I C Engines

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Introduction :-

Heat engines are otherwise called Thermal Engine. It is a machine which converts heat energy in to useful mechanical work. Heat engines developed more than 80% the energy generated in the world. Heat engines can be broadly classified into two categories.

(i) External Combustion engine :- An engine in which combustion of fuel takes place outside the engine cylinder

Ex: Steam engines, Steam turbine, closed cycle gas turbine

(ii) Internal Combustion engine :- An engine in which combustion of fuel takes place inside the engine cylinder is called internal combustion engine.

Ex: Petrol engine, diesel engine, gas engine etc.,

Classification of I C. Engine :-

1) According to the type of fuel used.

a) Petrol engine : In this type of engine, the fuel used is Petrol.

b) Diesel engine : In this type of engine, the fuel used is diesel

c) Gas engine : In this type of engine, the gaseous fuels like natural gas, biogas are used.

d) Bi-fuel engines: There engines use a mixture of two fuels

2) According to the number of strokes per cycle.

a) 4-stroke engine: In this type of engine, the working cycle is completed in fours different stroke

b) 2-stroke engine: In this type of engine, the working cycle is completed in two different stroke

3) According to the method of ignition

a) Spark ignition engine (SI Engine): In this type of engines, fuel is ignited by an electric spark generated by a spark plug

b) Compression ignition engine (CI Engine): In this type of engines, fuel is ignited ~~by~~ as it comes in contact with the hot compressed air.

4) According to the Cycle of combustion

a) Otto cycle engine: In this type of engines, combustion of fuel takes place at constant volume.

b) Diesel cycle engine: In this type of engines, combustion of fuel takes place at constant pressure.

c) Duel combustion engine: In this type of engines, combustion of fuel first takes place at constant volume & then at constant pressure.

5) According to the number of cylinder

(a) Single cylinder engine : this type of engine consists of only one cylinder

(b) Multi cylinder engine : this type of engine consists of 2, 3, 4, 6 or 8 cylinder

6) According to the arrangement of cylinders

(a) Vertical engine: In this type of engines, the cylinder is arranged in a vertical position

(b) Horizontal engine: In this type of engine, cylinder is arranged in horizontal position

(c) In line engine : In this type of engine, cylinder are arranged in line

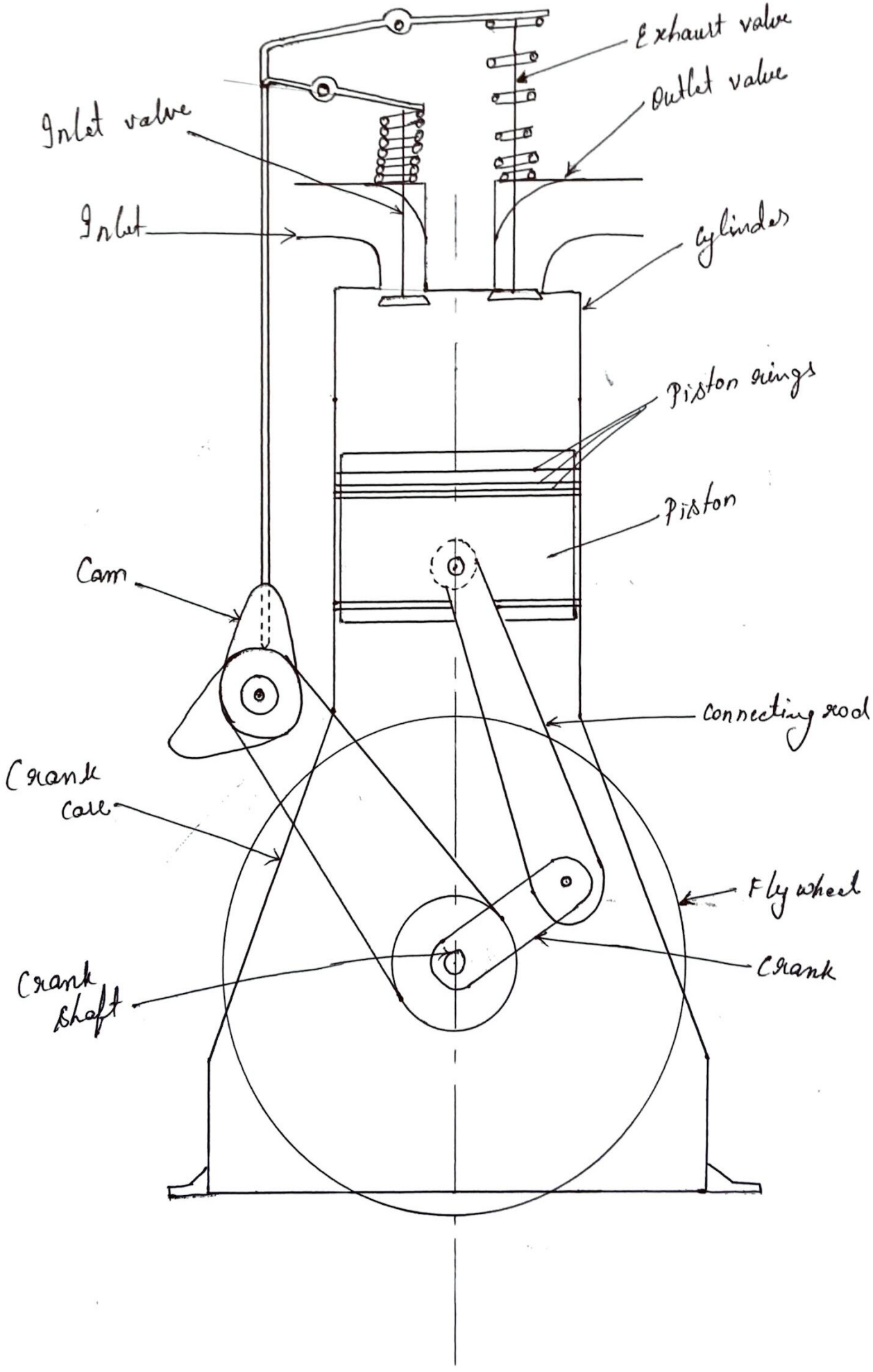
(d) Radial engine: In this type of engine cylinders are arranged along the circumference of circle

(e) V-engine: In this type of engines, combination of two inline engines equally set an angle

7) According to the method of cooling

(a) Air cooled engine: In this types of engines, the heated cylinder walls are cooled by continuous flow of air

(b) Water cooled engines: In this type of engines water is used for cooling the heated cylinder walls.


Exhaust valve
Outlet valve
Inlet valve
Inlet
Cylinder
Piston rings
Piston
Cam
Connecting rod
Crank case
Fly wheel
Crank
Crank shaft

1) Cylinder: It is the cylindrical vessel in which the fuel is burnt & the power is developed. It is considered as heart of the engine. The primary function of cylinder is

→ To contain the working fluid under pressure

→ To guide the piston while reciprocating inside the cylinder.

2) Cylinder head :- The top end of the cylinder is closed by a removable cylinder head. The cylinder head consists of two valves "Inlet valve" & "exhaust valve"

3) Piston Rings :- The rings which are placed in the grooves cut towards top of the piston are called piston Rings. There are two set of rings inserted into the groves. They are compression rings & oil rings.

→ Compression rings :- The compression rings press hard with the cylinder walls forming a tight seal between the piston & cylinder. This prevents escaping of high pressure gases into the crankcase

→ Oil rings :- The function of oil rings is to extract the lubricating oil from the cylinder walls & send it back to oil sump through the holes provided on the piston.

4) Connecting rod :- It is the link that connects the piston & the crankshaft. Its function is to convert the reciprocating motion of the piston into rotary motion of the crankshaft.

5) Crank : The crank is a lever with one of its end connected to the connecting rod by a pin joint with other end connected rigidly to the crankshaft. The power required for any useful purpose is taken from the crankshaft.

6) Crank case : It encloses the crankshaft & serves as a sump for lubricating oil.

7) Valves : The valves are control devices that allows the air/fuel to enter into the cylinder & also to discharge the burnt gases to atmosphere.

→ Inlet valve is one through which fresh charge (air & fuel or air) enters into the cylinder

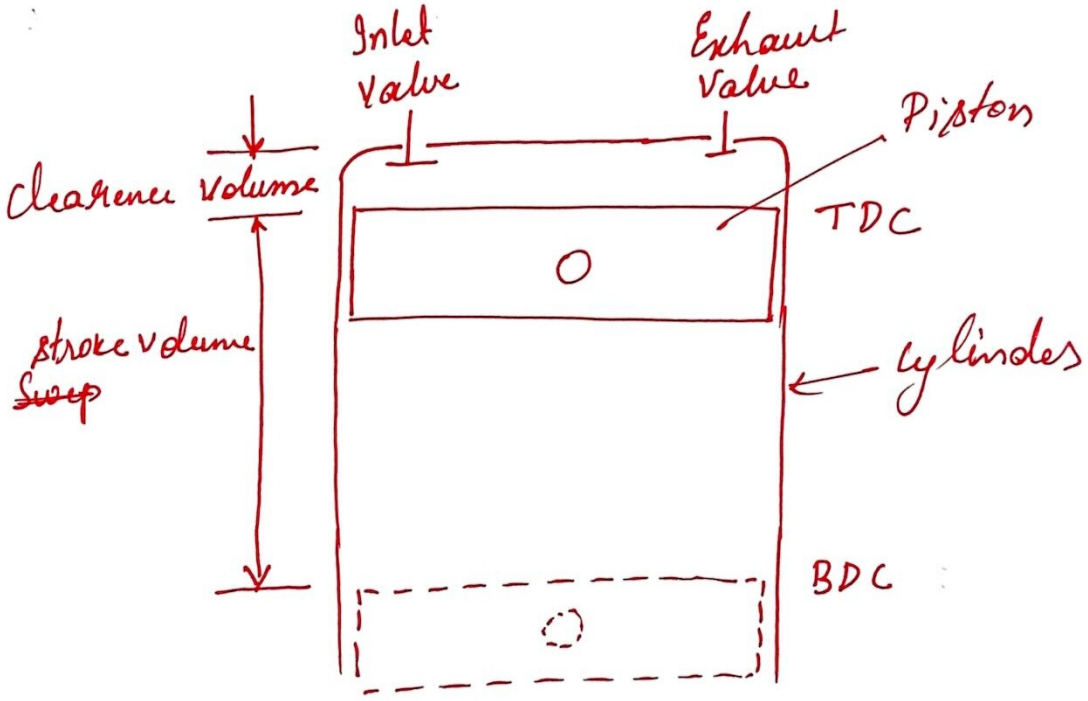
→ Exhaust valve is one through which the burnt gases are discharged out of the cylinder

There valves are actuated by means of cams.

8) Cams : It is an element designed to control the movement of both the inlet & exhaust valve

9) Flywheel :- It is a heavy mass of rotating wheel mounted on the crankshaft & is used as an energy storing device. The flywheel stores energy received during the power stroke & supplies the same during other strokes.

I.C Engine Terminology :-



1) Bore :- The inside diameter of the cylinder is called 'bore'

2) Top dead center (TDC): The extreme position of the piston nearer to the cylinder head is called TDC.

3) Bottom dead Center (BDC): The extreme position of the piston nearer to the crankshaft is called BDC.

4) Stroke: It is the linear distance travelled by the piston from the TDC to BDC or BDC to TDC

5) Clearance volume (V_c): It is the volume of the cylinder above the top of the piston, when the piston is at the TDC.

6) Swept volume or Stroke volume (V_s) :- It is the volume swept by the piston as it moves from BDC to TDC.

7) Compression ratio (R_c) :- The ratio of the total cylinder volume to the clearance volume

Total cylinder volume = Stroke volume (V_s) + Clearance volume V_c

$$R = \frac{V_s + V_c}{V_c}$$

Four-Stroke Engines:-

In 4-stroke engine, piston performs four different strokes to complete all the operations of the working cycle. The four different stroke performed are.

1) Suction stroke
2) Compression stroke
3) Power stroke [Expansion stroke or Working stroke].
4) Exhaust stroke

Each stroke is completed when the crankshaft rotates by 180°. Hence in 4-stroke engines, four different stroke are completed through 720° of the crankshaft rotation or 2 revolution of the crankshaft based on the type of fuel used

Note: In 4-stroke engines, opening & closing of valves during different strokes with respect to piston position & the rotation of crank is given in the table below

Stroke	Position of Piston		Inlet Valve	Exhaust Valve	Crank rotation
	Initial	final			
Suction	TDC	BDC	Open	Close	0° - 180°
Compression	BDC	TDC	close	close	180° - 360°
Power	TDC	BDC	close	close	360° - 540°
Exhaust	BDC	TDC	close	Open	540° - 720°

4-Stroke engines are classified as

1) 4-stroke petrol Engine

2) 4-Stroke Diesel Engine.

4-Stroke Petrol Engine :-

The working principle of 4-Stroke petrol engine is based on theoretical Otto cycle. Hence it is also known as Otto cycle engine

A-4-Stroke petrol engine performs 4 different strokes to complete one cycle. The working of each stroke is shown in fig & its details are discussed below

(a) Suction Stroke :

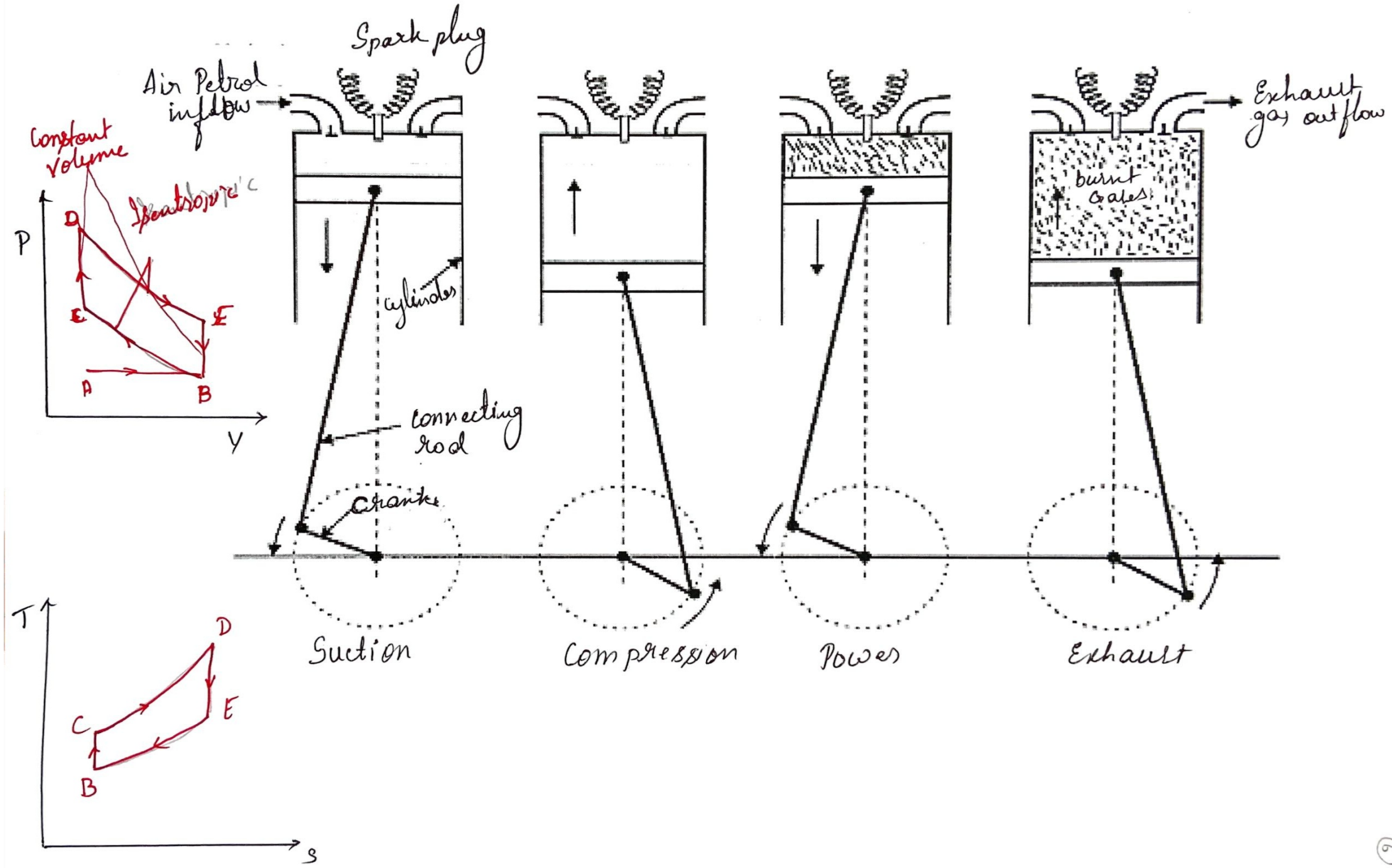
At the begining of the Stroke, piston is in TDC & during the stroke the piston moves from TDC to BDC, The inlet valve opens & the exhaust valve will be closed. As the piston moves downwards suction is created in the cylinder as a result, fresh air-petrol mixture (charge) is drawn into the cylinder through the inlet valve. As the piston reaches BDC, the suction stroke completes & inlet valve closes. The suction stroke is represented by the line AB on P-V diagram.

b) Compression stroke.

At the begining of the stroke piston is in BDC & during the stroke the piston moves from BDC to TDC. Both inlet & exhaust valve are closed. As the piston moves upwards, the air-petrol mixture in the cylinder is compressed adiabatically. The pressure & temperature of the charge increases & this is shown by the curve BC on the P-V diagram. When the piston reaches the TDC, the spark plug ignites the charge. The combustion of the fuel takes place at the constant volume & is shown by a line CD on the P-V diagram. The compression ration in petrol engine ranges from 7:1 to 11:1

c) Power stroke / Expansion stroke / Working stroke

At the beginning of the stroke, piston is in TDC & during the stroke the piston moves from TDC to BDC. Both inlet & exhaust valves remain closed. The combustion of fuel liberates gases & these gases starts expanding. Due to expansion, the hot gases exert a large force on the piston & as a result the piston is pushed from TDC to BDC. The power impulse is transmitted down through the piston to the crank shaft through the connecting rod. This causes crank-shaft to rotate at high speeds. Thus work


Spark plug
Air Petrol inflow
Exhaust gas outflow
Constant volume
Isentropic
P
V
D
E
A
B
cylinder
burnt gases
connecting rod
crank
Suction
Compression
Power
Exhaust
T
S
D
C
E
B

is obtained in this stroke. Hence, this stroke is also called working stroke. Also gas expands & does work on the piston so this stroke is also called an expansion stroke.

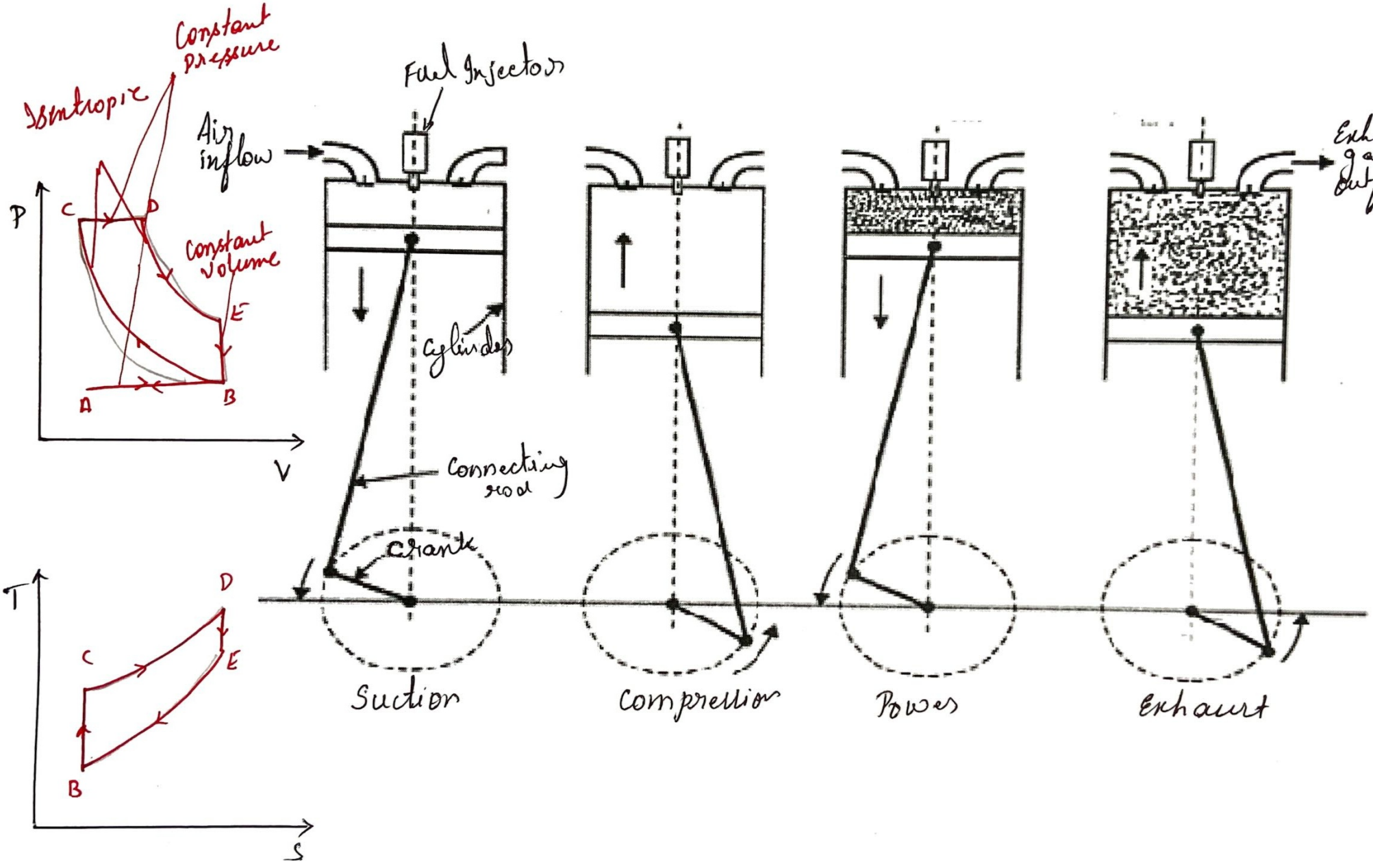
The expansion of gases is adiabatic in nature & this is shown by the curve DE on P-V diagram. As the piston reaches BDC, the exhaust valve opens. A part of burnt gases escape through the exhaust valve out of the cylinder due to their own expansion.

d) Exhaust stroke:

At the beginning of the stroke piston is in BDC & during the stroke the piston moves from BDC to TDC. The inlet valve is closed & exhaust valve is opened. As the piston moves upward, it forces the remaining burnt gases out of the cylinder to the atmosphere through the exhaust valve. This is shown by line EB & SA on PV diagram. When the piston reaches the TDC, the exhaust valve closes & this completes the cycle.

In the next cycle the piston which is at TDC moves to BDC thereby allowing fresh charge to enter the cylinder & the process continues. ~~The~~

4 - Stroke Diesel Engine



The working principle of a 4-stroke diesel engine is based on theoretical diesel cycle. Hence it is also called diesel cycle engine. A 4-stroke diesel engine performs 4-different strokes to complete one cycle of operation. The 4 different strokes are

1) Suction stroke
2) Compression Stroke
3) Power stroke
4) Exhaust Stroke

1) Suction stroke :-

At the beginning of the stroke piston is in TDC & during the stroke, piston moves from TDC to BDC The inlet valve opens & the exhaust valve will be closed. The downward movement of the piston creates suction in the cylinder and as a result, fresh air is drawn into the cylinder through the inlet valve. When the piston reaches the BDC, the suction stroke completes & this is represented by the line AB on P-V diagram.

b) Compression stroke :-

At the beginning of the stroke piston is in BDC & during the stroke piston moves from BDC to TDC. Both inlet & the exhaust valves are closed. As the piston moves upwards, air in the cylinder is compressed to a high pressure & temperature. The compression process is adiabatic in nature & is shown by the curve BC in P-V diagram. At the end of the stroke, the fuel (diesel) is sprayed into the cylinder by fuel injector. As the fuel comes in contact with the hot compressed air, it gets ignited & undergoes combustion at constant pressure. This process is shown by the line CD on PV diagram. At the point D fuel supply is cut-off. The compression ratio ranges from 16:1 to 22:1

c) Power stroke / Expansion stroke / working stroke :-

At the beginning of this stroke, piston is in TDC & during the stroke, piston moves from TDC to BDC. Both inlet & the exhaust valve remain closed. As combustion of fuel takes place, the burnt gases expand & exert a large force on the piston Due to this piston is pushed from TDC to BDC. The power impulse is transmitted down through

the speeds. Thus work is obtained in this stroke.

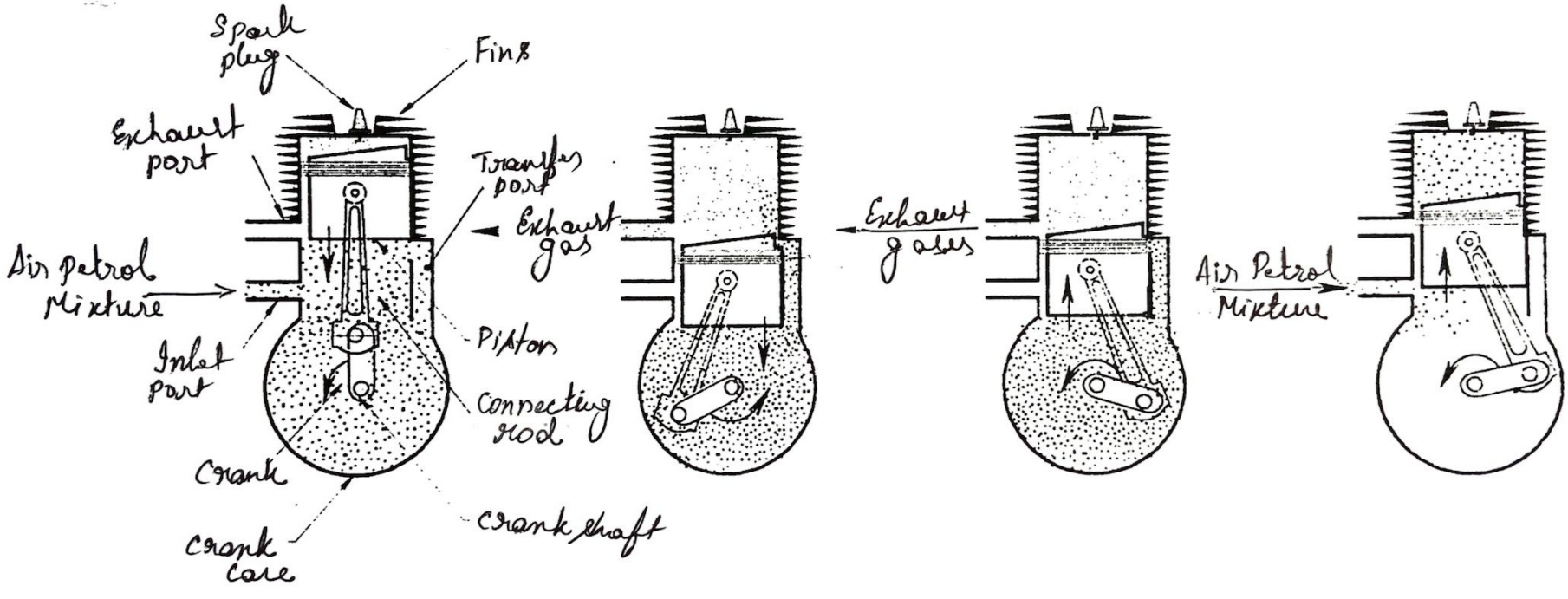
The expansion of gases is adiabatic in nature & this is shown by the curve DE on P-V diagram. When the piston reaches the BDC, the exhaust valve opens. A part of burnt gases escapes through the exhaust valve out of the cylinder due to self expansion. The drop in pressure at constant volume is shown by line EB on P-V diagram

d) Exhaust stroke :-

At the beginning of the stroke, piston is in BDC & during this stroke, piston moves from BDC to TDC. The inlet valve is closed & the exhaust valve is opened. As the piston moves upward, it forces the remaining burnt gases out of the cylinder through the exhaust valve. This is shown by line EA on P-V diagram. When the piston reaches the TDC the exhaust valve closes. This completes the cycle.

In the next cycle the piston which is at the TDC moves to BDC thereby allowing fresh air to enter into the cylinder & the process continues.

Two-Stroke Petrol Engine



Two Stroke engine :-

In a 2-stroke engine, ports are present in the cylinder in place of valves. The ports are the openings in the cylinder opened & closed by the movement of piston within the cylinder

There are three ports, namely

1) Inlet port : Through which admitting of charge into the crankcase take place.
2) Transfer port : Through which the charge is ~~transfered~~ transferred from the crankcase to the cylinder.
3) Exhaust port : Through which the burnt gases are discharged out of the cylinder.

In two stroke engine, piston performs two different strokes or crank completes one revolution to complete all the operations of the working cycle In these engines there are no suction & exhaust stroke, instead they are performed while the compression & power strokes are in progress. Based on the type of fuel used, 2-stroke engines are classified as

1) 2-Stroke petrol engine
2) 2-Stroke diesel engine.

2- Stroke Petrol Engine :-

2- Stroke petrol engine works on the principle of theoretical Otto Cycle. The two different strokes performed are first stroke (downward stroke) & second stroke (upward stroke).

The table below shows an opening & closing of the different ports with respect to the position of the piston within the cylinder.

Position of the piston	Inlet Port	Exhaust port	Transfer Port
In T.D.C	opens	closes	closes
In B.D.C	closes	Open	opens.

1) First Stroke (Downward Stroke).

At the beginning of this stroke, the piston is in the TDC as shown in fig (a). At this position, inlet port is opened & hence fresh air petrol mixture enters into the crank case. At this position, Compressed air-petrol mixture present in the cylinder in the previous cycle is ignited by the

spark generated by the spark plug. The combustion of fuel releases hot gases which increases the pressure in the cylinder. The high pressure gases exert a pressure on the piston & hence the piston moves from TDC to BDC. Thus piston performs power stroke. The power impulse is transmitted from the piston to the crankshaft through the connecting rod. This causes the crankshaft to rotate at high speeds. Thus work is obtained in this stroke.

As this piston moves downwards, it uncovers the exhaust port & hence burnt gases escape out of the cylinder as shown in fig(b). As the piston moves downwards further, it opens the transfer port & the charge in the crank case is compressed by the underside of the piston as shown in fig(b) The compressed charge from the crank case rushes into the cylinder through the transfer port as shown in fig(c). The charge entering the cylinder drives away the remaining exhaust gases through the exhaust port.

The process of removing the exhaust gases with the help of fresh charge is known as Scavenging. The piston is provided with a projection at its top known as "deflector". The purpose of providing a deflector is to deflect the fresh charge coming through the transfer port to move towards the top end of the cylinder. By doing this, the fresh charge will be able to drive the entire burnt gases out of the cylinder.

2) Second Stroke (Upward Stroke)

At the beginning of the stroke, piston is in BDC & it covers the inlet port as shown in the fig(c) & stops the flow of fresh charge into the ~~cylinder~~ crank case. During the stroke, piston ascends & move towards TDC. As the piston moves upward, it closes the transfer port, there by stopping the flow of fresh charge into the cylinder as shown in fig(d)

Further upward movement of the piston closes the exhaust port & actual compression of the charge begins. In the meantime, the inlet port is opened & the upward movement of the piston creats

suction in the crankcase. Fresh charge enters into the crankcase through the inlet port as shown in fig(a). The compression of the charge in the cylinder continues till the piston reaches the TDC. This complete the cycle

Comparison between 2-Stroke & 4-Stroke I C Engine

Petrol Engine (SI engine)	Diesel Engine (CI Engine)
1) Draws a mixture ~~of~~ air & ~~fuel~~ petrol during suction stroke	1) Draws only air during suction stroke
2) Carburetor is employed to mix air & petrol in the required proportion & to supply it to the engine during suction stroke	2) The fuel injector is employed to inject the fuel at the end of compression stroke.
3) Compression ratio ranges from 7:1 to 12:1	3) Compression ratio ranges from 18:1 to 22:1
4) The charge (Petrol & air mixture) is ignited with the help of spark plug. This type of ignition is called Spark ignition	4) The ignition of the diesel is accomplished by the compressed air which will have been heated due to high compression ratio, to the temperature higher than the ignition temperature of the diesel. This type of ignition is called Compression ignition.

5) The combustion of fuel takes place approximately at constant volume	5) The combustion of fuel takes place approximately at constant pressure.
6) Works on theoretical Otto cycle	6) Works on theoretical Diesel cycle
7) Power developed is less	7) Power developed is more
8) thermal efficiency is less	8) thermal efficiency is high
9) these are high speed engines	9) these are low speed engines
10) Maintenance cost is less	10) Maintenance cost is more
11) Running cost is high because of the higher cost of petrol	11) Running cost is low because of lower cost of diesel.
12) Lighter & cheaper because of low compression ratio	12) Heavier & costlier because of high compression ratio

Comparison between 2-Stroke & 4-Stroke IC Engine

2-Stroke Engine	4-Stroke Engine
1) Requires two seperate stroke to complete one cycle of operations	1) Requires four seperate to complete one cycle of operation
2) Power is developed in every revolution of the Crankshaft	2) Power is developed for every two revolution of the Crankshaft.
3) The inlet, transfer & exhaust ports are opened & closed by the movement of piston itself	3) The inlet & exhaust are opened & closed by the Valves.
4) Turning movement is uniform & hence requires lighter flywheel	4) Turning movement is not uniform & hence requires a heavier fly wheel
5) The charge is first admitted into the Crankcase & then transferred to the engine cylinder	5) The charge is directly admitted into the engine cylinder during the suction stroke
6) For the same power developed the engine is light & compact	6) For the same power developed the engine is heavy & bulky.

7) Thermal efficiency is low	7) Thermal efficiency is high
8) Requires greater lubricant & coolant	8) Requires lesser lubricant & coolant.
9) Fuel consumption is more	9) Fuel consumption is less
10) Initial cost is less	10) Initial cost is more

APPLICATION OF IC ENGINES

The most important application of IC engines is in transport on land, sea and air. Other applications include industrial power plants and as prime movers for electric generators. Table gives, in a nutshell, the applications of both IC and EC engines.

Internal Combustion (IC) Engine	
Type	**Application**
Gasoline Engines	Automotive, Marine, Aircraft
Gas Engines	Industrial Power
Diesel Engines	Automotive, Railways, Power, Marine
Gas Turbines	Power, Aircraft, Industrial, Marine

Two-Stroke Gasoline Engines

Small two-stroke gasoline engines are used where simplicity and low cost of the prime mover are the main considerations. In such applications a little higher fuel consumption is acceptable. The smallest engines are used in mopeds (50 cc engine) and lawn mowers. Scooters and motor cycles, the commonly used two-wheeler transport, have generally, 100-150 cc, two-stroke gasoline engines developing a maxi- mum brake power of about 5 kW at 5500 rpm. High powered motor cycles have generally 250 cc two-stroke gasoline engines developing a maximum brake power of about 10 kW at 5000 rpm. Two-stroke gasoline engines may also be used in very small electric generating sets, pumping sets, and outboard motor boats. However, their specific fuel consumption is higher due to the loss of fuel-air charge in the process of scavenging and because of high speed of operation for
which such small engines are designed

Two-Stroke Diesel Engines

Very high-power diesel engines used for ship propulsion are commonly two-stroke diesel engines. In fact, all engines between 400 to 900 mm bore are loop scavenged or uniflow type with exhaust valves. The brake power on a single crankshaft can be upto 37000 kW. Nordberg, 12-cylinder 800 mm bore and 1550 mm stroke, two-stroke diesel engine develops 20000 kW at 120 rpm. This speed allows the engine to be directly coupled to the propeller of a ship without the necessity of gear reducers.

Four-Stroke Gasoline Engines

The most important application of small four-stroke gasoline engines is in automobiles. A typical automobile is powered by a four-stroke four-cylinder engine developing an output in the range of 30-60 kW at a speed of about 4500 rpm. American automobile engines are much
bigger and have 6- or 8-cylinder engines with a power output up to 185 kW. However, the oil crisis and air pollution from automobile engines have reversed this trend towards smaller capacity cars.

Four-stroke gasoline engines were also used for buses and trucks. They were generally 4000 cc, 6-cylinder engines with maximum brake power of about 90 kW. However, in this application gasoline engines have been practically replaced by diesel engines. The four-stroke
gasoline engines have also been used in big motor cycles with side cars. Another application of four-stroke gasoline engine is in small pumping sets and mobile electric generating sets. Small aircraft generally use radial four-stroke gasoline engines. Engines having maximum power output from 400 kW to 4000 k W have been used in aircraft. An example is the Bristol Contours 57, 18-cylinder two row, sleeve valve, air-cooled radial engine developing, a maximum brake power of about 2100 kW.

Four-Stroke Diesel Engines

The four-stroke diesel engine is one of the most efficient and versatile prime movers. It is manufactured in sizes from 50 mm to more than 1000 mm of cylinder diameter and with engine speeds ranging from 100 to 4500 rpm while delivering outputs from 1 to 35000 kW. Small diesel engines are used in pump sets, construction machinery, air compressors, drilling rigs and many miscellaneous applications. Tractors for agricultural application use about 30 kW diesel
engines whereas jeeps, buses and trucks use 40 to 100 kW diesel engines. Generally, the diesel engines with higher outputs than about 100 kW are supercharged. Earth moving machines use supercharged diesel engines in the output range of 200 to 400 kW. Locomotive applications require outputs of 600 to 4000 kW. Marine applications, from fishing vessels to ocean going ships use diesel engines from 100 to 35000 kW. Diesel engines are used both for mobile and stationary electric generating plants of varying capacities. Compared to gasoline engines, diesel engines are more efficient and therefore manufacturers have come out with diesel engines in personal transportation. However, the vibrations from the engine and the unpleasant odour in the exhaust are the main drawbacks.

1. Application of IC engines in Power generation

In a power plant, many diesel ICE's are grouped into blocks called generating unit sets. Every engine is connected to a shaft that is connected to its electric generator. These generating unit sets provide modular electric generating capacity and come in standardized sizes, ranging from 4 to 20 MW

2. Application of IC engines in Agriculture

Use of IC engines allow faster production, more food to be grown and harvested, and superior procedures concerning countless tasks. The different tasks to be performed are ploughing, sowing, weeding, harvesting and thrashing etc. Farm equipment's and machinery are at the heart of the agricultural industry. Tractors, planters, and combiners are all powered with IC engines to plant and harvest crops.

3. Application of IC engines in Marine

Marine engines on ships are responsible for the propulsion of the vessel from one port to another. The engines used on board ships are internal combustion engines, in which, the combustion of fuel takes place inside the engine cylinder and the heat is generated post the combustion process. The ships of all types from goods to cruise and small boats are run by IC engines.

4. Application of IC engines Aircraft Propulsion

The internal combustion (IC) engine is the power plant used on almost all light general aviation aircraft today. Modem aircrafts using the turbofan engines. Also, electrical aircraft motors can promise a new and cleaner aviation future but are still a way off, powering prototypes. We will therefore focus on the internal combustion engine in this series discussing light aircraft propulsion.

5. Application of IC engines in Automobile

Internal combustion (IC) engines are used in almost all automobiles or Road vehicles like scooters, motorcycles, cars, buses, trucks and heavy vehicles etc. The IC engine used may be petrol (SI) engine or Diesel (CI) engine.

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Marine engines on ships are responsible for the propulsion of the vessel from one port to another. The engines used on board ships are internal combustion engines, in which, the combustion of fuel takes place inside the engine cylinder and the heat is generated post the combustion process. The ships of all types from goods to cruise and small boats are run by IC engines.

4. Application of IC engines Aircraft Propulsion

The internal combustion (IC) engine is the power plant used on almost all light general aviation aircraft today. Modem aircrafts using the turbofan engines. Also, electrical aircraft motors can promise a new and cleaner aviation future but are still a way off, powering prototypes. We will therefore focus on the internal combustion engine in this series discussing light aircraft propulsion.

5. Application of IC engines in Automobile

Internal combustion (IC) engines are used in almost all automobiles or Road vehicles like scooters, motorcycles, cars, buses, trucks and heavy vehicles etc. The IC engine used may be petrol (SI) engine or Diesel (CI) engine.

Module-3

INSIGHT INTO FUTURE MOBILITY TECHNOLOGY

Electric and Hybrid Vehicles. Components of Electric and Hybrid Vehicles. Drives and Transmission. Advantages and disadvantages of EVs & Hybrid vehicles.

Introduction:

Electric vehicles (EV)

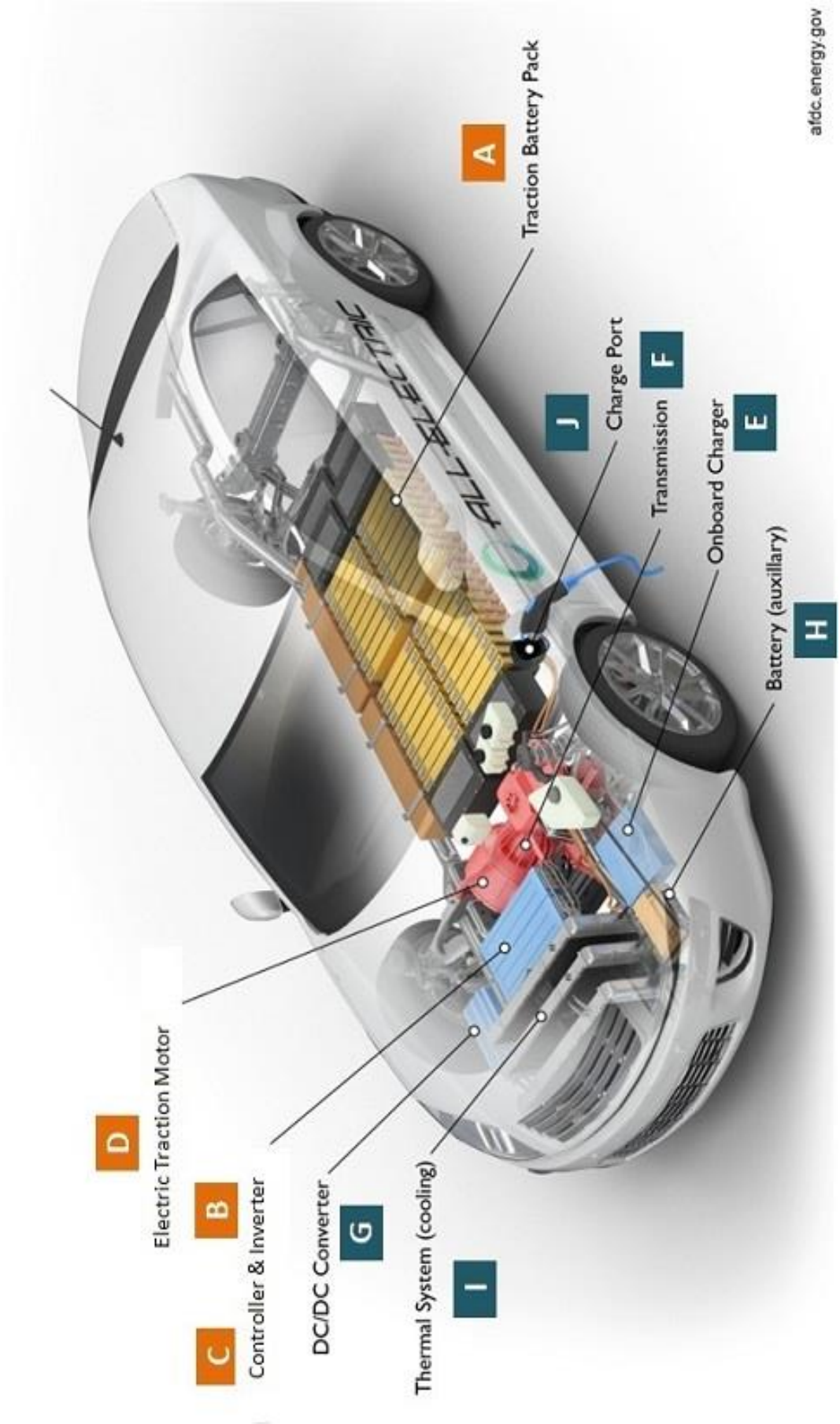
An EV is a shortened acronym for an electric vehicle. EVs are vehicles that are powered by electric motors and batteries. Electric vehicles have low running costs as they have less moving parts for maintenance and also are very environmentally friendly as they use no fossil fuels (petrol or diesel).

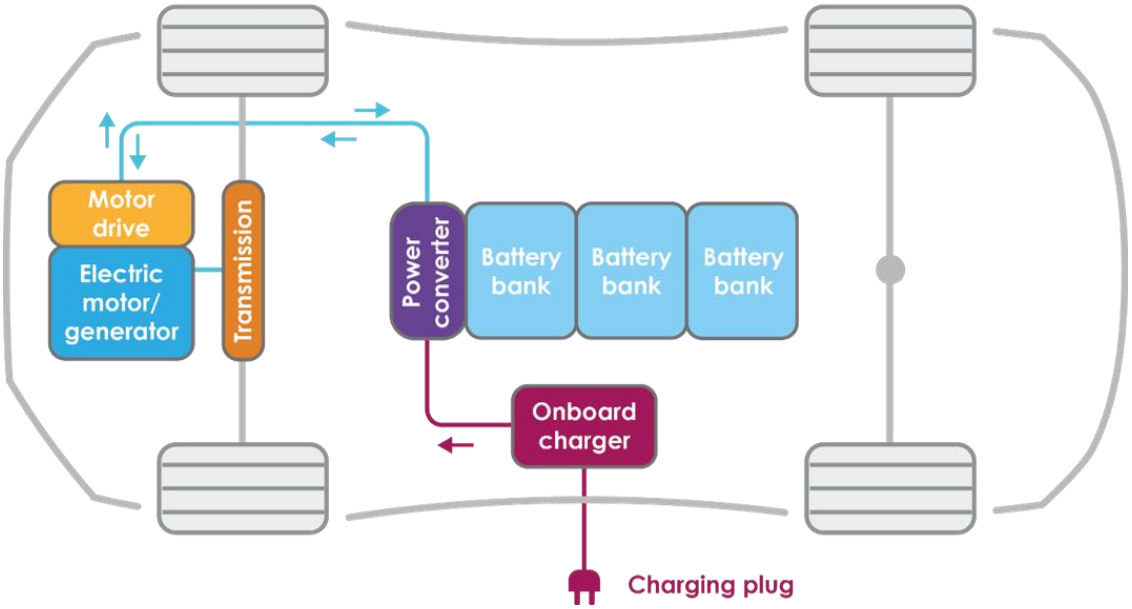
An electric vehicle, also called an electric drive vehicle, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels or a generator to convert fuel to electricity. EVs include road and rail vehicles, surface and underwater vessels, electric aircraft and electric spacecraft.

EVs first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. The internal combustion engine has been the dominant propulsion method for motor vehicles for almost 100 years, but electric power has remained commonplace in other vehicle types, such as trains and smaller vehicles of all types.

In the 21st century, EVs saw a resurgence due to technological developments and an increased focus on renewable energy.

Components of EV:





Traction Battery Pack: The function of the battery in an electric car is as an electrical energy storage system in the form of direct-current electricity (DC). If it gets a signal from the controller, the battery will flow DC electrical energy to the inverter to then be used to drive the motor. The type of battery used is a rechargeable battery that is arranged in such a way as to form what is called a traction battery pack.

There are various types of electric car batteries. The most widely used is the type of lithium-ion batteries.

Power inverter: The inverter functions to change the direct current (DC) on the battery into an alternating current (AC) and then this alternating current is used by an electric motor. In addition, the inverter on an electric car also has a function to change the AC current when regenerative braking to DC current and then used to recharge the battery.

Controller: The main function of the controller is as a regulator of electrical energy from batteries and inverters that will be distributed to electric motors. While the controller itself gets the main input from the car pedal (which is set by the driver). This pedal setting will determine the frequency variation or voltage variation that will enter the motor, and at the same time determine the car's speed.

Electric Traction Motor: Because the controller provides electrical power from the traction battery, the electric traction motors will work turning the transmission and wheels. Some hybrid electric cars use a type of generator-motor that performs the functions of propulsion and regeneration. In general, the type of electric motor used is the BLDC (brushless DC) motor.

Charger: Charger is a battery charging device. Chargers get electricity from outside sources, such as the utility grid or solar power plants. AC electricity is converted into DC electricity and then stored in the battery.

Transmission: The transmission transfers mechanical power from the electric traction motor to drive the wheels.

DC/DC Converter: This one of electric car parts that to converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.

Battery: In an electric drive vehicle, the auxiliary battery provides electricity to power vehicle accessories.

Thermal System – Cooling: This system maintains a proper operating temperature range of the engine, electric motor, power electronics, and other components.

Charge Port: The charge port allows the vehicle to connect to an external power supply in order to charge the traction battery pack.

Working Principle:

When the car pedal is pressed, then:

- Controller takes and regulates electrical energy from batteries and inverters.
- With the controller set, the inverter then sends a certain amount of electrical energy to the motor (according to the depth of pressure on the pedal)
- Electric motor converts electrical energy into mechanical energy (rotation)
- Rotation of the motor rotor rotates the transmission so the wheels turn and then the car moves.

Advantages and Disadvantages of Electric vehicles

Advantages of an Electric Vehicle

1. No fossil fuel is Required. Electric vehicles are entirely charged by electricity. You don't need to buy any fuel.
2. Electric vehicles are energy efficient.
3. Electric vehicles are more convenient.
4. Environmentally friendly as they do not emit pollutants.
5. Lower maintenance due to an efficient electric motor.
6. Electric vehicles are safe to Drive.
7. Economic and Cost-Effective.

8. Better Performance.

Disadvantages of an Electric vehicle

1. Recharge Points. Electric charging stations are still in the development stages.
2. The Initial Investment is Steep.
3. Electricity is not Free.
4. Short Driving Range and Speed.
5. Longer Recharge Time.
6. Silence as a Disadvantage.
7. Normally 2 Seaters.
8. Battery Replacement.

Hybrid vehicles (HV)

Hybrid vehicles are powered by both an internal combustion engine and an electric motor, which uses energy stored in batteries. The battery can also power auxiliary loads and reduce engine idling when stopped. Together, these features result in better fuel economy without sacrificing performance. These are also environmentally friendly as they use less or no fossil fuels

What is a hybrid? A hybrid vehicle combines any two power (energy) sources. Possible combinations include diesel/electric, gasoline/fly wheel, and fuel cell (FC)/battery. Typically, one energy source is storage, and the other is conversion of a fuel to energy. The combination of two power sources may support two separate propulsion systems. Thus to be a True hybrid, the vehicle must have at least two modes of propulsion.

For example, a truck that uses a diesel to drive a generator, which in turn drives several electrical motors for all-wheel drive, is *not a hybrid.* But if the truck has electrical energy storage to provide a second mode, which is electrical assists, then it is a hybrid Vehicle.

These two power sources may be paired in series, meaning that the gas engine charges the batteries of an electric motor that powers the car, or in parallel, with both mechanisms driving the car directly.

A hybrid electric vehicle (HEV) has two types of energy storage units, electricity and fuel. Electricity means that a battery (sometimes assisted by ultra-caps) is used to store the energy, and thatan electromotor (from now on called *motor*) will be used as traction motor.

Fuel means that a tank is required, and that an Internal Combustion Engine (ICE, from now on called*engine*) is used to generate mechanical power, *or* that a fuel cell will be used to convert fuel to electrical energy. In the latter case, traction will be performed by the electromotor only. In the first case, the vehicle will have both an engine and a motor.

- Depending on the drive train structure (how motor and engine are connected), we can distinguish between parallel, series or combined HEVs.
- Depending on the share of the electromotor to the traction power, we can distinguish betweenmild or micro hybrid (start-stop systems), power assist hybrid, full hybrid and plug-in hybrid.
- Depending on the nature of the non-electric energy source, we can distinguish between combustion (ICE), fuel cell, hydraulic or pneumatic power, and human power. In the first case, the ICE is a spark ignition engine (gasoline) or compression ignition direct injection (diesel) engine. In the first two cases, the energy conversion unit may be powered by gasoline,methanol, compressed natural gas, hydrogen, or other alternative fuels.

Motors are the "work horses" of Hybrid Electric Vehicle drive systems. The electric traction motor drives the wheels of the vehicle. Unlike a traditional vehicle, where the engine must "ramp up" beforefull torque can be provided, an electric motor provides full torque at low speeds. The motor also has low noise and high efficiency. Other characteristics include excellent "off the line" acceleration, good drive control, good fault tolerance and flexibility in relation to voltage fluctuations.

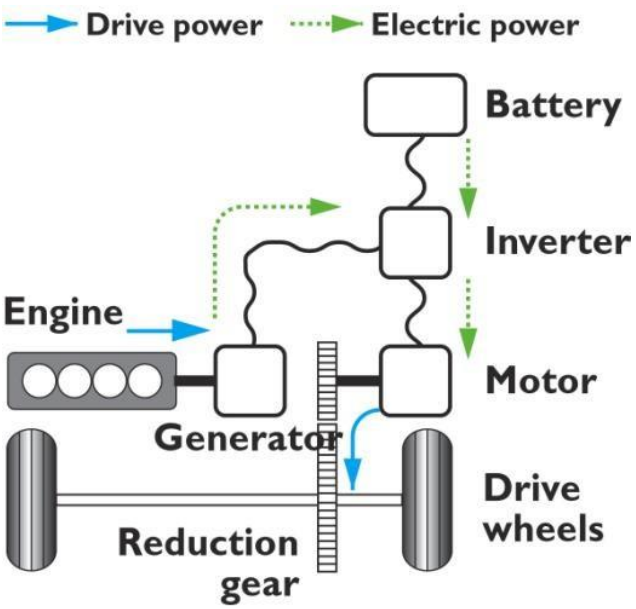
The front-running motor technologies for HEV applications include PMSM (permanent magnet synchronous motor), BLDC (brushless DC motor), SRM (switched reluctance motor) and AC induction motor.

A main advantage of an electromotor is the possibility to function as generator. In all HEV systems,mechanical braking energy is regenerated.

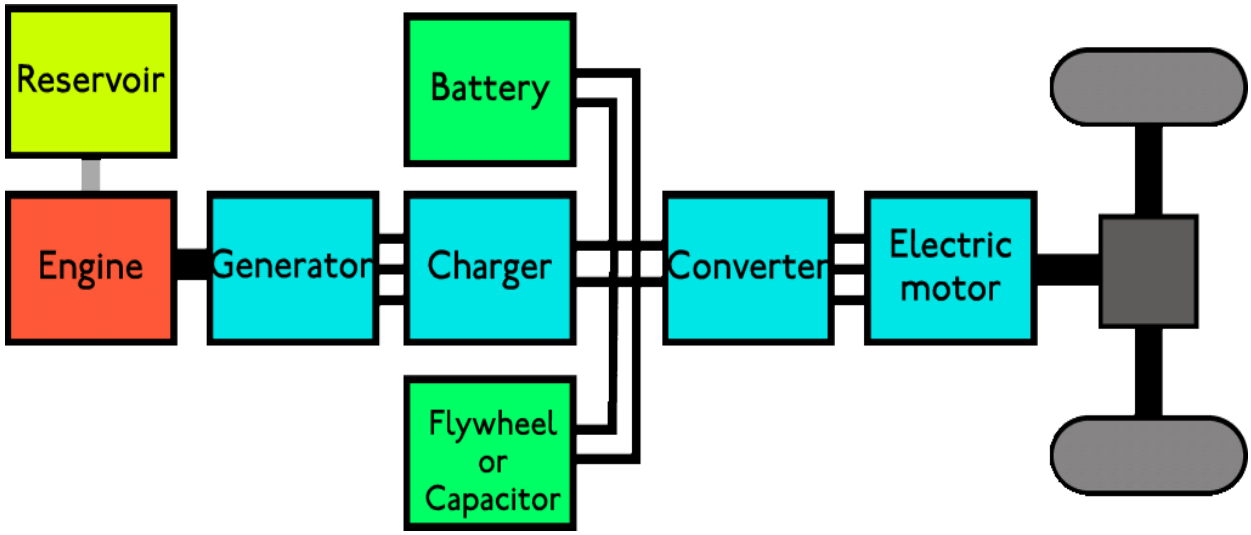
The max. operational braking torque is less than the maximum traction torque; there is always amechanical braking system integrated in a car.

The battery pack in a HEV has a much higher voltage than the SIL automotive 12 Volts battery, inorder to reduce the currents and the I^2R losses.

Accessories such as power steering and air conditioning are powered by electric motors instead of being attached to the combustion engine. This allows efficiency gains as the accessories can run at aconstant speed or can be switched off, regardless of how fast the combustion engine is running.



Structure of a hybrid vehicle



Advantages and Disadvantages of Hybrid Vehicles

Advantages of a Hybrid vehicle

1. Environmentally Friendly.
2. Less running costs.
3. Less Dependence on Fossil Fuels.
4. Regenerative Braking System.
5. Built From Light Materials.
6. Assistance From Electric Motor.
7. Smaller Engines.

8. Automatic Start and Stop.

Disadvantages of a Hybrid vehicle

1. Less Power. Hybrid vehicles are twin powered engine.
2. Can be Expensive.
3. Higher Maintenance Costs.
4. Accident from High Voltage in Batteries.
5. Battery Replacement is Pricey.
6. Battery Disposal and Recycling.
7. Hydrogen Fuel Cell Issues.

Electric Vehicle Drivetrain

The transmission elements and the propulsion unit combined are referred to as the drivetrain of the vehicle. The transmission is the mechanical linkage that transmits power between the electric motor shaft and the wheels. The drivetrain is also often referred to as the powertrain of the vehicle. The drivetrain of an electric vehicle (EV) consists of the electric motor, gearbox, driveshaft (only in rear wheel drives), differential, half-shafts, and wheels. The ability of electric motors to start from zero speed and operate efficiently over a wide speed range makes it possible to eliminate the clutch that is used in internal combustion engine vehicles (ICEV). A single gear ratio is sufficient to match the wheel speed with the motor speed. EVs can be designed without a gear, but the use of a speed reducer allows the electric motor to operate at much higher speeds for given vehicle speeds, which minimizes the motor size because of the low torque requirement at higher speeds.

The transmission of a hybrid electric vehicle (HEV) is more complex than that of the EV because of the coupling necessary between the electric motor and the internal combustion (IC) engine.

EV TRANSMISSION CONFIGURATIONS

In the case of front-wheel drive, the electric motor drives the gearbox, which is mounted on the front axle, as shown in Figure below. This configuration is for an EV using a single propulsion motor. The single motor drives the transaxle on a common axis, delivering power to the two wheels differentially through a hollow motor shaft.

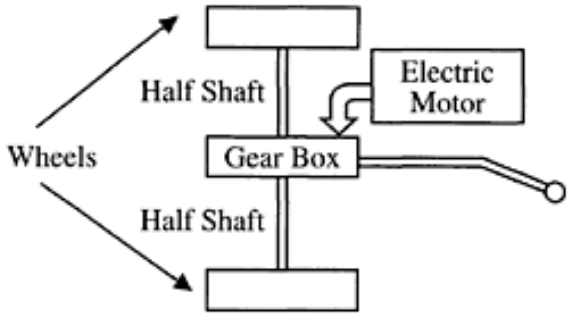


FIGURE: Typical front-wheel drive

The use of two motors driving two front wheels simplifies the transmission and eliminates the differential. Several configurations are possible with two propulsion motors driving two wheels. In one arrangement, the motors, mounted to the chassis, can be connected to the wheels through two short half shafts. The suspension system of the vehicle isolates the wheels and its associated parts from the rest of the components of the vehicle for easier handling of the vehicle,

depending on roadway conditions. The wheels are able to move freely without the weight of the motors when they are mounted on the chassis. In an alternate arrangement, the motors are mounted on the half-shafts with the motor driveshaft being part of the half-shaft. The half-shafts connect the wheels on one side and the chassis through a pivot on the other side. In-wheel mounting of motors is another arrangement possible in EVs. The difficulty in this case is that the unsprung weight of the vehicle increases due to motors inside the wheels, making traction control more complex. To minimize the unsprung weight of the vehicle and because of the limited space available, the in-wheel motors must be of high-power density. As mentioned at the beginning, the use of a speed reducer is desirable, which adds to the constraint of limited space. The cost of a high-power, high-torque motor is the primary impediment in using in-wheel motors for EVs. Another problem with in-wheel motors is the heating due to braking compounded by the limited cooling capability in the restricted space. Nevertheless, the transmission simplicity has led to several projects for the development of in-wheel motors for EVs.

The transmission is more complex in the case of a rear-wheel drive, which requires a differential to accommodate unequal speeds of the inside and outside wheels of the rear axle during vehicle cornering. A typical rear-wheel drive transmission configuration is shown in Figure below.

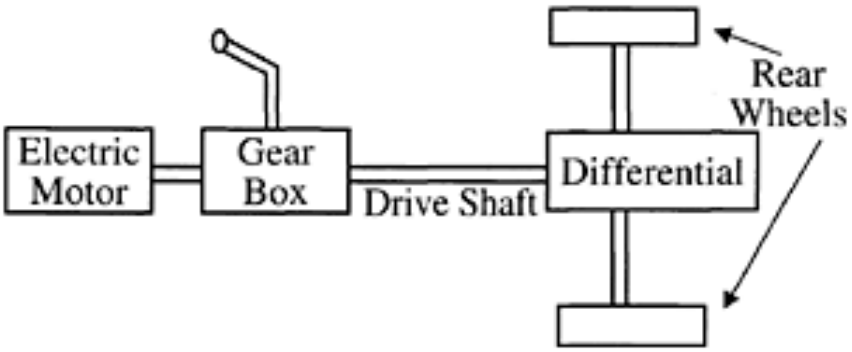


FIGURE: Typical rear-wheel drive

TRANSMISSION COMPONENTS

The gearbox (including the clutch or automatic transmission), driveshaft, and differential (in the case of a rear-wheel drive) are the major components of the transmission. The axles, wheels, and the braking systems are the auxiliary components of the transmission or powertrain. The output of the electric motor is the input to the transmission.

GEARS

The gear is a simple mechanical power transmission machine used to gain a mechanical advantage through an increase in torque or reduction in speed. This simple mechanical device uses the law of conservation of energy, maintaining the steady flow of power or energy, because torque times speed is power that remains constant in the ideal transmission process. In an ideal gearbox, the motion is frictionless, and the power and energy supplied at the input point of the gearbox are equal to the power and energy available at the delivery point. The gearbox is not used to increase the shaft speed of an electric motor, because this means that a high-torque motor is unnecessarily designed, where the size of a motor is proportional to the torque output. Therefore, the gearbox can be used as a torque multiplier or speed reducer.

AUTOMOBILE DIFFERENTIAL

The automobile differential provides a mechanism of differential movement of the wheels on the rear axle. When a vehicle is turning a corner, the rear wheel to the outside of the curve must rotate faster than the inside wheel, because the former has a longer distance to travel. The type of gear used in an automobile differential is known as the planetary gear, where a set of gear trains operates in a coordinated manner.

CLUTCH

The clutch is a mechanical device used to smoothly engage or disengage the power transmission between a prime mover and the load. The most common use of a clutch is in the transmission system of an automobile, where it links the IC engine with the rest of the transmission system of the vehicle. The clutch allows the power source to continue running, while the load is freely running due to inertia or is idle. Clutches can be eliminated in EVs, because the motor can start from zero speed and operate all the way to its maximum speed using a single gear ratio.

BRAKES

The brakes in automobiles are mechanical clutches known as friction clutches, which use friction to slow a rotational disk. The driver controls the brake action through a foot-operated linkage. The friction clutch is composed of two disks, each connected to its own shaft. As long as the disks are not engaged, one disk can spin freely without affecting the other. When the rotating and the stationary disks are engaged through the operation action, friction between the two disks reduces the speed of the rotating disk. The kinetic energy of the vehicle transfers directly between the disks and is wasted due to friction

IC ENGINE

1. Introduction

Heat engine (Thermal engine) is a machine for converting heat, developed by burning fuel into useful work. It can be said that heat engine is equipment which generates thermal energy and transforms it into mechanical energy.

Heat engines can be broadly classified into two categories

(i) **External combustion engine**: An engine in which combustion of fuel takes place outside the engine cylinder is called external combustion engine. These engines are generally called EC engines.

Ex: Steam engines, steam turbines, closed cycle gas turbine etc.

(ii) **Internal combustion engine**: An engine in which combustion of fuel takes place inside the engine cylinder is called internal combustion engine. These engines are generally called IC engines.

Ex: Petrol engine, diesel engine, gas engine etc.

Advantages of I.C Engines over E.C Engines

- High efficiency
- Simplicity
- Compactness
- Light Weight
- Easy Starting
- Comparatively Lower Cost

2. Classification of I.C. Engines

IC engines may be classified in several ways. They include

i. **According to the type of fuel used**

a) **Petrol engines**: In this type of engines, the fuel used is petrol.

b) **Diesel engines**: In this type of engines, the fuel used is diesel.

c) **Gas engines**: In this type of engines, the gaseous fuels like natural gas, biogas, LPG is used.

d) **Bi-fuel engines (Bio-fuel)**: These engines use a mixture of two fuels. Examples: Mixtures of Diesel and Natural gas, Mixture of Diesel and Neem oil.

ii. **According to the number of strokes per cycle**

a) **4-stroke engine:** In this type of engines, the working cycle is completed in four different strokes.

b) **2-stroke engine:** In this type of engines, the working cycle is completed in two different strokes.

iii. **According to the method of ignition**

a) **Spark ignition engine (S.I.Engine):**In this type of engines, fuel is ignited by an electric spark generated by a spark plug.

b) **Compression ignition engine (C.I. Engine):**In this type of engines, the fuel gets ignited as it comes in contact with the hot compressed air.

iv. **According to the cycle of combustion**

a) **Otto cycle engine**: In this type of engines, combustion of fuel takes place at constant volume.

b) **Diesel cycle engine**: In this type of engines, combustion of fuel takes place at constant pressure.

c) **Duel combustion engine**: In this type of engines, combustion of fuel first takes place at constant volume and then at constant pressure.

v. **According to the number of cylinders**

a) **Single cylinder engine:** This type of engines consists of only one cylinder.

b) **Multi cylinder engine:** This type of engines consists of 2, 3, 4, 6 or 8 cylinders.

vi. **According to the arrangement of cylinders**

a) **Vertical engine:**In this type of engines, the cylinder is arranged in a vertical position

b) **Horizontal engine:**In this type of engines, cylinder is arranged in horizontal position.

c) **Inline engine:**In this type of engines, cylinders are arranged in-line.

d) **Radial engine:**In this type of engines, cylinders are arranged along the circumference of a circle.

e) **V-engine:**In this type of engines, combination of two inline engines equally set an angle.

vii. **According to the method of cooling**

a) **Air cooled engine:** In this type of engines, the heated cylinder walls are cooled by continuous flow of air.

b) **Water cooled engine:**In this type of engines, water is used for cooling the heated cylinder walls.

3. Parts of an I.C. Engine

Figure 2.1 shows the principal parts of an I.C. engine.The details regarding the various parts of the engine are described below.

i) **Cylinder:** It is the cylindrical vessel in which the fuel is burnt and the power is developed. It is considered as heart of the engine. The primary functions of cylinder is

- To contain the working fluid under pressure.
- To guide the piston while reciprocating inside the cylinder.

ii) **Cylinder head:** The top end of the cylinder is closed by a removable component called cylinder head. The cylinder head consists of two valves ***inlet valve*** and ***exhaust valve***, or the other components like sparkplug, or fuel injector.

iii) **Piston:** The piston is a cylindrical shaped component that fits perfectly inside the engine cylinder. The primary functions of piston include,

- To compress the charge (fuel) during the compression stroke.
- To receive the force impulse produced by the combustion of fuel, and to transmit this force to the crankshaft through the connecting rod.
- Act as a guide (supporting member) for the upper end of the connecting rod.
- Serve as carrier of the piston rings that are used to seal the combustion chamber from the crankcase.

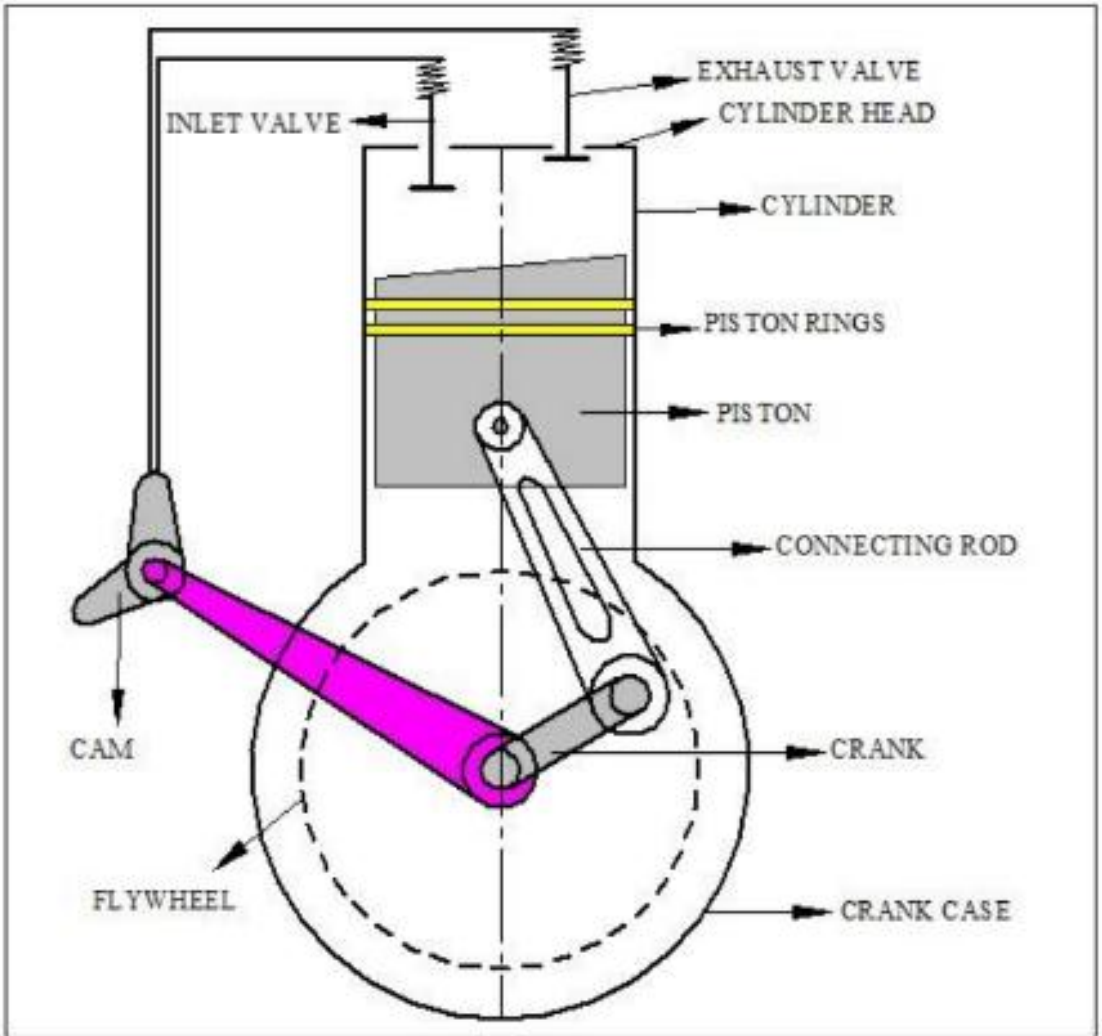


FIGURE 2.1: PARTS OF I.C. ENGINE

iv) **Piston Rings:** The rings which are placed in the grooves cut towards top of the piston are called Piston Rings. The piston rings are of two types; compression rings and oil rings.

- **Compression rings:** The compression rings press hard with the cylinder walls forming a tight seal between the piston and the cylinder. This prevents escaping of the high pressure gases into the crankcase.
- **Oil rings:** The function of oil rings is to extract the lubricating oil from the cylinder walls and send it back to oil sump through the holes provided on the piston.

v) **Connecting rod:** The connecting rod is a link that connects the piston and the crankshaft. Its function is to convert the reciprocating motion of the piston into rotary motion of the crankshaft.

vi) **Crank:** The crank is a lever with one of its end connected to the connecting rod by a pin joint with other end connected rigidly to the crankshaft. The power required for any useful purpose is taken from the crankshaft.

vii) **Crank case:** It encloses the crankshaft and serves as a sump for the lubricating oil.

viii) **Valves:** The valves are control devices that allow the air/fuel to enter into the cylinder and also to discharge the burnt gases to atmosphere. There are two valves.

(i) Inlet valve (ii) Exhaust valve

(i) Inlet valve is the one through which fresh charge (air and fuel or air) enters into the cylinder.

(ii) Exhaust valve through which the burnt gases are discharged out of the cylinder. These valves are actuated by means of cams driven by the crankshaft.

ix) **Cams:** It is an element designed to control the movement of both the inlet and exhaust valves.

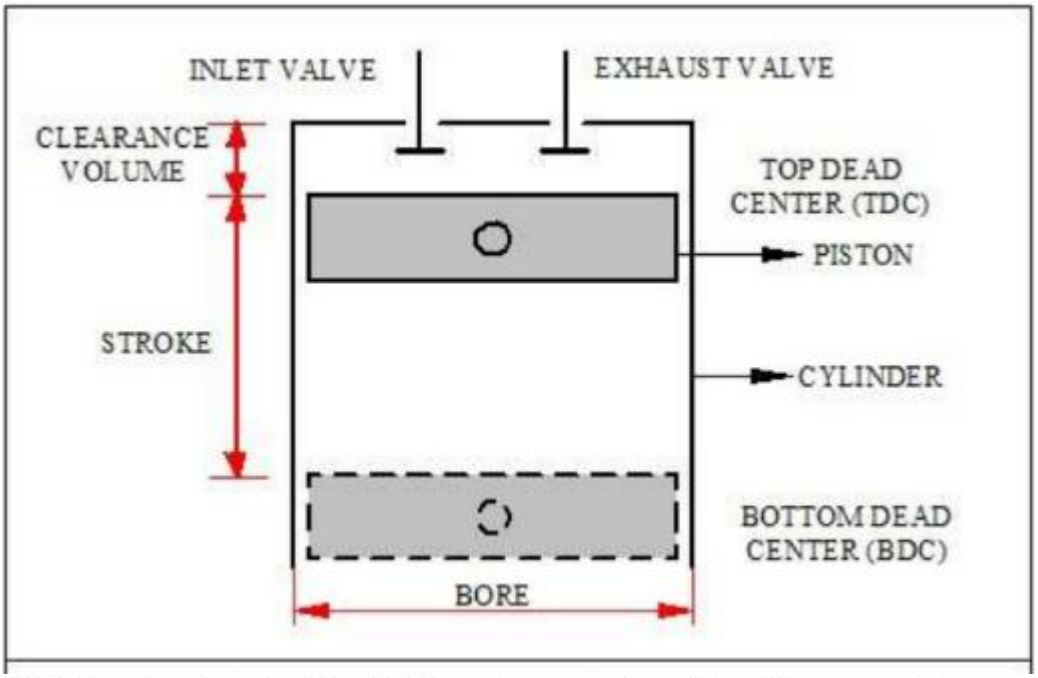
x) **Flywheel:** It is a heavy mass of rotating wheel or large disc mounted on the crankshaft and is used as an energy storing device. The flywheel stores energy received during the power stroke and supplies the same during other strokes.

4. I.C. Engine Terminology

Figure.2 shows the details regarding the terms used in I.C. engines

i) **Bore:** The inside diameter of the cylinder is called Bore.

ii) **Top dead center (TDC):** The extreme position of the piston near to the cylinder head is called top dead center or TDC.



iii) **Bottom dead center (BDC):** The extreme position of the piston nearer to the crankshaft is called bottom dead center or BDC.

iv) **Stroke:** It is the linear distance travelled by the piston from the TDC to BDC or BDC to TDC.

v) **Clearance volume (V_C):** It is the volume of cylinder above the top of the piston, when the piston is at the TDC.

vi) **Swept volume or Stroke volume (V_S):**It is the volume swept by the piston as it moves from BDC to TDC or TDC to BDC.

vii) **Compression ratio**(R_C)**:**The ratio of the total cylinder volume to the clearance volume is called Compression ratio.

Total cylinder volume = Stroke volume(V_S) +Clearance volume (V_C)

$$R_C = \frac{V_S + V_C}{V_C}$$

viii) **Piston Speed:** The average speed of the piston is called piston speed.

Piston speed = **2*L*N**

Where; L = Stroke length in m.

N = Speed of engine in RPM.

5. Four-Stroke Engines

In Four-stroke engines, piston performs four different strokes to complete all the operations of the working cycle. The four different strokes performed are;

i. **Suction stroke**
ii. **Compression stroke**
iii. **Power stroke / Expansion stroke / Working stroke**
iv. **Exhaust stroke**

Each stroke is completed when the crankshaft rotates by 180°. Hence in a 4-stroke engine, four different strokes are completed through 720° of the crankshaft rotation or 2revolutions ofthe crankshaft based on the type of fuel used.

Note: In Four-strokeengines, opening and closing of valves during different strokes with respect to piston position and the rotation of crank is given in the table below.

Stroke	Position of the Piston		Inlet valve	Exhaust valve	Crank rotation
	Initial	Final			
Suction	TDC	BDC	Open	Close	0^0 - 180^0
Compression	BDC	TDC	Close	Close	180^0 - 360^0
Power/Working	TDC	BDC	Close	Close	360^0 - 540^0
Exhaust	BDC	TDC	Close	Open	540^0 - 720^0

Four-stroke engines are classified as;

- **Four-Stroke Petrol Engine.**
- **Four-Stroke Diesel Engine.**

6. Four-Stroke Petrol Engine

The working principle of a Four-strokePetrol engine is based on theoretical Otto cycle (Constant Volume Cycle). Hence it is also known as Otto cycle engine (Nikolaus august Otto).

A Four-strokepetrol engine performs four different strokes to complete one cycle. The working of each stroke is shown in the Figure 2.3 and its details are discussed below.

(a) Suction stroke:

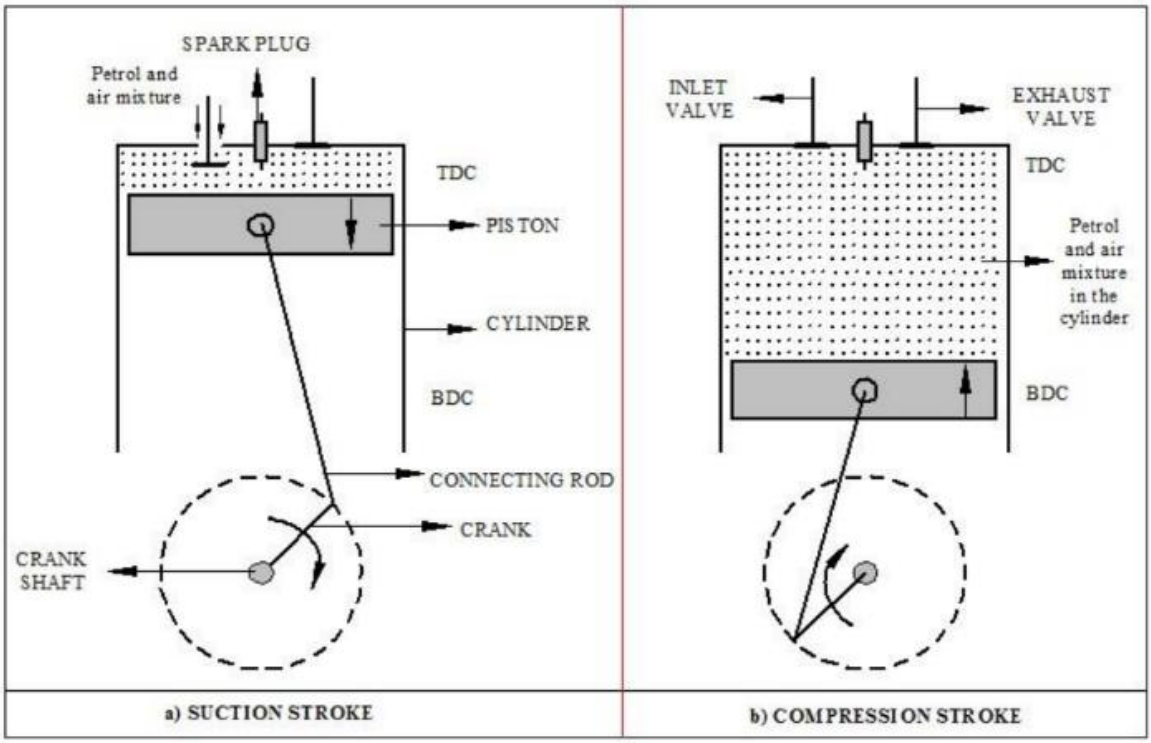
- This stroke starts when the piston is at TDC and about to move downwards.
- During this cycle inlet valve remains open and exhaust valve remains closed.
- Due to low pressure created by the downward moving piston, the charge (air-fuel mixture) is drawn into the cylinder.
- At the end of this stroke the inlet valve closes.
- The suction stroke is represented by the line AB on P- V diagram as shown in the Figure 2.4.

(b) Compression stroke:

- During this stroke the compression of fresh drawn charge takes place by the return stroke (BDC to TDC) of piston.
- During this stroke both inlet and exhaust valves are closed.
- As the piston moves upwards, the air -petrol mixture in the cylinder is compressed adiabatically. The pressure and temperature of the charge increases and this is shown by the curve BC on the P- V diagram.
- When the piston reaches the TDC (or) just before the completion of compression stroke, the spark plug ignites the charge. The combustion of the fuel takes place at the constant volume and is shown by a line CD on the P- V diagram.
- The compression ratio in petrol engines ranges from 7:1 to 11:1.

(c) Power stroke/Expansion stroke/Working stroke

- At the beginning of the stroke, piston is in TDC and during the stroke piston moves from TDC to BDC. During this strokeboth inlet and exhaust valves remain closed.
- The combustion of fuel liberates gases and these gases start expanding. Due to expansion, the hot gases exert a large force on the piston and as a result the piston is pushed from TDC to BDC.



a) SUCTION STROKE | b) COMPRESSION STROKE

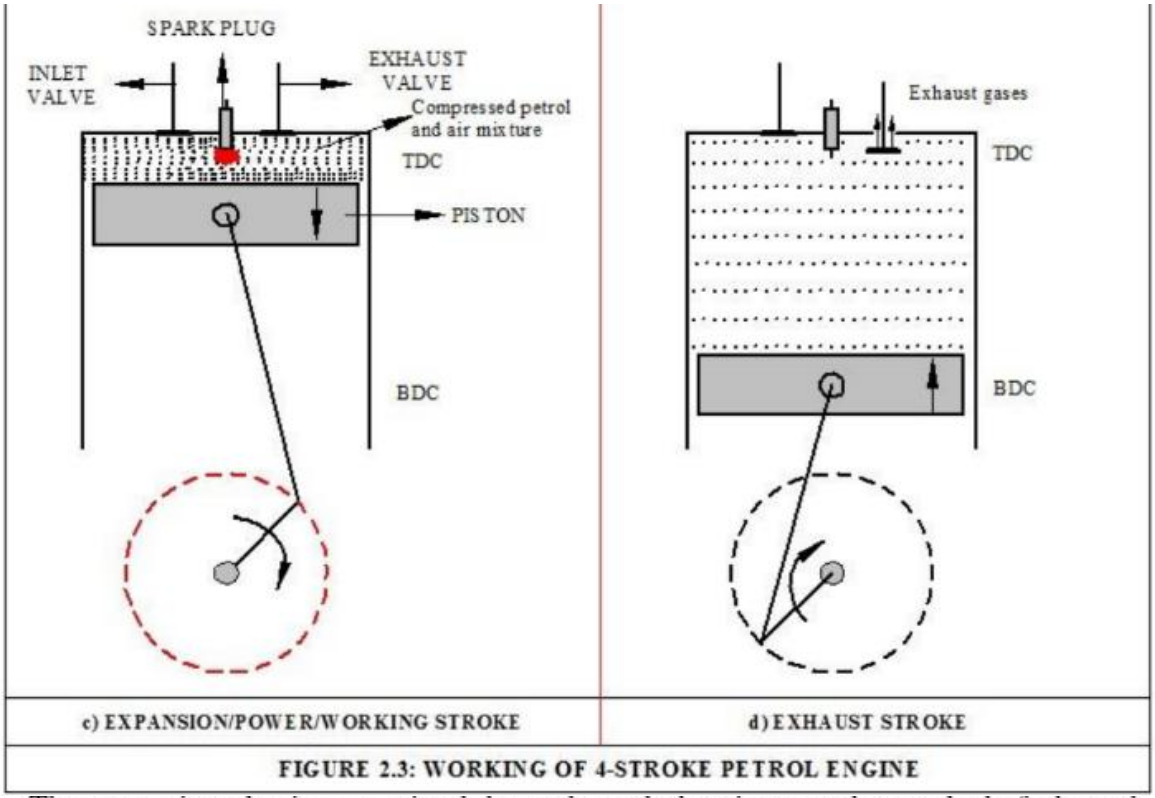


FIGURE 2.3: WORKING OF 4-STROKE PETROL ENGINE

- The power impulse is transmitted down through the piston to the crank shaft through the connecting rod. This causes crankshaft to rotate at high speeds. Thus work is obtained in this stroke. Hence, this stroke is also called working stroke. Also gas expands and does work on the piston so this stroke is also called an expansion stroke.
- The expansion of gases is adiabatic in nature and this is shown by the curve DE on P-V diagram. As the piston reaches the BDC, the exhaust valve opens. A part of the burnt gases escape through the exhaust valve out of the cylinder due to their own expansion.

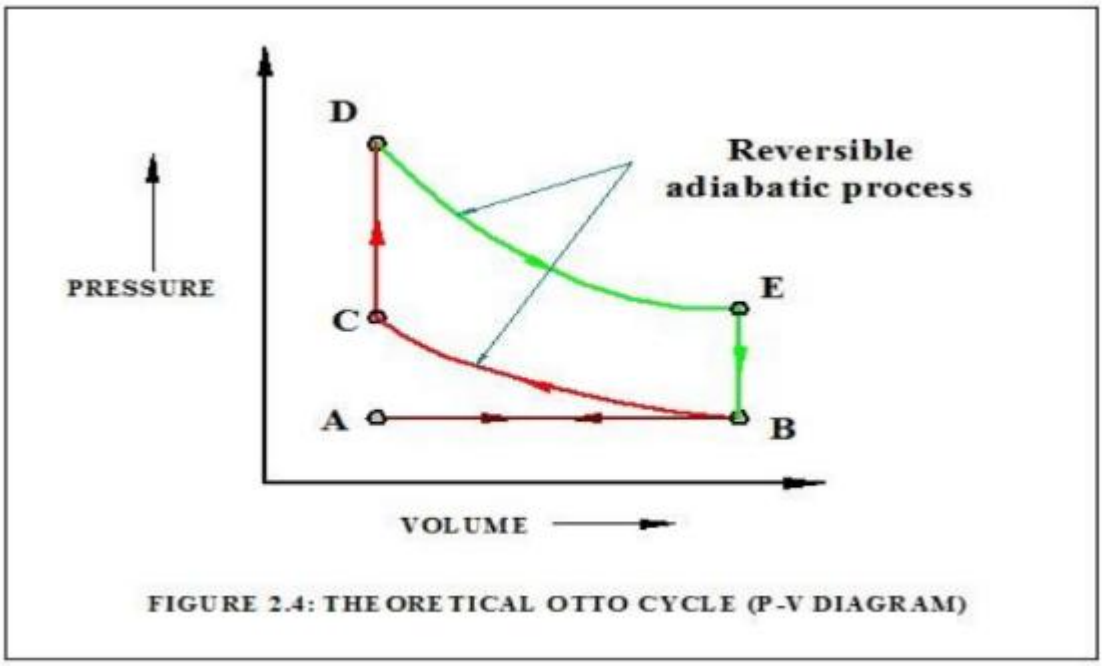


FIGURE 2.4: THEORETICAL OTTO CYCLE (P-V DIAGRAM)

(d) Exhaust stroke:

- At the beginning of the stroke piston is in BDC and during the stroke the piston moves from BDC to TDC.
- During this stroke inlet valve is closed and exhaust valve is opened.
- As the piston moves upward, it forces the remaining burnt gases out of the cylinder to the atmosphere through the exhaust valve. This is shown by the line EB and BA on P- V diagram.
- When the piston reaches the TDC, the exhaust valve closes and this completes the cycle.

In the next cycle the piston which is at TDC moves to BDC thereby allowing fresh charge to enter the cylinder and the process continues.

7. Four-Stroke Diesel Engine

The working principle of a Four-stroke diesel engine is based on theoretical diesel cycle. Hence it is also called diesel cycle engine.

A Four-strokediesel engine performs four different strokes to complete one cycle. The working of each stroke is shown in the Figure 2.5 and its details are discussed below.

(a) Suction stroke:

- At the beginning of the stroke piston is in TDC and during the stroke, piston moves from TDC to BDC.
- During this strokethe inlet valve opens and the exhaust valve will be closed.
- The downward movement of the piston creates suction in the cylinder and as a result, fresh air is drawn into the cylinder through the inlet valve.
- When the piston reaches the BDC, the suction stroke completes and this is represented by the line AB on P-V diagram as shown in the Figure 2.6.

(b) Compression stroke

- At the beginning of the stroke piston is in BDC and during the stroke piston moves from BDC to TDC.
- During this stroke both inlet and the exhaust valves are closed.
- As the piston moves upwards, air in the cylinder is compressed to a high pressure and temperature. The compression process is adiabatic in nature and is shown by the curve BC in P-V diagram.
- At the end of the stroke, the fuel (diesel) is sprayed into the cylinder by fuel injector. As the fuel comes in contact with the hot compressed air, it gets ignited and undergoes combustion at constant pressure. This process is shown by the line CD on PV diagram. At the point D fuel supply is cutoff.
- The compression ratio ranges from 16:1 to 20:1.

(c) Power stroke / Expansion stroke/ Working stroke

- At the beginning of this stroke, piston is in TDC and during the stroke, piston moves from TDC to BDC.
- During this strokeboth inlet and the exhaust valve remain closed.
- As combustion of fuel takes place, the burnt gases expand and exert a large force on the piston. Due to this, piston is pushed from TDC the BDC.

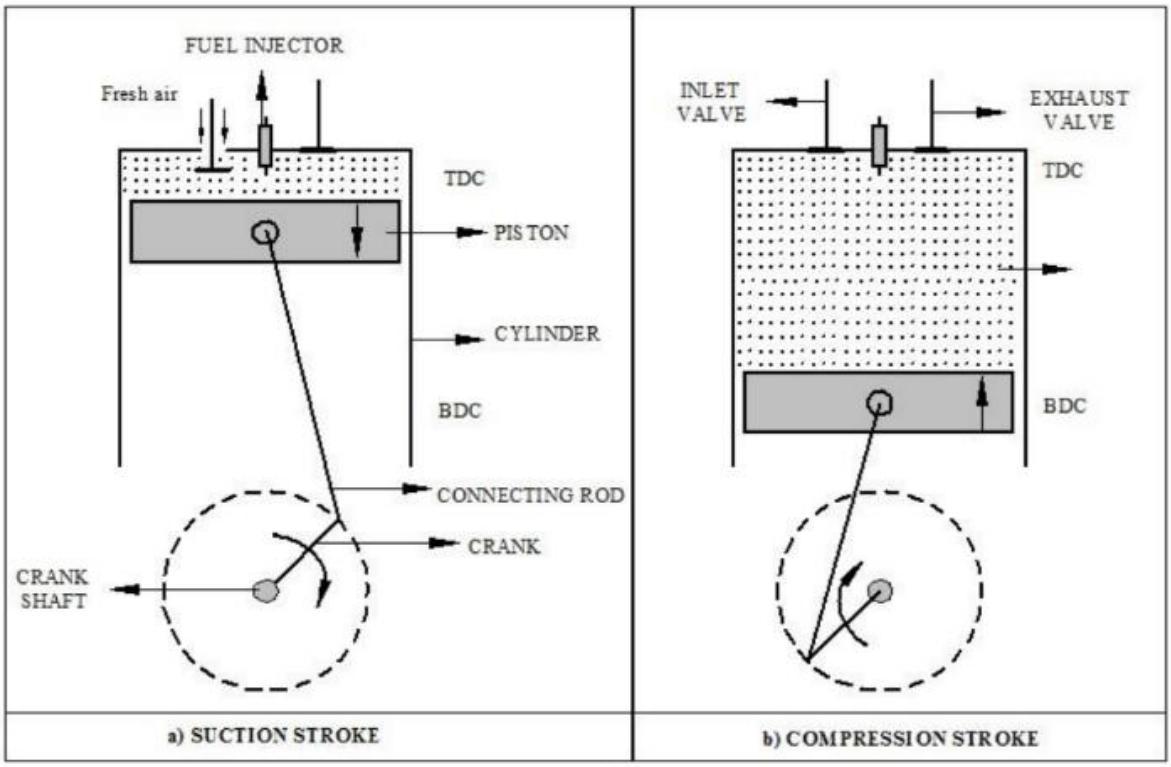


FIGURE 2.5: WORKING OF 4-STROKE DIESEL ENGINE

- The power impulse is transmitted down through the piston to the crank shaft through the connecting rod. This causes the crankshaft to rotate at high speeds. Thus work is obtained in this stroke.
- The expansion of gases is adiabatic in nature and this is shown by the curve DE on P- V diagram. When the piston reaches the BDC, the exhaust valve opens. A part of burnt gases escapes through the exhaust valve out of the cylinder due to self-expansion. The drop in pressure at constant volume is shown by the line EB on P- V diagram.

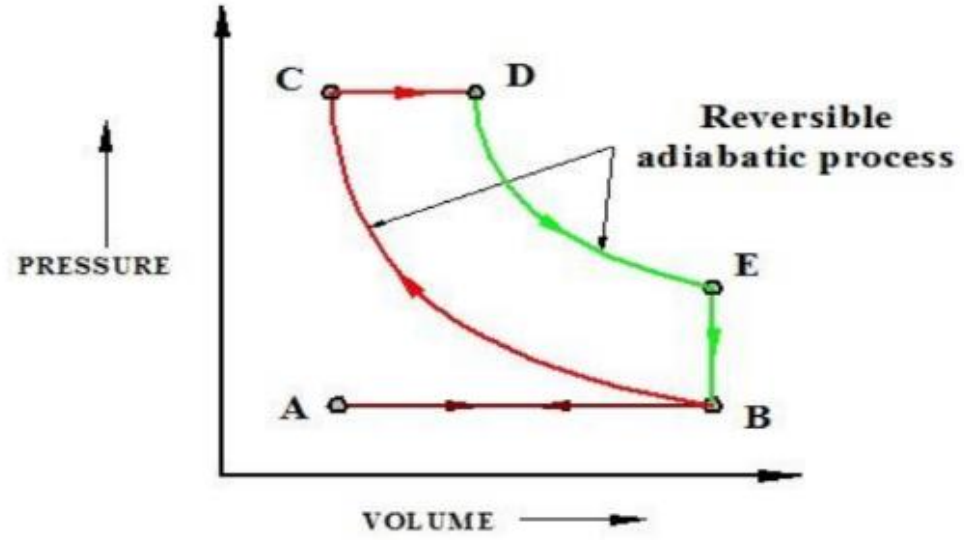


FIGURE 2.6: THEORETICAL DIESEL CYCLE (P-V DIAGRAM)

(d) Exhaust stroke

- At the beginning of the stroke piston is in BDC and during this stroke, piston moves from BDC to TDC.
- During this strokethe inlet valve is closed and the exhaust valve is opened.
- As the piston moves upward, it forces the remaining burnt gases out of the cylinder through the exhaust valve. This is shown by the line BA on P- V diagram. When the piston reaches the TDC the exhaust valve closes. This completes the cycle.

In the next cycle the piston which is at the TDC moves to BDC thereby allowing fresh air to enter into the cylinder and the process continues.

10. Comparison between Petrol and Diesel Engine

Sl.No.	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
1	Draws a mixture of petrol and air during suction stroke	Draws only air during suction stroke.
2	The carburetor is employed to mix air and petrol in the required proportion and to supply it to the engine during suction stroke.	The injector is employed to inject the fuel at the end of compression stroke.
3	Compression ratio ranges from 7: 1 to12: 1	Compression ratio ranges from 18:1 to22:1
4	The charge (petrol and air mixture) is ignited with the help of spark plug. This type of ignition is called spark ignition.	The ignition of the diesel is accomplished by the compressed air which will have been heated due to high compression ratio, to the temperature higher than the ignition temperature of the diesel. This type of ignition is called compression ignition.
5	The combustion of fuel takes place approximately at constant volume.	The combustion of fuel takes place approximately at constant pressure.
6	Works on theoretical Otto Cycle.	Works on theoretical Diesel Cycle.
7	Power developed is less.	Power developed is more.
8	Thermal efficiency is low. It is up to about 26%.	Thermal efficiency is high. It is up to about 40%.
9	These are high speed engines	These are low speed engines.
10	The maintenance cost is less.	The maintenance cost is more.
11	The running cost is high because of the higher cost of petrol.	The running cost is low because of lower cost of diesel
12	Lighter and cheaper because of low compression ratio	Heavier and costlier because of high compression ratio.