I[st] Year

* IC ENGINES *

Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine. Heat engines can be broadly classified into two categories:

i. Internal Combustion Engines (IC Engines)
ii. External Combustion Engines (EC Engines)

External combustion engines are those in which combustion takes place outside the engine whereas in internal combustion engines combustion takes place within the engine. For example, in a steam engine or a steam turbine, the heat generated due to the combustion of fuel is employed to generate high pressure steam which is used as the working fluid in a reciprocating engine or a turbine. In case of gasoline or diesel engines, the products of combustion generated by the combustion of fuel and air within the cylinder form the working fluid.

BASIC ENGINE COMPONENTS:

Even though reciprocating internal combustion engine look quite simple in appearance, they are highly complex machines. There are a large number of components which have to perform their functions effectively to produce output power. The major components of the engine and their functions are described below.

Cylinder: It is a hollow cylindrical structure closed at one end with cylinder head. The combustion of the fuel takes place inside the cylinder. This is known as heart of the engine. It is made of hard and high thermal conductivity materials by casting. A piston reciprocates inside the cylinder and produces power.

Cylinder head: It covers one end of the cylinder and consists of valves, port and spark plug/injector.

Cylinder liner: The internal surface of the cinder is equipped with replaceable liner which can be easily replaced after wear and tear. Liner is used to protect the wear of the cylinder so that replacement of complete cylinder can be avoided.

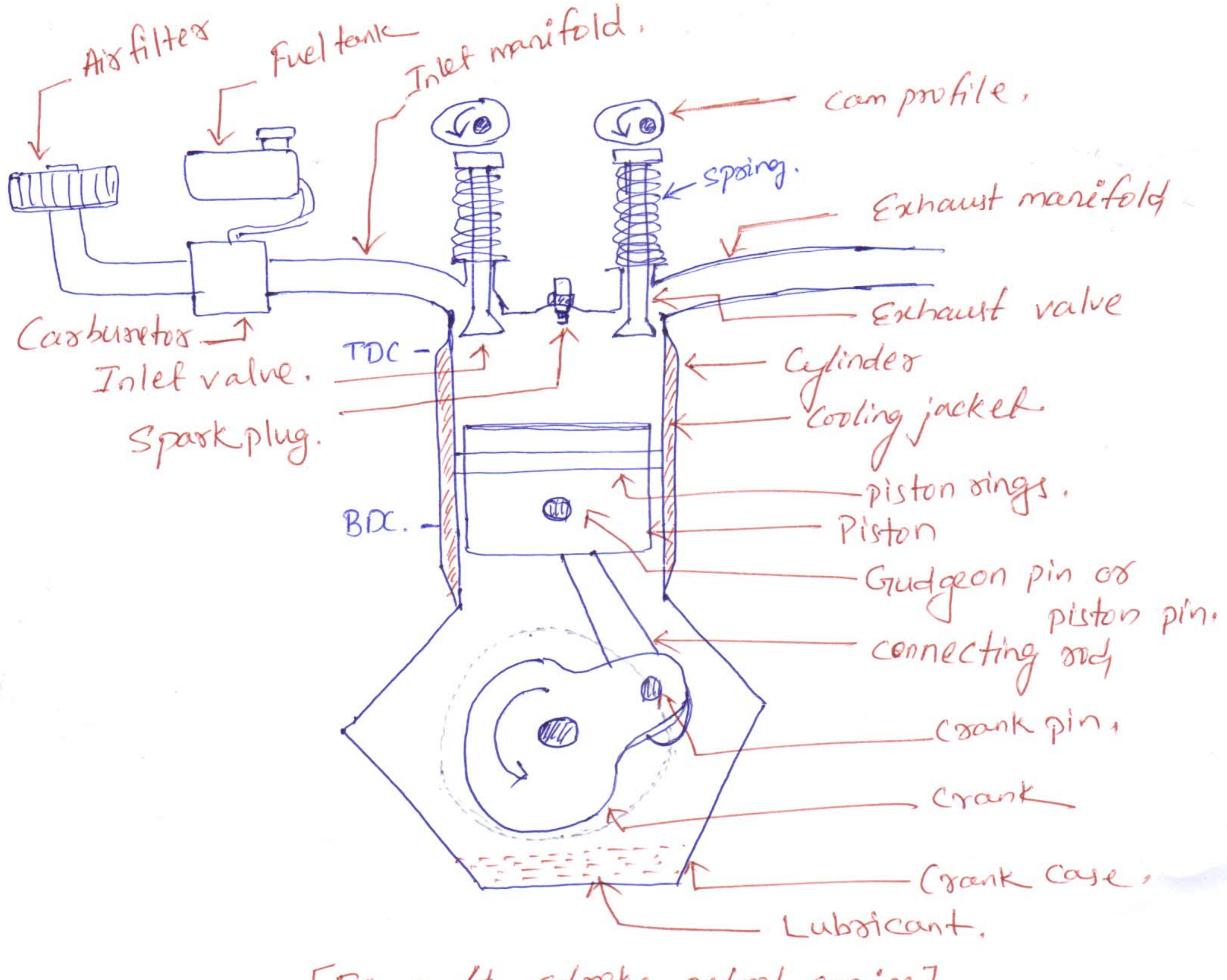
Piston: It is a cylindrical component which is fitted perfectly inside the cylinder providing a gas tight space with the piston rings and the lubricant. The piston is connected to connecting rod by hardened gudgeon pin. The main function of the piston is to transfer the power produced by combustion of the fuel to the crankshaft.

Piston rings: The outer periphery of the piston is provided with several grooves into which piston rings are fitted. The piston is fitted with these rings. The upper ring is known as compression ring and the lower rings are known as oil rings. The function of the compression ring is to compress the air-fuel mixture and the function of the oil rings is to collect the surplus lubricating oil on the liner surface.

Combustion Chamber: The space enclosed in the upper part of the cylinder, by the cylinder head and the piston top during the combustion process, is called the combustion chamber. The combustion of fuel and the consequent release of thermal energy results in the building up of pressure in this part of the cylinder.

Inlet and Exhaust Valves: Valves are commonly mushroom shaped poppet type. They are provided either on the cylinder head or on the side of the cylinder for regulating the charge coming into the cylinder (inlet valve) and for discharging the products of combustion (exhaust valve) from the cylinder.

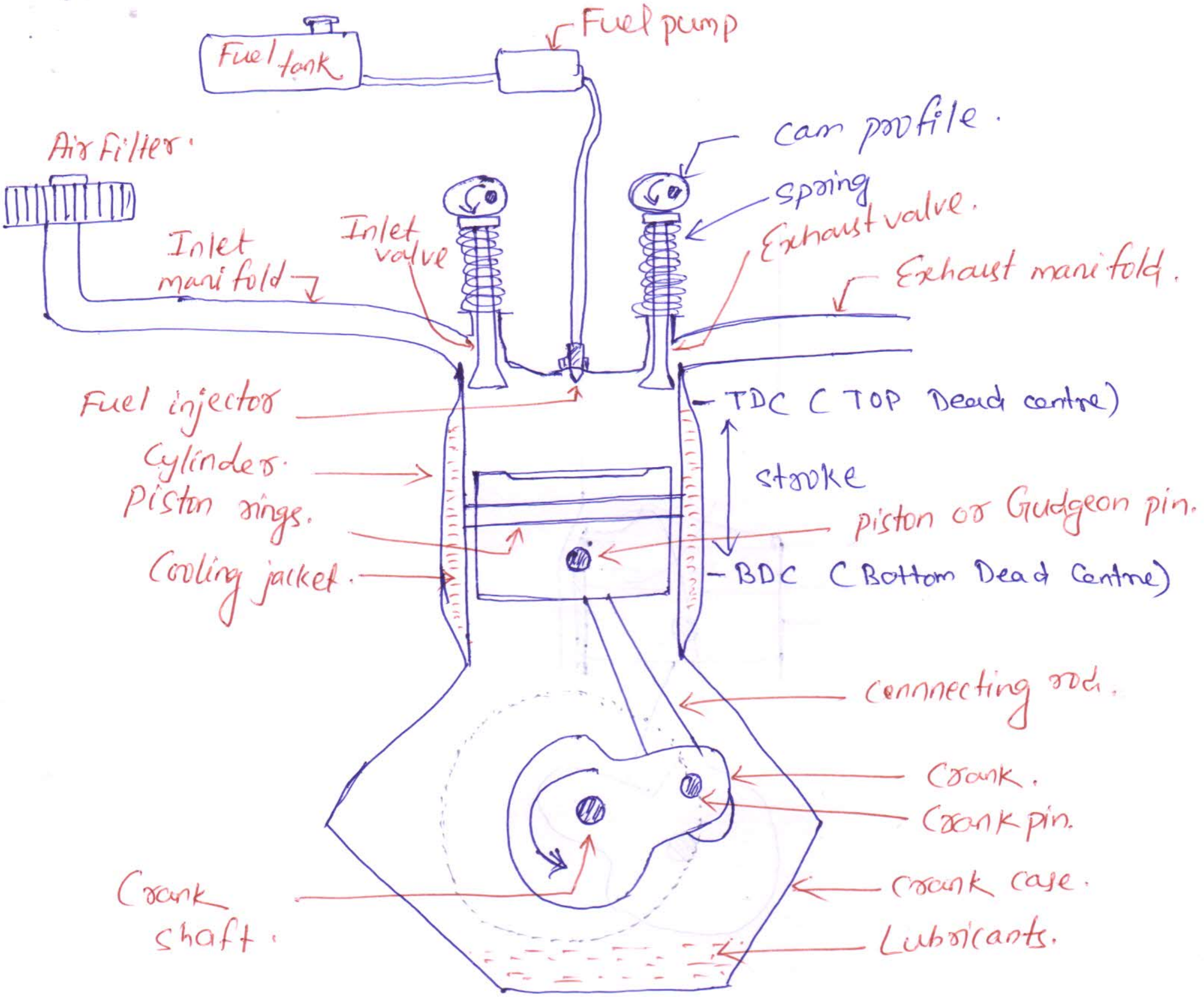
Inlet Manifold: The pipe which connects the intake system to the inlet valve of the engine and through which air or air-fuel mixture is drawn into the cylinder is called the inlet manifold.



[Fig : 4- stroke petrol engine]

or

[4-stroke spark ignition (S.I) engine]



[Fig: 4-stroke diesel engine]

or

[4-stroke compression ignition (C.I.) engine]

Exhaust Manifold: The pipe which connects the exhaust system to the exhaust valve of the engine and through which the products of combustion escape into the atmosphere is called the exhaust manifold.

Spark Plug: It is a component to initiate the combustion process in Spark Ignition (SI) engines and is usually located on the cylinder head.

Connecting Rod: It interconnects the piston and the crankshaft and transmits the gas forces from the piston to the crankshaft. The two ends of the connecting rod are called as small end and the big end. Small end is connected to the piston by gudgeon pin and the big end is connected to the crankshaft by crankpin.

Crankshaft: It converts the reciprocating motion of the piston into useful rotary motion of the output shaft. In the crankshaft of a single cylinder engine there are a pair of crank arms and balance weights. The balance weights are provided for static and dynamic balancing of the rotating system. The crankshaft is enclosed in a crankcase.

Gudgeon Pin: It links the small end of the connecting rod and the piston.

Camshaft: The camshaft and its associated parts control the opening and closing of the two valves. The associated parts are push rods, rocker arms, valve springs and tappets. This shaft also provides the drive to the ignition system. The camshaft is driven by the crankshaft through timing gears.

Cams: These are made as integral parts of the camshaft and are so designed to open the valves at the correct timing and to keep them open for the necessary duration.

Fly Wheel: The net torque imparted to the crankshaft during one complete cycle of operation of the engine fluctuates causing a change in the angular velocity of the shaft. In order to achieve a uniform torque an inertia mass in the form of a wheel is attached to the output shaft and this wheel is called the flywheel.

NOMENCLATURE:

These are various term frequently used In an IC engine and are discussed as below.

Cylinder Bore (d): The nominal inner diameter of the working cylinder is called the cylinder bore and is designated by the letter d and is usually expressed in millimeter (mm).

Piston Area (A): The area of a circle of diameter equal to the cylinder bore is called the piston area and is designated by the letter A and is usually expressed in square centimeter (cm^2).

Stroke (L): The nominal distance through which a working piston moves between two successive reversals of its direction of motion is called the stroke and is designated by the letter L and is expressed usually in millimeter (mm).

Dead Centre: The position of the working piston and the moving parts which are mechanically connected to it, at the moment when the direction of the piston motion is reversed at either end of the stroke is called the dead centre. There are two dead centres in the engine as indicated in. They are:

- **i.** Top Dead Centre (TDC): It is the dead centre when the piston is farthest from the crankshaft. It is designated as TDC for vertical engines and Inner Dead centre (IDC) for horizontal engines.
- **ii.** Bottom Dead Centre (BDC): It is the dead centre when the piston is nearest to the crankshaft. It is designated as BDC for vertical engines and Outer Dead Centre (ODC) for horizontal engines.

Displacement or Swept Volume (Vs): The nominal volume swept by the working piston when travelling from one dead centre to the other is called the displacement volume. It is expressed in terms of cubic centimeter (cc) and given by Vs = A x L.

Cubic Capacity or Engine Capacity: The displacement volume of a cylinder multiplied by number of cylinders in an engine will give the cubic capacity or the engine capacity. For example, if there are K cylinders in an engine, then Cubic capacity = Vs x K.

Clearance Volume (Vc): The nominal volume of the combustion chamber above the piston when it is at the top dead centre is the clearance volume. It is designated as Vc and expressed in cubic centimeter (cc).

Compression Ratio (r): It is the ratio of the total cylinder volume (V_T) when the piston is at the bottom dead centre, to the clearance volume (Vc). It is designated by the letter r.

THE WORKING PRINCIPLE OF ENGINES

If an engine is to work successfully then it has to follow a cycle of operations in a sequential manner. The sequence is quite rigid and cannot be changed. In the following sections the working principle of both SI and CI engines is described. Even though both engines have much in common there are certain fundamental differences.

The credit of inventing the spark-ignition engine goes to Nicolaus A. Otto (1876) whereas compression-ignition engine was invented by Rudolf Diesel (1892). Therefore, they are often referred to as Otto engine and Diesel engine.

1. Four-Stroke Spark-Ignition Engine:

In a four-stroke engine, the cycle of operations is completed in four strokes of the piston or two revolutions of the crankshaft. During the four strokes, there are five events to be completed, viz., suction, compression, combustion, expansion and exhaust. Each stroke consists of 180^0 of crankshaft rotation and hence a four-stroke cycle is completed through 720^0 of crank rotation.

The cycle of operation for an ideal four-stroke SI engine consists of the following four strokes: (i) suction or intake stroke; (ii) compression stroke; (iii) expansion or power stroke and (iv) exhaust stroke

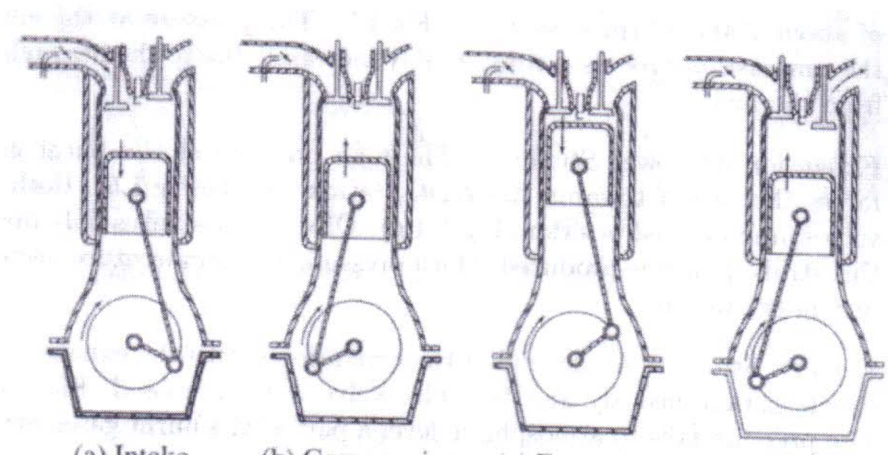


Fig. working principle of a four stroke SI engine.

i. **Suction or Intake Stroke:** Suction stroke starts when the piston is at the top dead centre and about to move downwards. The inlet valve is assumed to open instantaneously and at this time the exhaust valve is in the closed position as shown in the above figure. Due to the suction created by the motion of the piston towards the bottom dead centre the charge consisting of fuel-air mixture is drawn into the cylinder. When the piston reaches the bottom dead centre the suction stroke ends and the inlet valve closes instantaneously.

ii. **Compression Stroke:** The charge taken into the cylinder during the suction stroke is compressed by the return stroke of the piston. During this stroke both inlet and exhaust valves are in closed position. The mixture which fills the entire cylinder volume is now compressed into the clearance volume. At the end of the compression stroke the mixture is ignited with the help of a spark plug located on the cylinder head. In ideal engines it is assumed that burning takes place instantaneously when the piston is at the top dead centre and hence the burning process can be approximated as heat addition at constant volume. During the burning process the chemical energy of the fuel is converted into thermal energy. The pressure at the end of the combustion process is considerably increased due to the heat release from the fuel.

iii. **Expansion or Power Stroke:** The high pressure of the burnt gases forces the piston towards the BDC. Both the valves are in closed position. Out of the four-strokes only during this stroke power is produced. Both pressure and temperature decrease during expansion.

iv. **Exhaust Stroke:** At the end of the expansion stroke the exhaust valve opens instantaneously and the inlet valve remains closed. The pressure falls to atmospheric level a part of the burnt gases escape. The piston starts moving from the bottom dead centre to top dead centre and sweeps the burnt gases out from the cylinder almost at atmospheric pressure. The exhaust valve closes when the piston reaches TDC.

2. **<u>Four-Stroke Compression-Ignition Engine.</u>**

The four-stroke CI engine is similar to the four-stroke SI engine but it operates at a much higher compression ratio. The compression ratio of an SI engine is between 6 and 10 while for a CI engine it is from 16 to 20. The ideal sequence of operations for the four-stroke CI engine as shown in the below figure is as follows:

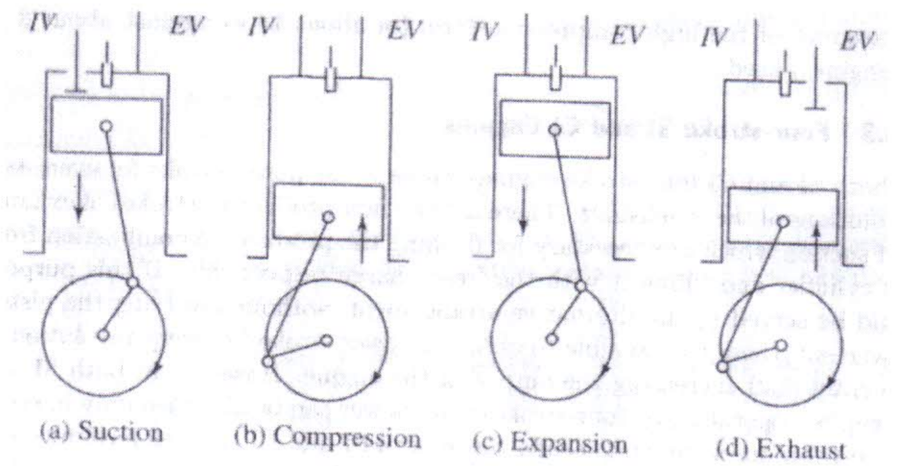


Fig. working principle of a four stroke CI engine.

Suction Stroke: Air alone is inducted during the suction stroke. During this stroke inlet valve is open and exhaust valve is closed.

Compression Stroke: Air inducted during the suction stroke is compressed into the clearance volume. Both valves remain closed during this stroke.

Expansion Stroke: Fuel injection starts nearly at the end of the compression stroke. The rate of injection is such that combustion maintains the pressure constant in spite of the piston movement on its expansion stroke increasing the volume. Heat is assumed to have been added at constant pressure. After the injection of fuel is completed the products of combustion expand. Both the valves remain closed during the expansion stroke.

Exhaust Stroke: The piston travelling from BDC to TDC pushes out the products of combustion. The exhaust valve is open and the intake valve is closed during this stroke.

Two-Stroke Engine:

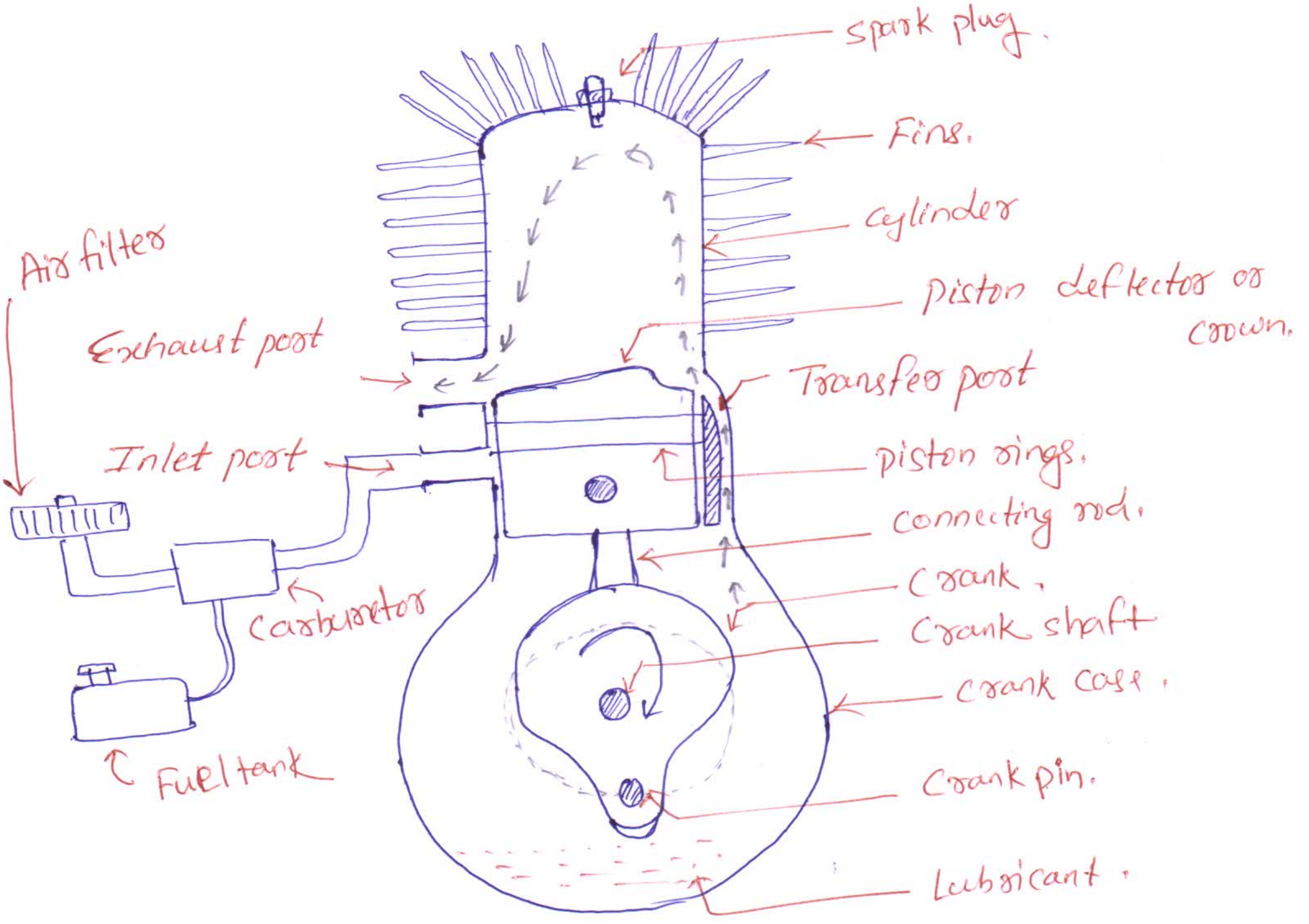
If two unproductive strokes such as the suction and exhaust could be served by an alternative arrangement, especially without the movement of the piston then there will be a power stroke for each revolution of the crankshaft. In such an arrangement, theoretically the power output of the engine can be doubled for the same speed compared to a four-stroke engine. Based on this concept, Dugald Clark (1878) invented the two-stroke engine.

In two-stroke engines the cycle is completed in one revolution of the crankshaft. The main difference between two-stroke and four-stroke engines is in the method of filling the fresh charge and removing the burnt gases from the cylinder. In the four-stroke engine these operations are performed by the engine piston during the suction and exhaust strokes respectively. In a two stroke engine, the filling process is accomplished by the charge compressed in crankcase. The induction of the compressed charge moves out the product of combustion through exhaust ports. Therefore, no separate piston strokes are required for these two operations. Two strokes are sufficient to complete the cycle, one for compressing the fresh charge and the other for expansion or power stroke.

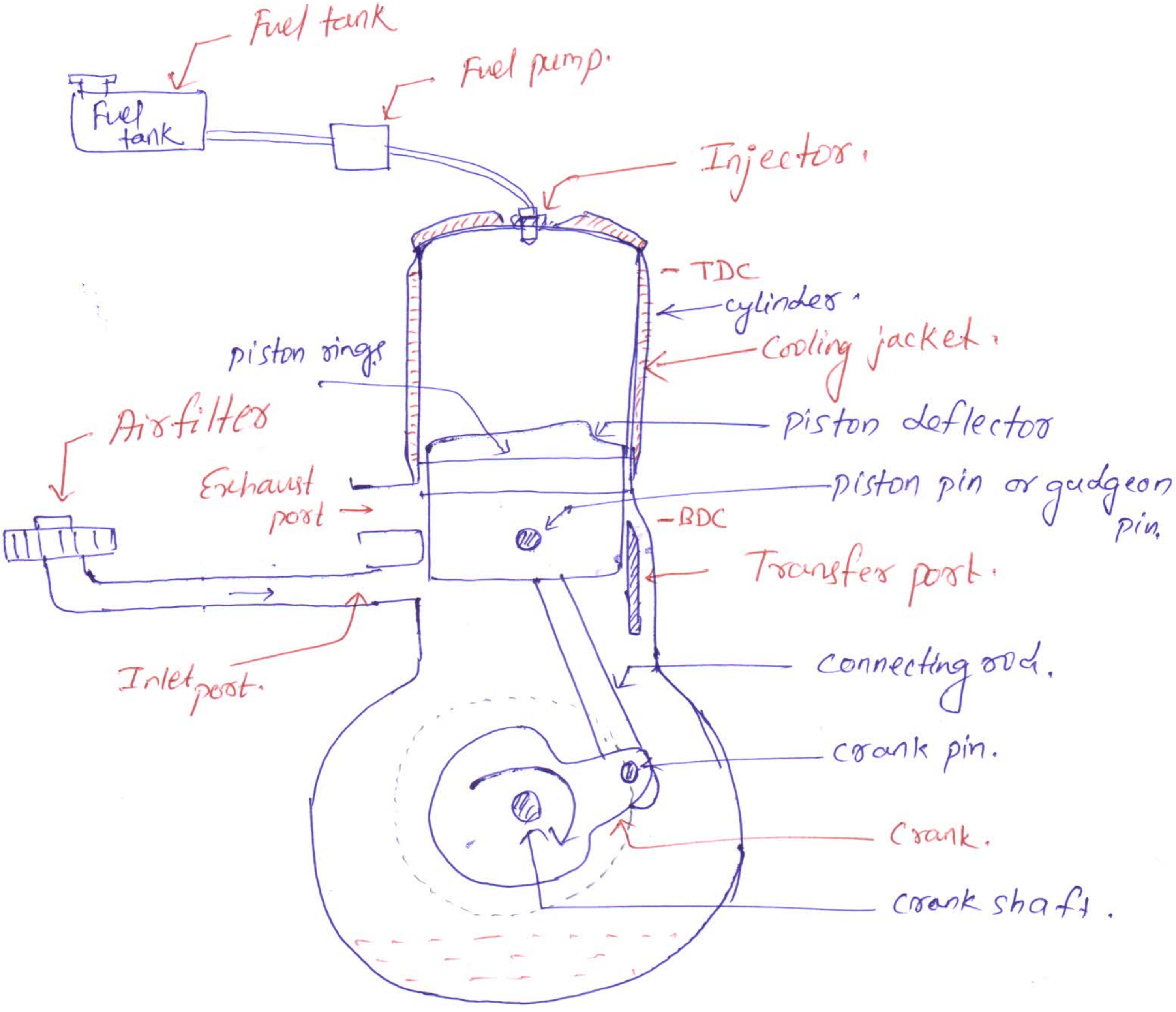
- → The air-fuel charge is inducted into the crankcase through the uncovered inlet port when the pressure in the crankcase is reduced due to upward motion of the piston from BDC to TDC during compression stroke.
- → After the compression and ignition, expansion takes place in the usual way. During the expansion stroke the charge in the crankcase is compressed slightly. Near the end of the expansion stroke, the piston uncovers the exhaust ports and the cylinder pressure drops to atmospheric pressure as the combustion products leave the cylinder.
- → Further movement of the piston uncovers the transfer ports, permitting the slightly compressed charge in the crankcase to enter the engine cylinder. The piston top usually has a projection to deflect the fresh charge towards the top of the cylinder preventing the flow through the exhaust ports. This serves the double purpose of scavenging the combustion products from the upper part of the cylinder and preventing the fresh charge from flowing out directly through the exhaust ports.
- → The same objective can be achieved without piston deflector by proper shaping of the transfer port. During the upward motion of the piston from BDC the transfer ports close first and then the exhaust ports, thereby the effective compression of the charge begins and at the same time a new fresh air-fuel charge will be inducted into the crank case. In this way the cycle will be completed.
- → The above points are the working of a 2-stroke petrol engine. The working of two stroke CI engine is very similar to two stroke SI engine with the exception that only air is compressed and the spark plug is replaced by the fuel injector. A higher compression ratio is also used in case of CI engines.

The two-stroke engine was developed to obtain higher output from the same size of the engine. The engine has no valves and valve actuating mechanism making it mechanically simpler. This makes the two-stroke engine cheaper to produce and easy to maintain. Theoretically a two stroke engine develops twice the power of a comparable four-stroke engine because of one power stroke every revolution (compared to one power stroke every two revolutions of a four-stroke engine). The other advantage of two-stroke engines is more uniform torque on crank-shaft. In the SI engine, the incoming charge consists of fuel and air. During scavenging, as both inlet and exhaust ports are open simultaneously for some time, there is a possibility that some of the fresh charge containing fuel escapes with the exhaust. This results in high fuel consumption and lower thermal efficiency.

The two-stroke diesel engine does not suffer from this defect. There is no loss of fuel with exhaust gases as the intake charge in diesel engine is only air.



[Fig: 2-stroke petrol or S.I. engine]



[Fig: 2- stroke diesel or C. I. engine]

Comparison between SI and CI engines:

SI engines	CI engines
1. It is based on Otto cycle or constant volume heat addition and rejection cycle.	1. It is based on diesel cycle or constant pressure heat addition and constant volume heat rejection cycle.
2. A high volatile, high self-ignition temperature fuel, gasoline is used.	2. Comparatively low volatile and low self-ignition temperature fuel, diesel is used.
3. A gaseous mixture of fuel and air is inducted during suction stroke. A carburettor is necessary to provide the mixture.	3. Fuel is injected at high pressure at the end of compression stroke. A fuel pump and injector unit is used.
4. Throttle controls the quantity of fuel–air mixture introduced.	4. The quantity of fuel is regulated in pump. Air quantity is not controlled. There is quality control.
5. For combustion of the charge, it requires ignition system with stark plug in combustion chamber.	5. Auto ignition occurs due to high temperature of air resulting from high compression.
6. Compression ratio ranges from 6 to 10.	6. Compression ratio ranges from 16 to 20.
7. Due to light weight and homogeneous combustion, they are high speed engines.	7. Due to heavy weight and heterogeneous combustion, they are comparatively low speed engines.
8. It has lower thermal efficiency due to lower compression ratio but delivers more power for same compression ratio.	8. It has higher thermal efficiency due to high compression ratio and delivers lesser power for the same compression ratio.

Comparison between four stroke and two stroke engines:

Four stroke engines	Two strokes engines
1. The thermodynamic cycle is completed in four strokes of the piston and two revolutions of the crankshaft. Thus, one power stroke is obtained in two revolutions of crankshaft.	1. The thermodynamic cycle is completed in two strokes of the piston and one revolution of the crankshaft. Thus, one power stroke is obtained in one revolution of crankshaft.
2. Turning moment is not so uniform during all the four strokes and hence heavier flywheel is required.	2. Comparatively, turning moment is more uniform and hence lighter flywheel can be employed.
3. The power produced for same size engine is less than two strokes engine due to one power stroke in two revolutions of crankshaft. Or for same power output engine required is heavier and bulkier.	3. The power produced for same size engine is more than the four stroke engine due to one power stroke in each revolution of crankshaft.
4. Lesser cooling and lubrication is required due to one power stroke in two revolutions and hence less wear and tear occurs.	4. Larger cooling and lubrication is required due to one power stroke in each revolution and hence more wear and tear occurs.
5. It consists of valves and valve actuating mechanism such as cam, camshaft, rocker arm, spring, valve and valve sheet.	5. It has ports in place of valves.
6. It has higher volumetric efficiency as the time available for induction of charge is more.	6. Volumetric efficiency is lower due to lesser time available for induction.
7. It has higher thermal efficiency due to complete combustion of the fuel.	7. It has lower thermal efficiency due to partial wastage of fuel through the exhaust port and incomplete combustion.