RGPVNOTES.IN

Program : **B.Tech**

Subject Name: **Basic Mechanical Engineering**

Subject Code: **BT-203**

Semester: **2nd**

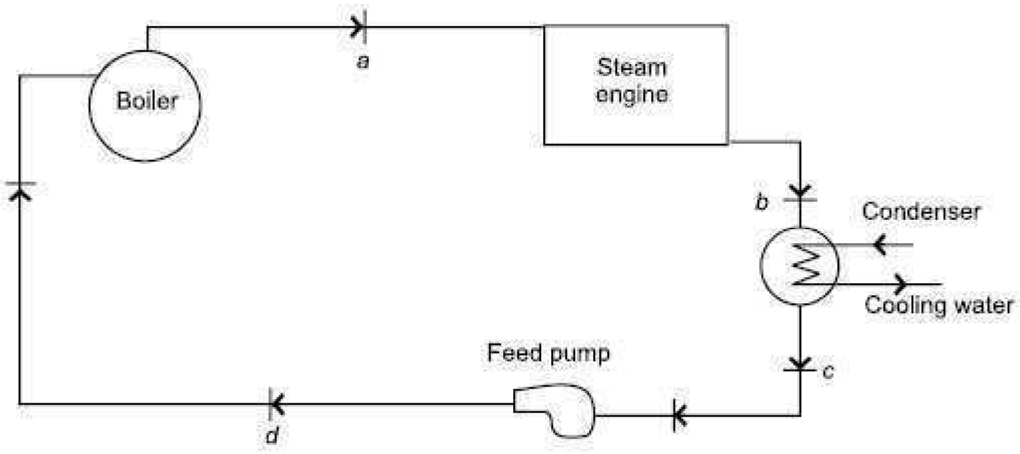
UNIT V

Reciprocating Machines: Working principle of steam Engine, Carnot, Otto, Diesel and Dual cycles P-V & T-S diagrams and its efficiency, working of 2- stroke & 4- stroke Petrol & Diesel engines. Working principle of compressor.

Introduction of Steam Engine

Steam engine is a device which is especially designed to transform energy. In steam engine the mechanical effect is seen due to the expansion of steam which is generated in boiler and supplied to steam engine. Steam engines have been successfully used in the mill, driving locomotive or steam boat, pumps, fans, blowers, small electricity generators, road rollers etc.

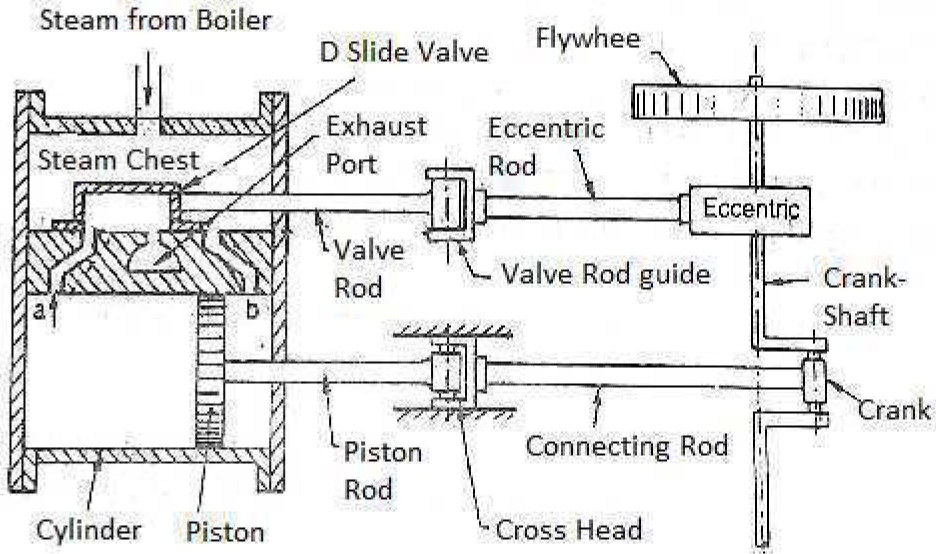
A steam engine plant shall have boiler, condenser, and feed pump along with steam engine. Steam generated in boiler is sent to steam engine where it is expanded up to certain pressure. Steam leaving engine are fed to condenser where steam gets converted into water which is sent back to boiler through feed pump. Figure shows the schematic of steam engine plant.



Schematic for simple steam engine plant

Working of Steam Engine

Schematic of simple steam engine is shown in below Fig along with important components in it.



Schematic of simple steam engine

Simple steam engine shown is a horizontal double acting steam engine having cylinder fitted with cylinder cover on left side of cylinder. Cylinder cover has stuffing box and gland through which the piston rod reciprocates. One end of piston rod which is inside cylinder has piston attached to it. Piston has piston rings upon it for preventing leakage across the piston. Other end of piston rod which is outside cylinder has cross head attached to it. Cross head slides in guide ways so as to have linear motion in line with engine axis. Cross head is connected to the small end of connecting rod by the gudgeon pin. Big end of connecting rod is mounted over crank pin of the crank. Reciprocating motion of piston rod is transformed into rotary motion of crankshaft by cross head, connecting rod and crank. Cross head transmits the motion of piston rod to connecting rod. Cross head guide ways bear the reaction force.
High pressure and high temperature steam enters from main inlet passage into steam chest. D-slide valve occupies such a position that passage from the steam chest to engine cylinder gets opened. High pressure steam enters cylinder and forces piston towards other dead centre. Linear motion of piston is transformed into rotation of crankshaft through crosshead, connecting rod, gudgeon pin and crank. When piston reaches other dead centre then the corresponding displacement of valve rod causes shifting of D-slide valve such that other passage from steam chest to cylinder gets opened and initial passage comes in communication with the exhaust passage. Thus the live steam enters from steam chest to cylinder through passage and dead steam leaves from cylinder to exhaust passage through another passage.

Parts of Steam Engine

1. **Frame: -** It is a heavy Cast Iron part, which supports all the stationary as well as moving parts and holds them in proper position. It generally rests on engine foundations.
2. **Cylinder: -** It is also a Cast Iron cylindrical hollow vessel, in which the piston moves To and Fro under the Steam Pressure. Both ends of the cylinder are closed and made steam tight. In small steam engines, the cylinder is made an integral part of the frame. One end is closed by a separate cover and the other end (Crank Side) carries the Stuffing Box through which the piston rod passes, as shown in fig.
3. **Steam Chest: -** It is Casted as an integral part of the cylinder and is closed by a separate cover. It can have a rectangular or circular section according to the type of valve used. Steam chest is connected to the cylinder through the valve passages as shown in fig. known as Ports. It also contains the D-Slide Valve. The steam is supplied alternately to the cylinder through the ports and it is exhausted alternately to the condenser from the cylinder through the ports as shown in fig.
4. **Inlet and Exhaust Ports: -** An opening at both ends of the cylinder is provided connecting it with the steam chest. These openings are known as Ports. A valve moving over these openings connects the cylinder to the live steam supply and to the exhaust alternately.
5. **D – Slide Valve: -** The function of D-Slide Valve as mentioned earlier is to connect the cylinder to the steam chest and to the exhaust side through the ports at the correct crank positions. The valve is actuated by an eccentric drive.
6. **Piston: -** It is also made of Cast Iron. The steam pressure acts on the piston and exerts a force on the piston. The piston is connected to the piston rod and which transmits the force to the crank through the cross-head and connecting rod. The piston diameter is slightly smaller than that of the cylinder bore to allow free movement. Steam tightness is achieved by the use of piston rings.
7. **Piston Rod: -** It is made of Mild Steel. One end of it is connected to the piston and the other is connected to the cross-head. The main function of the piston rod is to transmit the force on the piston to the cross-head.
8. **Piston Rings: -** These are made of Cast Iron and are fitted in the grooves provided on the piston. The function of the piston rings is to provide a leak tight joint between the cylinder and piston in order to prevent the leakage of steam from the high pressure side to the low pressure side, at the same time allowing the movement of the piston in the cylinder.
9. **Stuffing Box and Gland: -** It is fitted on the crank end side of the cylinder as shown in the fig. It is place at the point where the piston rod passes through the cylinder cover. The main function of the stuffing

box is to prevent leakage of the steam from the cylinder to atmosphere, at the same time allowing the piston rod a free movement.

10. **Cross – Head: -** It forms a connecting link between the piston rod and the connecting rod. It guides the motion of the piston rod and also carries the small end of the connecting rod.
11. **Connecting Rod: -** It is made up forged steel, whose one end is connected to the cross – head and the other to the crank. Its function is to convert reciprocating motion of the piston (or cross – head**)** into rotary motion of the crank.
12. **Crank Shaft:** - It is main shaft of the engine having crank. The crank works on the lever principle and produces rotary motion of the shaft. The crank shaft is supported on main bearing of the engine.
13. **Eccentric:** - It is generally made up of cast iron, and is fitted to the crank shaft. Its function is to provide reciprocating motion of the Slide Valve.
14. **Eccentric Rod and Valve Rod:** - The eccentric rod is made up of forged steel, whose one end is fixed to the eccentric and other to the valve rod. Its function is to convert rotary motion of the crank shaft into to and fro motion of the valve rod. The valve rod connects the eccentric and D-Slide valve. Its function is to provide Simple Harmonic Motion to the D – Slide Valve.
15. **Flywheel: -** It is a heavy cast iron wheel, mounted on the crank shaft. Its function is to prevent the fluctuation of engine. It also prevents the jerks to the crankshaft.
16. **Governor: -** It is a devise to keep the engine speed, more or less, uniform at all load conditions. It is done either by controlling the quantity of pressure of the steam supplied to the engine.

Classification of I. C. Engine:-

The I. C. Engines are classified on the basis on the following:

1. According to piston strokes in the working cycle:
i) Four Stroke Engine, ii) Two Stroke Engine

2. According to the Fuel used in the cycle:
i) Petrol Engine, ii) Diesel Engine, iii) Gas Engine, and iv) Multi-Fuel Engine

3. According to Method of Ignition:
i) Spark Ignition, ii) Compression Ignition

4. According to Cooling System:
i) Air-Cooled Engine, ii) Liquid-Cooled Engine

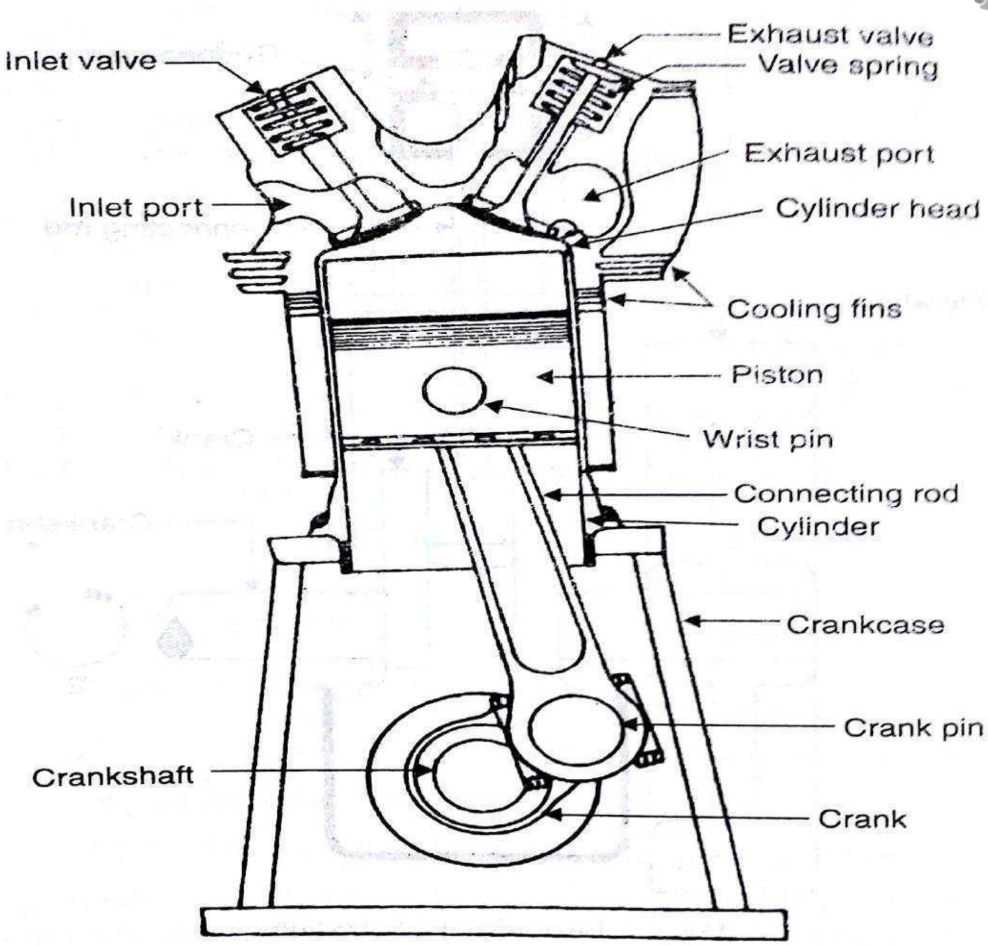
5. According to the Number of Cylinders:
i) Single Cylinder Engine, ii) Multi-Cylinder Engine

6. According to Speed of Engine:
i) Low Speed Engine, ii) Medium Speed Engine, and iii) High Speed Engine

7. According to Position of Engine:
i) Horizontal Engine, ii) Vertical Engine, and iii) V- Engine

COMPONENTS OF I. C. ENGINES:-

The essential Parts of Otto-cycle and Diesel-cycle Engines are same. A few of them are shown in fig.



Main Components of an Internal Combustion Engine

Cylinder: - It is the heart of the engine. The piston reciprocates in the cylinder. It has to withstand high pressure and temperature, thus it is made strong. Generally it is made up of Cast Iron.

Cylinder Head: - The top cover of the cylinder, towards TDC (Top Dead Centre) is called Cylinder Head. It houses the spark plug in petrol engines and fuel injector in Diesel Engines. For Four Stroke Cycle Engines, the cylinder head has the housing of inlet and exhaust valves.

Piston: - It is reciprocating part of engine. It is made of usually Cast Iron or Aluminum alloys. Its top surface is called Piston Crown and bottom surface is piston skirt. Its top surface is made flat for four stroke engines and deflected for two stroke engines.

Piston Rings: - The two or three piston rings are provided on piston. The piston rings seal the space between cylinder liner and piston in order to prevent leakage (blow by losses) of high pressure gases, from cylinder to crank case.

Crank: - It is rotating member. It makes circular motion in the crank case (its housing). Its one end is connected with shaft called Crank-Shaft and other end is connected with connecting rod.

Crank-Case: - It is housing of the crank and body of the engine to which cylinder and other engine parts are fastened. It also acts as a ground for lubricating oil.

Connecting Rod: - It is a link between piston and crank. It is connected at its one end with crank and on other end with piston. It transmits power developed on the piston to crank shaft through crank. It is usually made of medium carbon steel.

Crank Shaft: - It is shaft, a rotating member, which connects crank and the power developed by the engine is transmitted outside through this shaft. It is made up of medium carbon or alloy steel.

Cam Shaft: - It is provided on four stroke engines. It carries two cams, for controlling the opening and closing of inlet and exhaust valves.

Inlet Valve: - This valve controls the admission of charge into the engine during suction stroke.

Exhaust Valve: - The removal of exhausted gases after doing work on the piston is controlled by the valve.

Fly Wheel: - It is mounted on the crank shaft. It is made of Cast Iron. It stores energy in the form of inertia, when energy is in excess and it gives back energy when it is deficit. In other words, it minimizes the speed fluctuations on the engine.

Internal Combustion Engine Terminology

Some of the generally used terms in internal combustion engines are given as under.

Stroke: It is the nominal distance travelled by the piston between two extreme positions in the Cylinder.

Dead centre: It refers to the extreme end positions inside the cylinder at which piston reverses its motion. Thus, there are two dead centers in cylinder, called as 'top dead centre' or 'inner dead centre' and 'bottom dead centre' or 'outer dead centre'.

Swept volume: It is the volume swept by piston while travelling from one dead centre to the other. It may also be called stroke volume or displacement volume. Mathematically,

Swept volume = Piston area × Stroke

Clearance volume: It is the volume space above the piston inside cylinder, when piston is at top dead centre. It is provided for cushioning considerations and depends, largely upon compression ratio.

Compression ratio: It is the ratio of the total cylinder volume when piston is at BDC to the clearance volume.

Compression ratio = (Swept Vol. + clearance Vol.)/ Clearance Vol.

Carnot Cycle

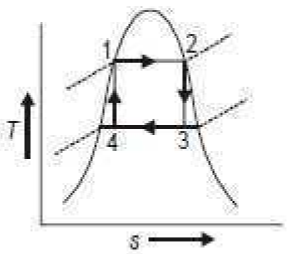
Carnot cycle is an ideal cycle having highest thermodynamic efficiency. Let us use Carnot cycle for getting positive work with steam as working fluid. Arrangement proposed for using Carnot vapor power cycle is as follows.

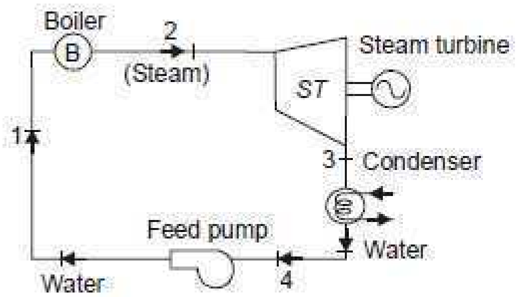
1 – 2 = Reversible isothermal heat addition in the boiler

2 – 3 = Reversible adiabatic expansion in steam turbine

3 – 4 = Reversible isothermal heat rejection in the condenser

4 – 1 = Reversible adiabatic compression or pumping in feed water pump





Carnot vapor power cycle and A schematic arrangement for Carnot cycle

Assuming steady flow processes in the cycle and neglecting changes in kinetic and potential energies, thermodynamic analysis may be carried out.

Thermal Efficiency = Net Work / Heat Added

Net Work = Turbine Work - Compression/Pumping Work

For Unit Mass flow,

$W = (h_2 - h_3) - (h_1 - h_4)$

Heat Added, $Q_{add} = (h_2 - h_1)$

$\eta_{carnot} = (h_2 - h_3) - (h_1 - h_4) / (h_2 - h_1)$

$\eta_{carnot} = 1 - (h_3 - h_4) / (h_2 - h_1)$

Here, Heat Rejected, $Q_{rejected} = (h_3 - h_4)$

Or, $\eta_{carnot} = 1 - Q_{rejected} / Q_{add}$

Also heat added and rejected may be given as function of temperature and entropy as follows:

$Q_{add} = T_1 \times (S_2 - S_1)$

$$Q_{rejected} = T_3 \text{ X } (S_3 - S_4)$$

Also $S_1 = S_4$ and $S_2 = S_3$

Therefore substituting values:

$$\eta_{carnot} = 1 - T_3 / T_1$$

Or, $$\eta_{carnot} = 1 - T_{minimum} / T_{maximum}$$

Working of 2-Stroke Petrol Engine:- In 1878, Dugald–Clerk, a British Engineer introduced a cycle which could be completed in Two Strokes of piston rather than Four Strokes as is the case with the Four Stroke Cycle Engines. The following operations take place in Two Stroke or in One Cycle of the engine:

Charge Transfer and Scavenging: When piston is nearer to crank case (Bottom Dead Centre), the Transfer Port and Exhaust Port are uncovered by piston, a mixture of Air and Fuel as a charge, slightly compressed in the crank case, enters through the Transfer Port and drives out the burnt gases of previous cycle through the Exhaust Port.

In Two Stroke Engines, the piston Top is made deflected. Therefore, the incoming charge is directed upward, aids in sweeping of the burnt gases out of the cylinder. This operation is known as Scavenging (A gas exchange process).

As piston moves upward the fresh charge passes into the cylinder 1/6th of the revolution and exhaust port remains open little longer than transfer port.

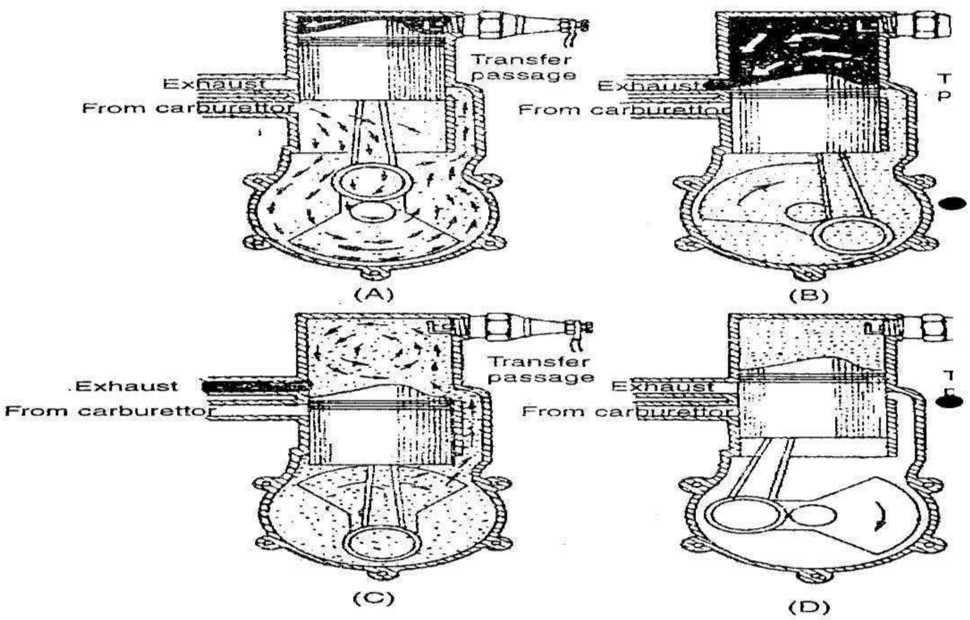
Compression and Suction: As piston moves upward, both Transfer Port and Exhaust Port are covered by piston and the charge trapped in the cylinder is compressed by the piston's upward movement as shown in fig. At the same time, the partial vacuum is created into crank case, the Suction Port opens by moving crank and fresh charge enters the crank case.

Combustion: When the piston reaches at its end of stroke nearer to cylinder head or at Top Dead Centre, a highly intensity Spark from Spark Plug ignites the charge and initiates the combustion in the cylinder. The burning of the charge generates the pressure in the cylinder.

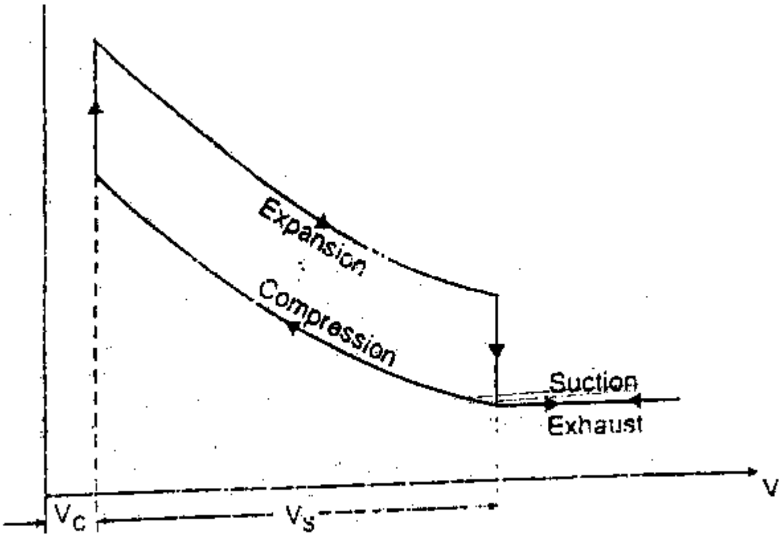
Power and Exhaust: The burning gases exert pressure on the top of the piston and piston is forced downward as a result of pressure generated.

As piston descends through about 80% of the expansion stroke, the Exhaust Port is uncovered by the piston, and the combustion gases leave the cylinder by pressure difference and at the same time, and at the same time, underside of piston causes compression of charge taken into crank case as shown in fig.

Charging: The slightly compressed charge in the crank case passes through Transfer Port and enters the cylinder as soon as it is uncovered by descending piston and when it approaches the Bottom Dead Centre, the cycle is completed.



TWO – STROKE PETROL ENGINE



P- V Diagram of a Two – Stroke Petrol Engine

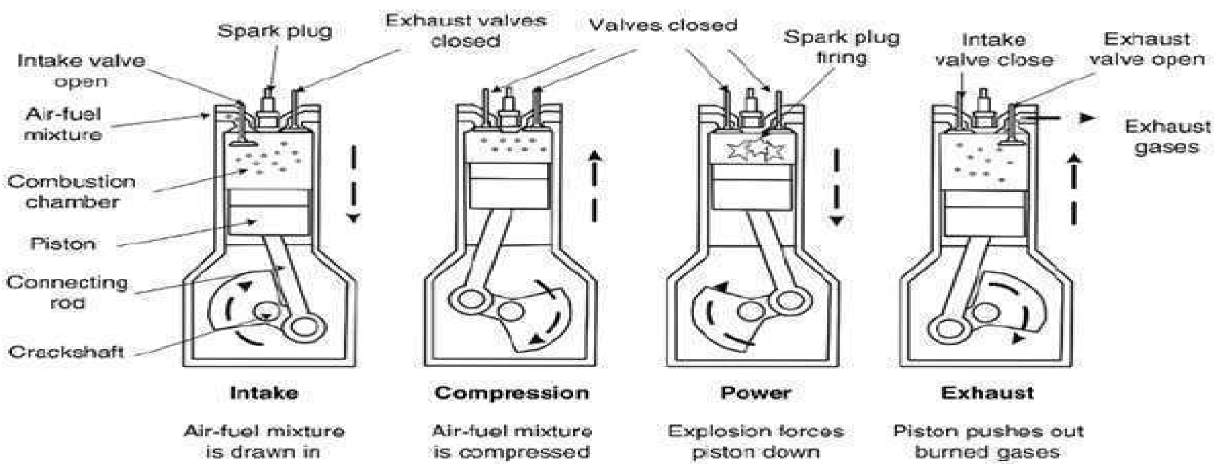
Working of Four Stroke Petrol Engine: - The 4 Stroke Otto Cycle refers to its use in Petrol Engines, Gas Engines, in which the mixture of Air and Fuel are drawn in the engine cylinder. Since ignition in these engines is due to a Spark, therefore they are also called Spark Ignition Engines. The work is obtained only during one stroke out of four. The strokes are as follows:-

Suction: During this stroke, the inlet valve stays open and the exhaust valve closed. The piston moves downward from TDC to BDC by means of crankshaft, this piston movement creates a pressure difference between outside and inside the cylinder and the higher pressure of the atmosphere forces the air fuel mixture from the carburetor into the cylinder through inlet valve.

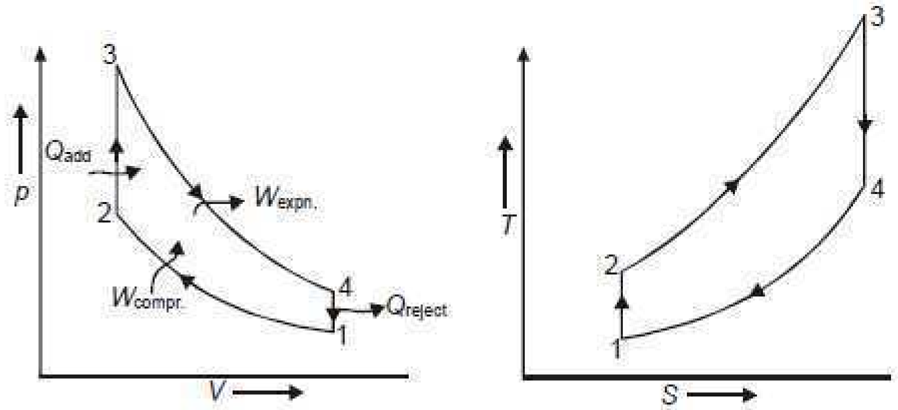
Compression: The air fuel mixture, sucked during the suction stroke, is compressed in this stroke. Piston moves from BDC to TDC. Just a little before the end of compression stroke, a spark produced by spark plug ignites the compressed mixture. Both the inlet and exhaust valves remain closed during this stroke.

Working or Power Stroke: The inlet and exhaust valves remain closed during this stroke. Product of combustion (hot gases) expands due to high temperature and pressure, due to this the piston starts to move downward from TDC to BDC and the power is obtained.

Exhaust: The inlet valve remains closed while the exhaust opens. The major portion of burnt gases escapes due to own expansion. The upward movement of the piston from BDC to TDC pushes the remaining gases out of the open exhaust valve. Only a small quantity of burnt gases stays in the clearance space. This cycle or series of events take place over and over again.

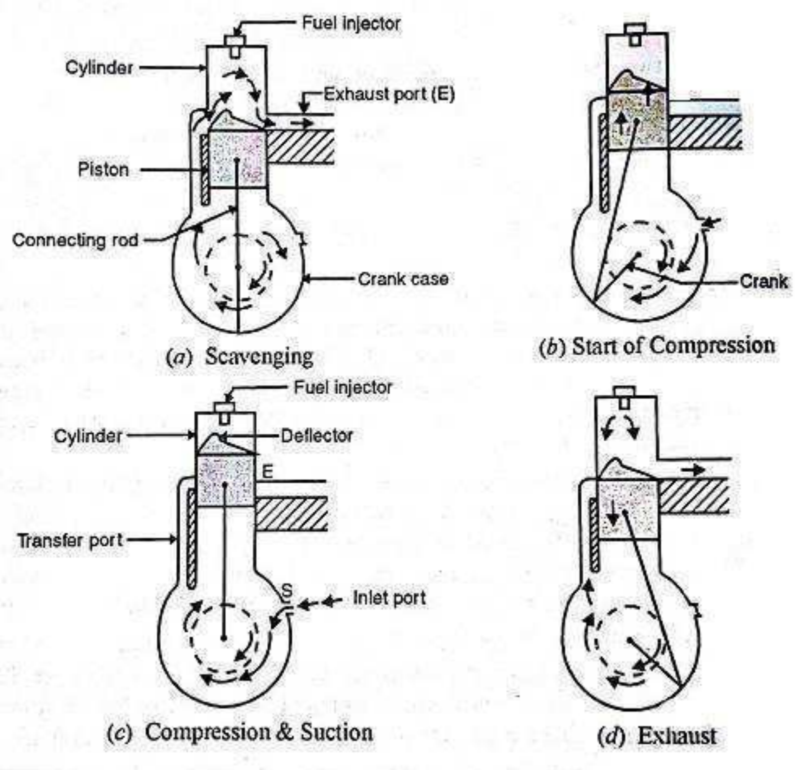


VALVE TIMING DIAGRAM OF FOUR STROKE PETROL ENGINE



P- V and T-S Diagram

Working of Two Stroke Diesel Engine: - All engines using Diesel as a fuel operate on Diesel Cycle. They work similar to Petrol Engine except they take in only Air as charge during suction and fuel is injected at the end of compression stroke. The Diesel Engines have Fuel Injector instead of Spark Plug in Cylinder head as shown in fig. The Diesel engines use high compression ratio in the range of 14 to 21. The temperature of intake air reaches a quite high value at the end of compression. Therefore, the injected fuel is self – ignited.



TWO STROKE DIESEL ENGINE

In Diesel Engines the following operations take place during a power stroke.

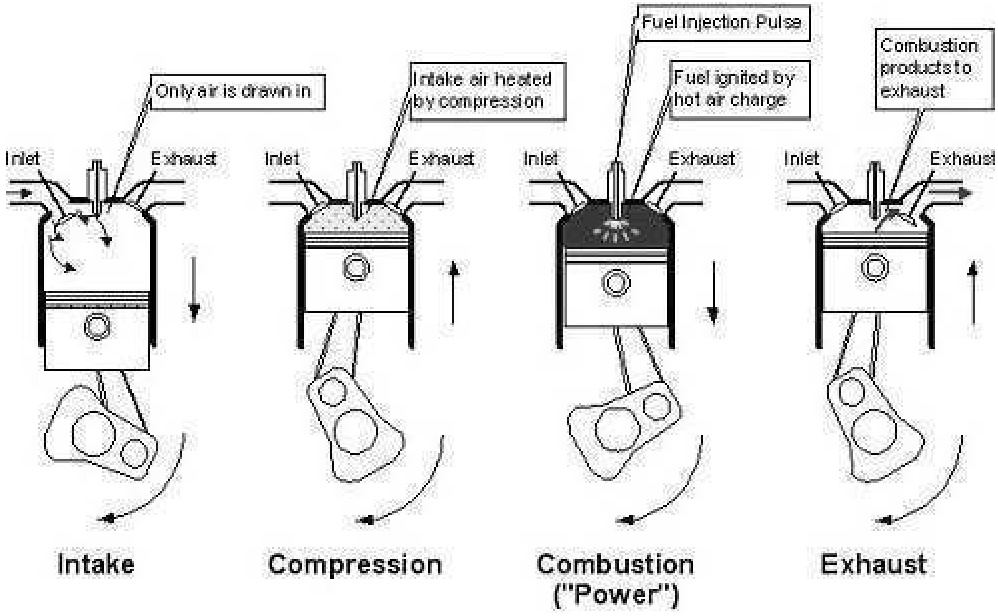
Suction or Induction Stroke: The piston moves down from the Top Dead Centre (TDC) to Bottom Dead Centre (BDC). The air is drawn into the cylinder through inlet valve, which closes at the end of this stroke. The exhaust valve remains closed during this stroke.

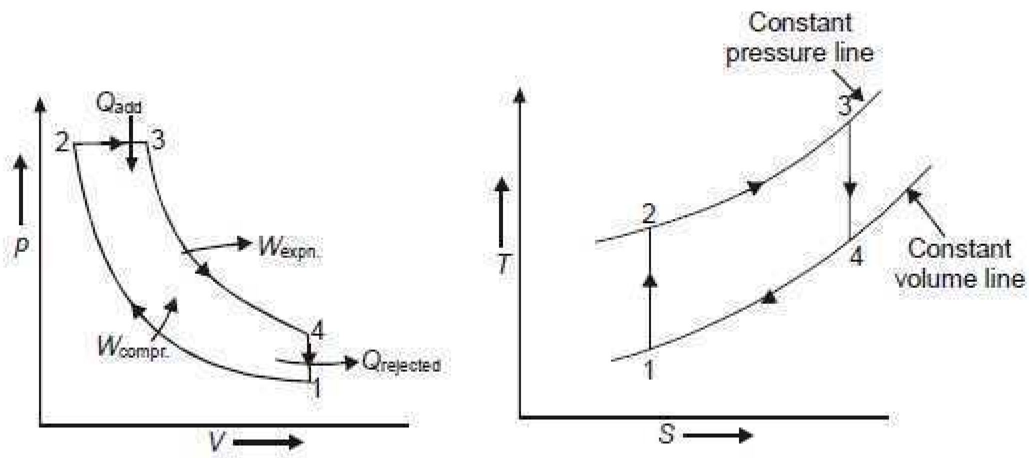
Compression Stroke: In a vertical engine the piston moves up towards TDC from BDC position. The inlet valve is now closed. The air drawn in the cylinder in the previous stroke is entrapped inside the cylinder and compressed with the upward movement of the piston. As the compression ratio used in this engine is high (14: 22) the air is finally compressed to a pressure as high as 40 bars at which its temperature is high (as high as 10000 C) enough to ignite the fuel. As the piston moves after reaching TDC the fuel is injected into the hot compressed air where it starts burning, maintaining the pressure constant.

Working or Power Stroke: Both inlet and exhaust valves remains closed during this stroke. The product of combustion now expands in the engine cylinder pushing the piston down, and hence doing work. The piston finally reaches the BDC position.

Exhaust Stroke: The piston now moves up once again. The inlet and fuel valves are closed but the exhaust valve opens. Major part of the burnt gases escape due to their own expansion. The upward movement of the piston pushes the remaining gasses out through the open exhaust valve. The exhaust valve closes at the end of the exhaust stroke. The cycle is thus completed.

All the above processes are shown in give diagrams

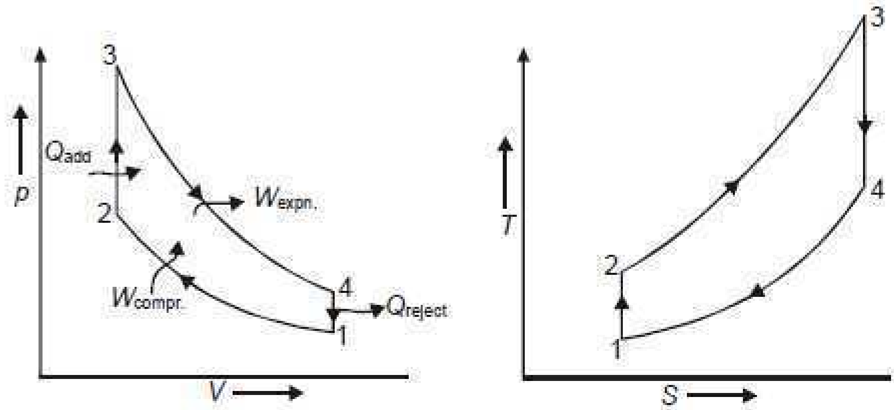




P- V and T-S Diagram for 4-stroke Diesel Engine

Efficiency of Otto Cycle

This is a modified form of Carnot cycle in order to make it a realistic cycle. Otto cycle has two constant volume and two adiabatic processes as shown below.



P- V and T-S Schematic Diagram Of Otto Cycle

Thermodynamic processes constituting Otto cycle are
1 – 2 = Adiabatic compression process,
2 – 3 = Constant volume heat addition process
3 – 4 = Adiabatic expansion process
4 – 1 = Constant volume heat rejection process
In order to have an engine based on Otto cycle let us find out the relevance of above processes. Spark ignition type internal combustion engines are based on this cycle.
Process 1 – 2, adiabatic compression process can be realized by piston moving from volume *V*1 to *V*2 and therefore compressing air.
Process 2 – 3, heat addition process can be undertaken in constant volume manner with piston at volume *V*2 and heat added to working fluid.
Heat addition is practically realized by combustion of fuel and air. As a result of heat addition the compressed air attains state 3 and it is allowed to expand from 3–4 adiabatically. After expansion air is brought back to original state 1 by extracting heat from it at volume *V*1.
Internal combustion engine based on Otto cycle is explained ahead. Let us find air-standard thermal efficiency of Otto cycle.
Compression ratio for the cycle shown can be given by the ratio of volumes of air before and after compression. It is generally denoted by *r*. For unit mass of air and properties at states given with
Subscript 1, 2, 3, 4, we can write,

$$r = V_1/V_2 = V_4/V_3$$

Heat added during 2–3, constant volume process

$$Q_{add} = C_V \times (T3 - T2)$$

Heat rejected during 4–1, constant volume process

$$Q_{rejected} = C_V \times (T4 - T1)$$

Air standard efficiency of Otto cycle

$$\eta_{otto} = \text{net work done / heat Supplied}$$

For a cycle,

$$\text{Net work} = \text{Heat added} - \text{Heat rejected}$$
$$= C_V \{(T3 - T2) - (T4 - T1)\}$$

Substituting in the expression for efficiency;

$$\eta_{otto} = C_v (T_3-T_2) - (T_4-T_1) / C_v (T_3-T_2)$$

OR

$$\eta_{otto} = 1 - (T_4-T_1)/ (T_3-T_2)$$

For perfect gas, by gas laws,

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

And

$$T_3/T_4 = r^{\gamma-1}$$

From above $T_2 / T_1 = T_3/T_4$

OR $1 - T_2 /T_3 = 1 – T_1 /T_4$

Substituting in the expression for ηotto

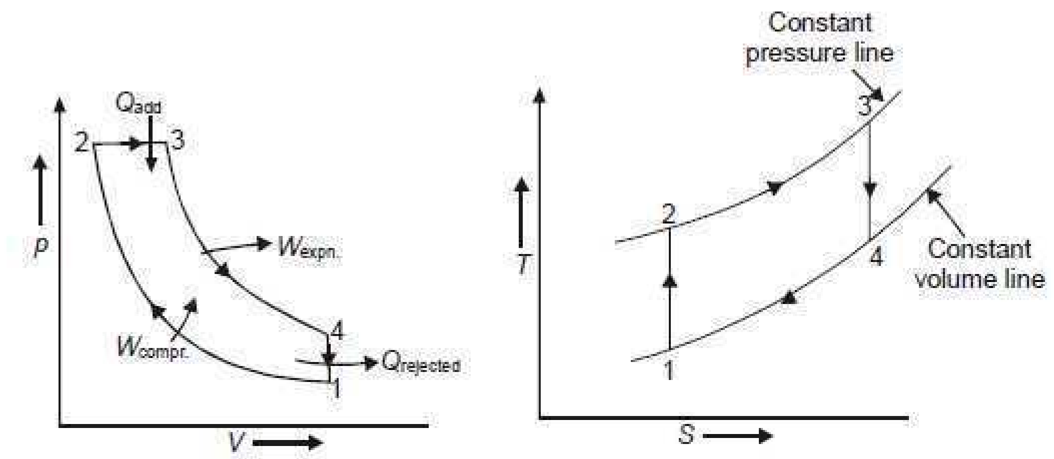
$$\eta\ otto = 1 – (1/r^{\gamma-1})$$

Efficiency of Diesel cycle

Diesel cycle is modified form of Otto cycle. Here heat addition process is replaced from constant volume type to constant pressure type. In a piston cylinder arrangement heat addition with piston at one position allows very little time for heat supply in Otto cycle. By having heat addition at constant pressure the sufficient time is available for heat supply in Diesel cycle. Compression ignition engines work based on Diesel cycles.

Thermodynamic processes constituting Diesel cycle are as given below.

1 – 2 = Adiabatic compression,
2 – 3 = Heat addition at constant pressure
3 – 4 = Adiabatic expansion,
4 – 1 = Heat rejection at constant volume



P- V and T-S diagram of Diesel Engine

Thermodynamic analysis of the cycle for unit mass of air shows;
Heat added = Cp ($T_3 – T_2$)
Heat rejected = Cv ($T_4 – T_1$)
Let us assume; Compression ratio,
$r = V_1/V_2$
Cut off Ration $\rho = V_3/V_2$ and Expansion Ratio = V_4/V_3

Air standard efficiency for Diesel cycle may be given as,

$$\eta_{diesel} = \text{net work done / heat Supplied}$$

$$\eta_{diesel} = 1 – (1/\gamma) (T_4-T_1)/(T_3-T_2)$$

Using perfect gas equation and governing equation for thermodynamic process 1 –2;
PV = RT
And
$P_1V_1^{\gamma} = P_2V_2^{\gamma}$
Combining above two, we get

$T_2 = T_1 r^{\gamma-1}$

$T3 = T1\, r^{\Upsilon-1}\, \rho$

Also for adiabatic process 3 – 4 combining the following:
We get,

$$T_3/T_4 = (r/\rho)^{\Upsilon-1}$$

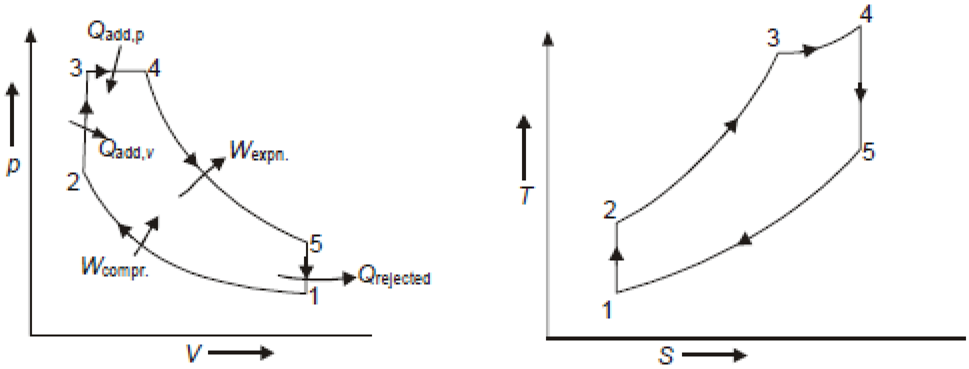
So

$$T_4 = T_1\,(r)^{\Upsilon-1}$$

Substituting T_2, T_3 and T_4 as function of T_1, in the expression of air standard efficiency of Diesel Cycle

$\eta_{diesel} = 1 - (1/\Upsilon)\, \{(\rho^{\Upsilon}-1)/\, r^{\Upsilon-1}(\rho-1)\}$

Efficiency of Dual cycle:
It is also called 'mixed cycle' or 'limited pressure cycle.' Dual cycle came up as a result of certain merits and demerits associated with Otto cycle and Diesel cycle due to heat addition occurring at constant volume and constant pressure respectively. Dual cycle is the combination of Otto cycle and Diesel cycle in which heat addition takes place partly at constant volume and partly at constant pressure.
Thermodynamic processes involved in Dual cycle are given as under.
1 – 2 = Adiabatic compression
2 – 3 = Heat addition at constant volume
3 – 4 = Heat addition at constant pressure
4 – 5 = Adiabatic expansion
5 – 1 = Heat rejection at constant volume



P - V and T - S Diagrams of Dual Cycle

Let us assume for following thermodynamics analysis:
Clearance Volume = Unity

Compression Ratio, $r = V_1/V_2$
Cut-off Ratio, $\rho = V_3/V_4$
Pressure Ratio during Heat Addition, $\alpha = P_3/P_2$
For unit mass of air as working fluid throughout the cycle.
Total Heat added = Heat added at Constant Volume (2 - 3) + Heat added at Constant Pressure (3 - 4)

$$Q_{add} = C_v\,(T_3 - T_2) + C_p\,(T_4 - T_3)$$

$$Q_{rejected} = C_v\,(T_5 - T_1)$$

Air standard efficiency for Dual Cycle can be given as:

$\eta_{dual} = (\text{Heat Added} - \text{Heat Rejected}) / (\text{Heat Added})$

$\eta_{dual} = [\{C_v(T_3 - T_2) + C_p\,(T_4 - T_3)\} - \{C_v\,(T_5 - T_1)\}] / [C_v(T_3 - T_2) + C_p\,(T_4 - T_3)]$

$\eta_{dual} = 1 - [C_v\,(T_5 - T_1)] / [C_v(T_3 - T_2) + C_p\,(T_4 - T_3)]$

$\eta_{dual} = 1 - [(T_5 - T_1)] / [(T_3 - T_2) + \gamma (T_4 - T_3)]$

From gas laws applied to process 2–3,

$P_3 / T_3 = P_2 / T_2$

Or, $T_2 = (P_2 \times T_3) / P_3$

$T_2 = T_3 / \alpha$

For process 3–4,

$V_4 / T_4 = V_3 / T_3$

$T_4 = (V_4 \times T_3) / V_3$

$T_4 = \rho T_3$

For adiabatic process 4–5,

$$T_4/T_5 = (V_5/V_4)^{\gamma-1}$$

$T_5 = T_4 / (V_5/V_4)^{\gamma-1}$

Substituting T_4

$T_5 = T_3 \times \rho^{\gamma} / (r)^{\gamma-1}$

For adiabatic Process 1-2,

$T_1 = T_2 / r^{\gamma-1}$

Substituting for T_2

$T_1 = T_3 / \alpha\, r^{\gamma-1}$

Substituting for T_1, T_2, T_4 and T_5 in expression for efficiency,

$\eta_{dual} = 1 - (1/r^{\gamma-1}) [(\alpha . \rho^{\gamma} - 1) / (\alpha -1) + \alpha. \gamma(\rho -1)]$

Working principle of compressor

Compressors are the devices which is used to compress the fluids like air or gases with the help of energy supplied to them in the form of electricity is used to compress the fluid.

Working of compressor is same as working of an engine in which during suction if only air is supplied when piston moves from TDC to BDC and during movement of piston from BDC to TDC this air will be compressed same as the charge is compressed during this stroke, The difference is only that here engine will run with the help of a electric motor for the movement of piston from TDC to BDC, and there is no spark and ignition as only air is going inside the system, this compressed air will be discharged from the exhaust port of the compressor and will be stored in a tank for further use like to fill the air in tires or for other industrial purpose.