The advantages of air cooling includes simplicity, lightness, cheapness and, absence of water and its circulation system. The main disadvantage of this system is the non uniformity in cooling. Also, it is difficult to control the cooling rate.

- **Advantages of Air Cooled System**

(a) Radiator/pump is absent hence the system is light.

(b) In case of water cooling system there are leakages, but in this case there are no leakages.

(c) Coolant and antifreeze solutions are not required.

(d) Due to absence of water, this system can be used in cold climates, where if water is used it may freeze.

- **Disadvantages of Air Cooled System**

(a) Comparatively it is less efficient.

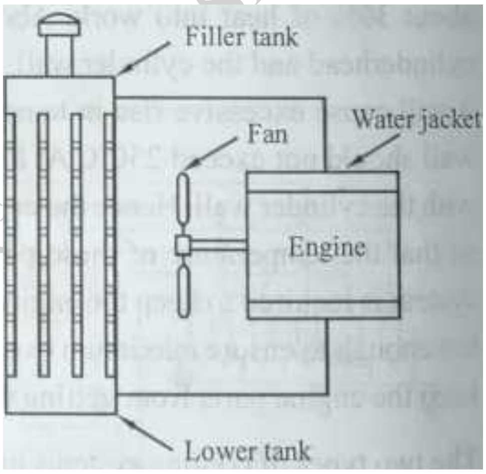
(b)Non uniformity in cooling.

(c) Difficult to control the cooling rate.

(d) It is used in aero planes and motorcycle engines where the engines are exposed to air directly.

Liquid cooling (water cooling)

In liquid cooling water is generally used as the cooling medium. It is circulated through passages around the main components which are getting heated. These passages are called water jackets. The circulation of water is obtained either by using a pump or by gravity force.



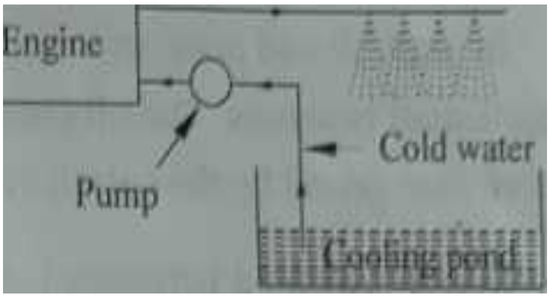
In this method, cooling water jackets are provided around the cylinder, cylinder head, valve seats etc. The water when circulated through the jackets, it absorbs heat of combustion. This hot water will then be cooling in the radiator partially by a fan and partially by the flow developed by the forward motion of the vehicle. The cooled water is again recirculated through the water jackets.

Fig. 3.19 shows water cooling system used in an automobile engine. In this, the water after passing through the engine jackets flows to a radiator. In the radiator the heated water gets cooled by an air flow caused by the forward motion of the automobile. To increase the heat transfer area the radiator tubes are provided with fins. In most cases, a fan is provided to establish forced circulation of air over the radiator tubes which increases the heat transfer rate.

Water cooling system is classified as

1) natural or gravity circulation system,
2) forced circulation system
3) open circulation system.

In natural circulation system the change in density of water due to cange in temperature causes it to circulate in the system. This system is also known as thermo-syphon cooling system**. In forced circulation system water is circulated through the water jackets using pump.** The power required to run the pump is taken from the engine itself. In this a pump is used to draw water from a cooling pond and to circulate it thorough the engine jackets. The water after circulation returns to the cooling pond as shown in fig. 3.20.



Lubrication of IC engines

Lubrication of engine parts are necessary in order to reduce friction between moving parts of the engine. If the moving parts are allowed to rub against each other, they will develop considerable friction and heat, resulting in excessive wear. This can be reduced by placing a film of lubricating oil between the moving part so that they ride on the oil film instead of against each other. This will decrease the power required to overcome friction and will reduce the wear between rubbing parts.

The oil in the engine has several functions to perform. It must remove the heat from the parts it comes in contact With, keep the metal surfaces apart and prevent friction and wear by maintaining an unbroken film of oil btween the moving and stationary surface. The oil must also seal the space between piston rings and cylinder walls to pervent leakage of working gases. In addition, the oil must clean the metal parts it comes in contact with and hold in suspension any dirt, metal and carbon particles in the oil.

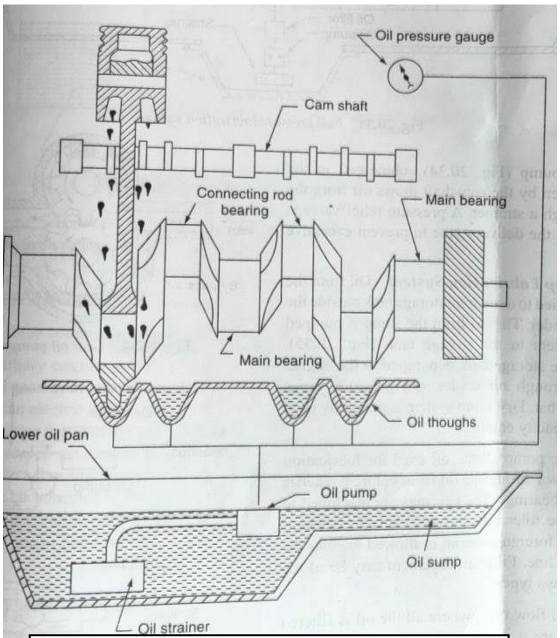
Main parts to be lubricated in an IC engine are crankshaft, bearings, crank pin, piston, cylinder walls, cams, valve stems, gears etc.

Types of lubricating systems

The various systems supply oil to the moving parts by splash, by gravity, by pressure feed or by some combination of these methods.

The splash system is the simplest method of lubrication. Such systems are usually designed with an oil reservoir in the base of the engine. When the connecting rod moves up it splashes the oil in the form of a spray. The internal parts of the engine are lubricated by this oil spray. This type of lubrication is employed in some types of small single cylinder stationary engines and on engines employed in scooters.

The splash and circulating system is similar in operation to the splash system, except tha an oil pump is employed to keep the reservoir with oil.



Splash lubrication system

In a splash and pressure system, an oil pump supplies oil under pressure to the main and crankshaft bearings. The oil pump also supplies oil to the reservoir. Other main parts to be lubricated get oil by the splash system.

In a forced feed (pressure) system, oil is forced by an oil pump to all main bearings connecting rod bearings, camshaft bearings and the gears. The valve mechanism also gets oil under pressure. The cylinder walls, piston and the piston pins are lubricated by the oil spray thrown off from the connecting rod and crank shaft. Most of the present day engines are lubricated by this type of lubricating system.

Desirable properties of lubricants

1. The oil should maintain sufficent viscosity under all ranges of temperatuers. Oil with high viscosity index is perferred. This will avoid very high viscosity at cold temperatures and very low viscosity at high temperatures.

2. The oil must not vaporise in its operating temperature range.

3. The oil should have high specific heat to remove the heat generated in the parts.

4. The oil must be free from corrosive acids, moisture etc.

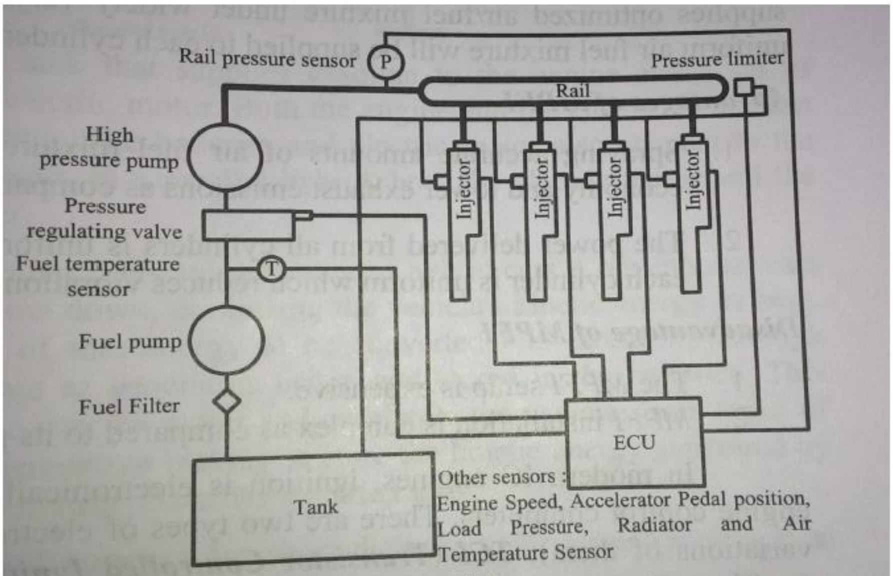
5. The oil should have considerable adhesive quality to permit the oil particles to cling to metal surface.

6. The oil should have good cohesive quality so that a continuous film is formed betwen rubbing surfaces.

Common Rail Direct Injection (CRDI)

CRDI is a type of advanced fuel injection technology used in Diesel engine fuel systems. CRDI consists of a common fuel rail to supply fuel to injectors. Common rail distributes the fuel to the computer controlled injectors at a constant pressure of up to 1600 bar. The rail is fed by a high pressure fuel pump. The pressure in the rail, as well as the start and end of the signal that activates the injector for each cylinder are electronically controlled.

Electronic control unit(ECU) receives signals from various sensors and uses those signals to operate injection. ECU calculates injected fuel quantity, start of injection, duration of injection and control the correct functioning of the injection system as a whole. Common rail engines maintain a constant pressure regardless of the injection sequence. More accurately measured and timed fuel spray in the combustion chamber significantly reduces unburned fuel and increases the fuel efficiency.



CRDi

Elements of CRDi

- **Low pressure circuit:** comprises of fuel tank, fuel pump and fuel filter. Responsible for transporting the fuel to the high pressure circuit
- **High pressure circuit:** comprises of high pressure pump with pressure control valve, common rail with rail pressure sensor and injectors.
- **ECU and Sensors:** ECU receives and evaluates the signal from the sensors, viz., speed sensor, air temperature sensor, air mass meter and rail pressure sensor.

Advantages of CRDI

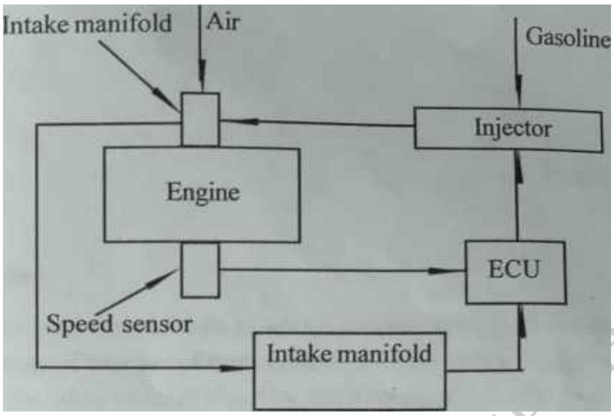
- Flexibility in controlling both the injection timing and injection rate.
- Deliver 25% more power and torque
- Lower level of noise and vibration
- Higher mileage
- Lower emission and improved performance

Disadvantages of CRDI

- Costly spare parts
- More maintenance

MULTI POINT FUEL INJECTION(MPFI)

MPFI is used in SI engines for fuel injection. In single point injection system one or two injectors are mounted inside the throttle body assembly of the engine. Multi Point Fuel Injection [MPFI] system has one injector for each engine cylinder.



Fuel is injected in more than one location. This system injects fuel into individual cylinders based on commands from the on board engine management system computer popularly known as Engine Control Unit. [ECU]. The ECU primarily controls the ignition timing and quantity of fuel to be injected.

The ECU is controlled by the data input from a set of sensors located all over the engine and its auxiliaries. These sensors detect the various operating conditions of the engine and the performance required out of it.

Fig shows the block diagram of an MPFI system, air enters into the intake manifold. The manifold pressure sensor detects the intake manifold vaccum and sends the information to the ECU. The speed sensors also sends information about the rpm of the engine to the ECU. The ECU in turn sends commands to the injector to control the amount of gasoline supply for injection. When the injectors spray fuel into the intake manifold the gasoline mixes with the air and the mixture enters the cylinder of the engine.

Advantages of MPFI

1. The difference in power developed in each cylinder is minimum.
2. Vibration of engine equipped With the system is less.
3. Immediate response to sudden acceleration and deceleration
4. Since the engine is controlled by ECM [Engine Control Module] more accurate amount of air fuel mixture will be supplied and as a result complete combustion takes place. This leads to effective utilization of fuel supplied and hence low emission level.
5. The mileage of the vehicle is more.
6. Better fuel economy and lower emissions

7. Better performance and less vibrations

Disadvantages

1. Expensive setup
2. System is complex

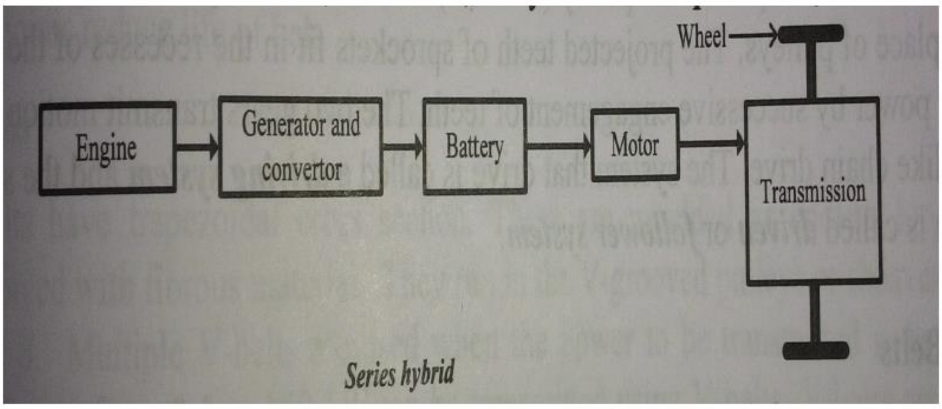
HYBRID ENGINES

A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle (eg. A conventional internal combustion engine and also a high voltage electric motor). Concept of hybrid drive combines the best aspects of IC engines and Electric drives. **The basic principle with hybrid vehicles is that the different motors work better at different speeds; the electric motor is more efficient at producing torque, or turning power, and the combustion engine is better for maintaining high speed** (better than typical electric motor). Switching from one to the other at the proper time while speeding up yields a win-win in terms of energy efficiency, as such that translates into greater fuel efficiency, for example.

Hybrid engines can be categorized into

1) Series Hybrid
2) Parallel Hybrid

Series Hybrid



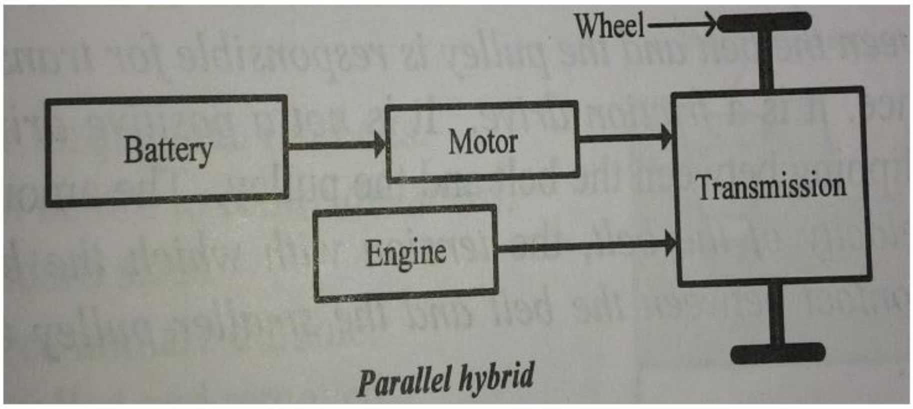
Series hybrid

In series hybrid engines, The IC engine turns a generator, and the generator can either charge the batteries or power an electric motor that drives the transmission. The operations can be;

Engine mode operation: Engine operates a generator, that operates a motor, which in turn drive the wheels.

Battery mode operation: Battery directly drives the motor which in turn drive the wheels

Parallel Hybrid



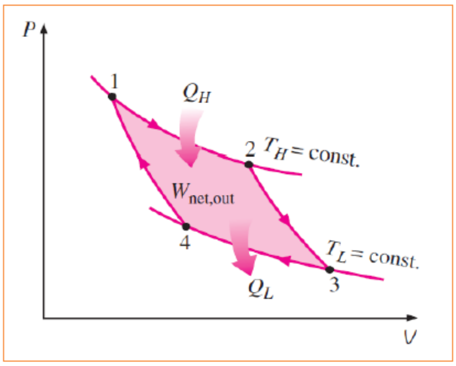
Parallel hybrid

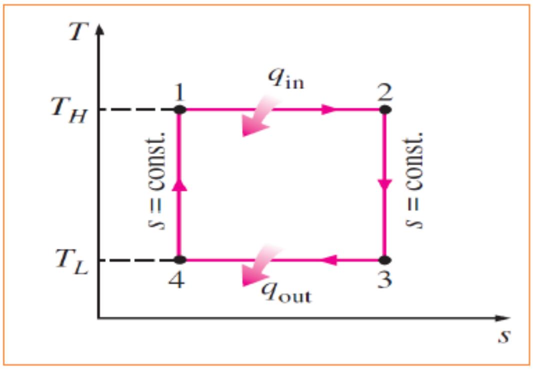
Fuel tank supplies gasoline to the engine and a set of batteries that supplies power to the electric motor. Depending on requirement, Engine alone or Motor alone or Engine and Motor together can drive the wheels. This system permits the engine to recharge the battery while powering the vehicle.

Problems of Air standard cycles

Q1. A Carnot cycle works with adiabatic compression ratio of 5. The volume of air at the beginning of isothermal expansion is $0.5 m^3$. If the maximum temperature and pressure is limited to 550 K and 21 bar, determine the minimum temperature in the cycle.

Ans:





Process 1-2, Isothermal expansion proc

Process 2-3, Isentropic expansion process

Process 3-4, Isothermal compression process

Process 4-1, Isentropic compression process

Given,

Adiabatic compression ratio, $V_4/V_1 = 5$

Volume of air at the beginning of isothermal expansio , $v_1 = 0.5m^3$

Maximum temperature in the cycle = T_3 = 550K

Maximum pressure in the cycle = P_2 = 21 bar

To find,

Minimum temperature in the cycle T_3

For process 4-1, Isentropic compression process

$T_4/T_1 \quad = (V1/V4)^{\Upsilon-1}$

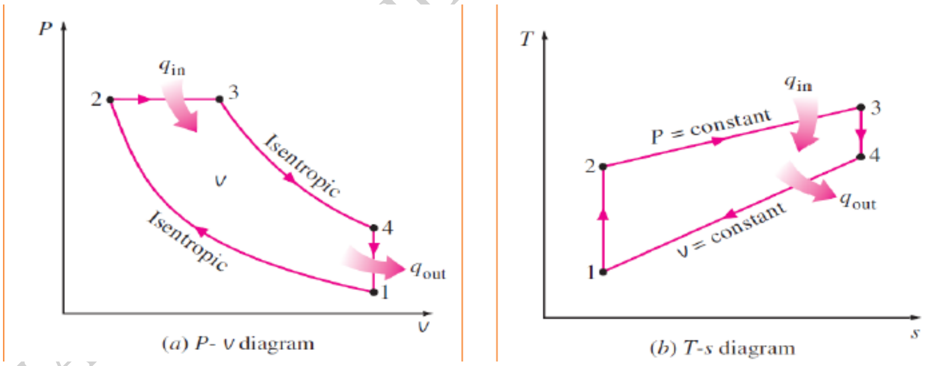
$T_4 \quad = T_1 \times (V1/V4)^{\Upsilon-1}$

$= 550 \times (1/5)^{1.4-1}$

$= 288.92$ K = 289 K

Q.2 An engine working on diesel cycle has diameter 150mm and stroke 200mm. The clearance volume is 20% of the swept volume. Determine the compression ratio and air standard efficiency of the engine if the cut off takes place at 10% of the stroke?

Ans:



(a) P- v diagram (b) T-s diagram

Process 1-2 Isentropic compression

Process 2-3 Isobaric heat addition (constant pressure heat addition)

Process 3-4 Isentropic expansion

Process 4-1 Isochoric heat rejection

Given,

Diameter of the cylinder = 150mm

Stroke length h = 200mm

Clearance volume V_2 = 20% of swept volume = .20 x $(v_1\text{-}v_2)$

Cut off takes place at 10% of the stroke.

To find,

(i) Compression ratio, r

Clearance volume V_2 = 20% of swept volume = .20 x $(V_1\text{-}V_2)$

$V_2 = .20 \times (V_1 - V_2)$

$V_2 = .2\ V_1 - .2\ V_2$

$r = 1.2/.2 = 6$

(ii) Air standard efficiency of the engine, η

Cut off takes place at 10% of the stroke

$V_3 = V_2 + 0.10\ (V_1 - V_2)$

$= V_2 + 0.10\ (6V_2 - V_2)$

$= 1.5\ V_2$

Cut off ratio, $\rho = V_3/V_2$

$= 1.5$

Air standard efficiency of the engine, η $= 1 - (1/r^{\Upsilon-1}) \times (1/\Upsilon) \times [(\rho^{\Upsilon}-1)/(\rho-1)]$

$= 1 - (1/6^{1.4-1}) \times (1/1.4) \times [(1.5^{1.4} - 1)/(1.5-1)]$

$= 1 - 0.488 \times 0.714 \times [0.76/0.5]$

$= 1 - 0.53$

$= 0.47$

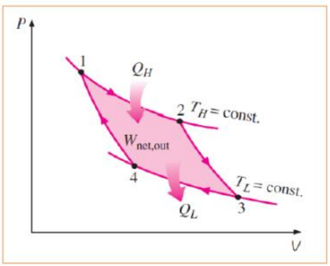
$= 47\%$

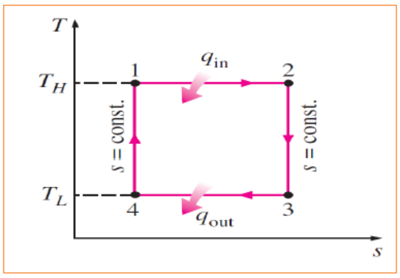
Q.3 A Carnot engine working between 400°C and 40°C produces 130 kJ of work. Determine

(i) The engine thermal efficiency.

(ii) The heat added.

Ans:





Process 1-2, Isothermal expansion process

Process 2-3, Isentropic expansion process

Process 3-4, Isothermal compression process

Process 4-1, Isentropic compression process

Given,

$T_1 = T_H = 400^0C = 673$ K

$T_3 = T_l = 40^0C = 313$ K

Work produced W = 130 kJ

To find

(i) The engine thermal efficiency.

The engine thermal efficiency η = $1 – T_3/T_1$

= 1- 313/673

= 0.53 = 53%

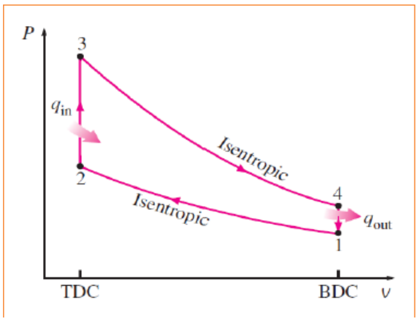
(ii) The heat added.

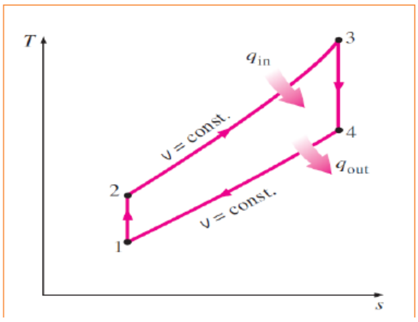
The engine thermal efficiency, η = Work done/ Heat added

⇨ Heat added = Work done / η
= 130/0.53
= 245.28 kJ

Q.4 A petrol engine takes air at 100 kPa and 300 K. Determine the air standard efficiency of the engine if the clearance volume is 10 % of that of cylinder volume. Also find the maximum pressure if the maximum temperature is limited to 600 ^{0}C.

Ans:





Process 1-2 Isentropic compression

Process 2-3 Isochoric heat addition

Process 3-4 Isentropic expansion

Process 4-1 Isochoric heat rejection

Given,

Pressure before isentropic compression P_1 = 100 kPa

Temperature before isentropic compression T_1 = 300 K

Clearance volume is 10% of the cylinder volume.

Maximum temperature in the cycle $T_3 = 600^0C$

To find,

(i) Air standard efficiency of the engine, η

Air standard efficiency of the engine, $\eta = 1 – [1/(r_k^{\gamma -1})]$

Cylinder volume $= V_1$

Clearance volume $V_2 = 0.1 \times V_1$

Compression ratio $r_k = V_1/V_2$

$= V_1/0.1V_1$

$= 10$

Air standard efficiency of the engine, $\eta = 1 – [1/(r_k^{\gamma -1})]$

$= 1 - [1/(10^{1.4-1})]$

$= 1 – 0.40$

$= 0.60 = 60\%$

(ii) Maximum pressure P_3

For process 1-2 Isentropic compression

$P_2/P_1 = (V_1/V_2)^{\gamma}$

$= r^{\gamma}$

$= 10^{1.4}$

$P_2 \quad = P_1 \times 10^{1.4}$

$= 100 \times 10^{1.4}$

$= 2511.89$ kPa

$T_2/T_1 \quad = (V_1/V_2)^{\gamma-1}$

$T_2 \quad = T_1 \times (V_1/V_2)^{\gamma-1}$

$= T_1 \times r^{\gamma-1}$

$= 300 \times 10^{1.4-1}$

$= 753.57$ K

Process 2-3 Isochoric heat addition

$P_3/T_3 \quad = P_2/T_2$

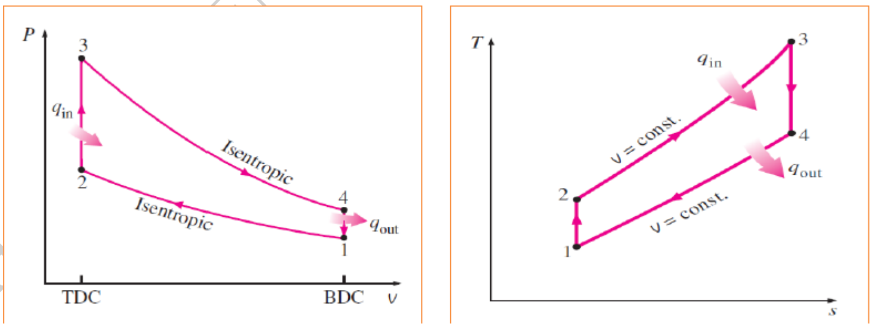
$P3 = T3 \times P_2/T_2$

$= 873 \times 2511.89/753.57$

$= 2909.98$ kPa $= 2910$ kPa

Q.5 The efficiency of an Otto cycle is 60% and $\gamma = 1.5$. Determine the compression ratio

Ans:



Given,

Efficiency of Otto cycle $\eta \quad = 60\% = 0.6$

$\gamma \quad = 1.5$

To find,

(i) Compression ratio

Efficiency of the Otto cycle, $\eta = 1 - [1/(r_k^{\gamma-1})]$

$0.6 = 1 - [1/(r_k^{1.5-1})]$

$\Rightarrow 1/r_k^{0.5} = 0.4$

$r_k^{0.5} = 2.5$

$r_k = 6.25$

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