Chapter 3

Internal Combustion Engines

3.1. HEAT ENGINES

A machine or device which derives heat from the combustion of fuel and converts part of this energy into mechanical work is called a heat engine. Heat engines are broadly classified into internal combustion engines and external combustion engines.

An internal combustion engine is a reciprocating heat engine in which fuel mixed with correct amount of air is burnt inside a cylinder. The gaseous products of combustion form the working substance which make the piston move and produce mechanical work at the engine crankshaft. In contrast, the combustion of fuel in steam engines is external. Combustion takes place on the fire grate of the boiler, and the heat energy of fuel thus released is used to convert water into steam. The steam is then led to the steam engine or steam turbine where work is produced. Obviously, the working substance (steam) is generated in a boiler which is outside the power producing device.

Compared to steam engines, the IC engines are noted for :

- high overall efficiency. The efficiency of IC engines ranges from 30 to 35% whereas efficiency of steam engines lies between 15–20%
- compact and small size
- low weight to power ratio
- easy and quick starting. In steam engines, firing of the boiler and generation of steam takes sufficient time
- less maintenance and operating cost.

The important applications of IC engines are:-

- Road vehicles, locomotives, ships and aircraft. As such IC engines enable passengers and cargos to cross lands, oceans and skies.
- Portable stand by units for power generation in case of scarcity of electric power.
- Extensively used in farm tractors, lawn movers, concrete mixing devices and motor boats.

3.2. CLASSIFICATION OF IC ENGINES

The IC engines are classified on the basis of following systems and their variations :

- *Number of strokes required for the completion of one cycle*

(*i*) Two stroke engines in which the engine cycle is completed in two stokes of the piston, *i.e.*, in one revolution of crank shaft.

(ii) Four stroke engines in which the engine cycle is completed in four strokes of the piston, *i.e.*, in two revolutions of crank shaft.

- *Thermodynamic cycle* : The thermodynamic cycles commonly used are :
  - (i) Constant volume combustion (Otto) cycle : Most of the petrol and gas engines work on this cycle.
  - (ii) Constant pressure combustion (Diesel) cycle : Low speed diesel engines work on this cycle.
  - (iii) Mixed or limited pressure (Dual) cycle : The high speed diesel engines work on this cycle.
- *Ignition system* : The following two methods are used for the ignition of fuel.
  - (i) Spark ignition : Petrol engines use a spark for the ignition of compressed charge (mixture of air and petrol) and the spark may be produced by magneto or battery.
  - (ii) Compression ignition : Diesel engines have a high compression ratio. The resulting high temperature is utilized to burn the fuel.
- *Kind of fuel used* :
  - (i) Light oil engines using kerosene or petrol. Petrol engines fall under this category.
  - (ii) Heavy oil or diesel oil engines: The oil used may be crude oil or mineral oil
  - (iii) Gas engines : The gas used may be coal gas, producer gas, blast furnace gas or coke oven gas
  - (iv) By-fuel engines : The gas is used as the main fuel and liquid fuel is used for starting purposes.
- *Number and arrangement of cylinders*
  - (i) In-line engines : all the cylinders are arranged with their axes parallel and they transmit power to a single crank shaft.
  - (ii) V-engines : the engines contain two banks of cylinders connected to the same crank and crank shaft. The crank shaft length for V-type engines is half of that for in-line engines.
  - (iii) Radial engines : the cylinders are arranged radially and are connected to a single crank shaft. Radial engines occupy less floor area and have little balancing problem.
- *Fuel supply system*
  - (i) Carburettor engines : mixture of petrol and air is prepared in the carburettor and is supplied to the engine during suction stroke.
  - (ii) Solid injection or airless injection : a fuel pump is used to inject the fuel in diesel engines.
  - (iii) Air injection : fuel is supplied, under pressure, to the engine cylinder of diesel engines by using compressed air.
- *Cooling system*
  - (i) Water cooled engines in which the heat from the cylinder walls is transferred to cooling water which is kept circulating in the water jackets provided in the cylinder block. The water picks up heat and is taken to the radiator where the heat is transferred to the surrounding air. The water is repeatedly returned to the engine after being cooled in the radiator. Medium and large sized engines and the automobile engines use the water cooling system.
  - (ii) Air cooling in which the heat from the cylinder walls is directly transferred to surrounding air. Air cooling is generally employed for small capacity engines like scooter and motor cycle engines.

- *Lubrication system* : Lubrication system refers to the act of reducing friction by introducing a substance (called lubricant) between the mating parts of the engine.
  - (i) Splash lubrication system suitable for small capacity engines with moderate speed and bearing loads.
  - (ii) Pressure lubrication system used for heavy duty engines.
- *Governing system* (speed control under variable load)
  - (i) Quality control engines in which composition of mixture (air-fuel ratio) is changed by admitting more or less fuel in accordance with variation in load on the engine. This method is used in diesel engines.
  - (ii) Quantity control engines in which the air-fuel mixture has a constant composition. However, the quantity of the mixture supplied is changed in accordance with load on the engine. This is used in petrol and gas engines.
- *Valve location* :
  - (i) overhead valve engine
  - (ii) side valve engine
- *Speed* : Engines having speeds above 900 rpm are called high speed engines, and less than 400 rpm are called slow speed engines.
- *Field of application* :
  - (i) Stationary engines used for small and medium capacity electric power plants, concrete mixers and pumping units
  - (ii) Mobile engines installed in motor vehicles, air planes and ships.

3.3. ENGINE PARTS AND THEIR FUNCTIONS

• ***Cylinder and cylinder head :*** The cylinder is the main body of the engine wherein direct combustion of fuel takes place. The cylinder is a stationary component and the piston reciprocates inside it. The cylinder head closes one end of the cylinder, and it is usually casted as one piece and is bolted to the top of the cylinder. It contains the valve seats and ports, and supports the valves and valve - actuated mechanism. Cylinders are usually made of ordinary cast iron. However, for heavy duty engines, alloy steels are used. In the interest of weight saving, particularly in aeroplanes, use is made of aluminium and magnesium alloys.

• ***Piston and piston rings :*** A piston is a metal cup with its crown facing the combustion space. The function of the piston, together with the rings, is to confine the gases in the combustion space and thus transmit the full force of expansion to the connecting rod and crank shaft. The piston also acts as a bearing for the small end of connecting rod. Pistons are usually made of grey iron or of aluminium alloys for high speed engines. Aluminium has the advantage of low density (the density of aluminium is about two-fifths that of cast iron).

The leakage of gases between the walls of piston and cylinder is prevented by means of three to six cast iron rings which may be square or rectangular in cross-section. These rings are inserted into the grooves provided on the piston. There are usually two sets of piston rings:

(i) upper piston rings (called the compression rings) provide gas tight seal and prevent the leakage of high pressure gas.

(ii) lower piston rings (called oil rings) provide effective seal and prevent the leakage of oil into the cylinder head.

• ***Connecting rod*** : The connecting rod transmits the force given by the piston to the crank, causing it to turn and thus convert the reciprocating motion of the piston into rotary motion of the crankshaft. The rotary motion is required to make wheels turn, a cutting blade spin or a pulley rotate.

The connecting rod connects the piston at one end and the crank at the other end. The piston end is called the small end and the crank end is called the big end. The connection at the small end is made by a pin called the gudgeon pin, wrist pin or piston pin. At the big end, the connecting rod embraces the crank arm by a pin named crank pin.

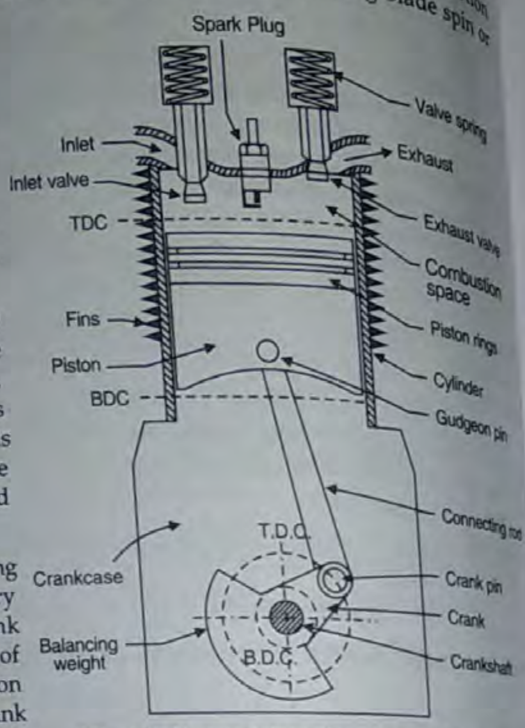

Fig. 3.1. Nomenclature of engine components

The connecting rod is usually a small forging of I-section which provides the maximum stiffness with minimum weight. It is normally tapered along its length so as to provide smaller cross-sectional area towards the small end. It has also a passage for the transfer of lubricating oil from the big end bearing to the gudgeon pin.

• ***Crank and crankshaft*** **:** The reciprocating motion of the piston is converted into rotary motion by the connecting rod and crank mechanism. All the auxiliary mechanism of the engine having mechanical transmission are geared in one way or the other to the crank shaft and obtain their motive power from it. The shape of the crank shaft, *i.e.*, the mutual arrangement of the cranks depends on the number and arrangement of cylinders and the turning order of the engine. Fig. 3.2 shows a typical crank shaft layout for a four-cylinder engine.

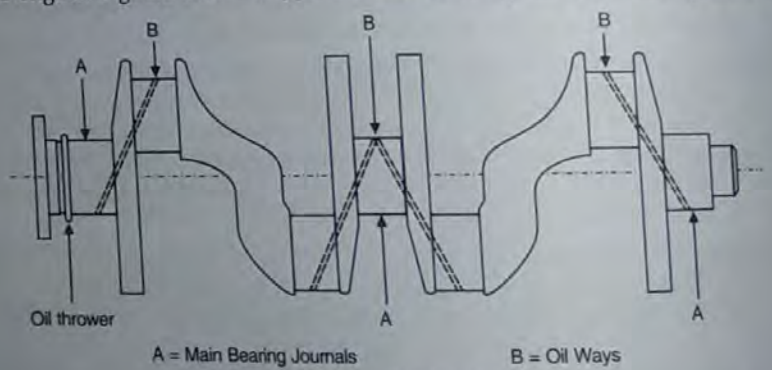

Fig. 3.2. Crankshaft

Both the crank and crank shaft are steel forgings machined to a smooth finish. The crankshaft mounts in bearings and can rotate freely. For smooth running, the crank shafts are perfectly balanced, both statically and dynamically.

• ***Crank case*** **:** The engine cylinder, piston and crankshaft are housed in the crank case which also serves as an oil sump for the storage of the lubricating oil. The oil level is checked with the help of an oil stick or dip stick.

The crank case is generally made of cast iron.

• ***Camshaft and valve mechanism*** **:** The camshaft operates the intake and exhaust valves through the cams, cam followers, push rods and rocker arms. On a four stroke engine, the inlet and exhaust valves operate once per cycle, *i.e.*, in two revolutions of the crankshaft. Consequently, the cam shaft is driven by the crankshaft at exactly half its rotational speed. The crankshaft material is commonly a steel forging with journals and cam faces case hardened.

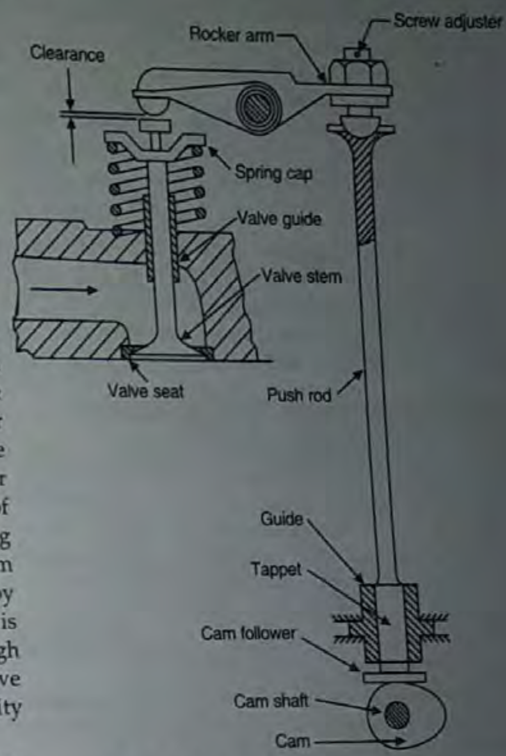

Fig. 3.3. Overhead valve mechanism

The valves are usually mushroom shaped (known as poppet valves) with conical seating surfaces. The poppet valve is practically universal on all modern car and commercial vehicle engines. The face of the valve and its seat on the cylinder are very accurately ground at an angle of 30 degree or 45 degree. Steel containing a small percentage of nickel and chromium is the usual valve material. Such an alloy has good heat-resisting qualities, and is considered good enough to withstand high temperatures, mechanical forces, corrosive and erosive effects of the high velocity cylinder gases.

The valves may be provided at the top or on the side of the engine cylinder. Fig. 13.3 shows a typical overhead-valve assembly with the principle parts named. The cam lifts the push rod through cam follower and the push rod actuates the rocker arm lever at one end. The other end of the rocker arm then gets depressed and that opens the valve. The valve returns to its seating by the spring after the cam has rotated. The valve stem moves in a valve guide which acts as a bearing. Some clearance is provided between the rocker arm and valve stem to take care of valve expansion during running of engine, and it can be adjusted by the abjusting screw. The exhaust valve usually has a greater clearance as it runs hotter.

• ***Flywheel*** **:** The flywheel is a heavy and thoroughly balanced disk fitted onto the end of crankshaft. It stores excess energy during the power stroke and returns this stored energy for use during the auxiliary strokes. Thus it serves to reduce cyclic variations of speed and ensures uniform rotation of crankshaft. Heavier the flywheel, more uniform and stable will be the operation of the engine.

Flywheels are generally manufactured from cast iron or cast steel.

• ***Governor*** **:** A governor is used to adjust the power output from an engine in conformity with the external load and accordingly make the engine operate at constant speed. The task is accomplished by regulating the quantity of charge in petrol engines, and the amount of fuel in diesel engines.

All types of engines generally have the components described above. Given below are the components used either only for diesel engines or for petrol engines.

Fuel pump and injector : In diesel engines, fuel pumps are used to deliver the correct quantity of fuel at the precise instant required for a wide range of loads and speeds. The nozzle atomises the fuel and distributes it into the combustion chamber of the engine. Atomisation of fuel means breaking of the fuel stream into mist like spray. Atomisation ensures that each particle of fuel is surrounded by air needed for combustion and that assists in rapid and successful burning of fuel. Atomisation is made possible by the high velocity of fuel through the nozzle which is due to high pressure created by the pump.

Carburettor and spark plug : The carburettor delivers to the gas and petrol engines a combustible mixture of air and fuel in a condition that can be easily and efficiently burnt in the engine cylinder. The process of mixture formation is called carburation.

Towards the end of compression stroke, the combustible mixture is ignited by a spark plug which has to spark several thousand times a minute under a wide range of temperatures. Each cylinder is provided with its own spark plug screwed into the lid.

3.4. FOUR STROKE PETROL ENGINE

A cycle is a sequence of operations constantly repeated, and 'four-stroke' refers to the number of strokes of the piston required to complete one cycle. Refer Fig. 3.4 for the arrangement of different parts of a four stroke cycle system. The piston reciprocating inside a cylinder, is connected to the crankshaft through connecting rod and the crank. The inlet (suction) and outlet (exhaust) valves are housed in the cylinder head. The cylinder head is also provided with an electric spark plug.

All events of the cycle namely suction, compression, combustion and expansion, and exhaust are completed in two revolutions of the crankshaft.

The salient features of the four strokes in a petrol engine are as given below :

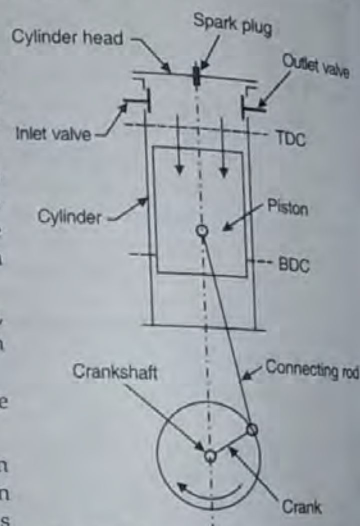

Fig. 3.4. Four stroke cycle system

1. *Intake or suction stroke* : (Fig. 3.5a) Initially the piston is at top dead centre (TDC) position, the inlet valve is open and the outlet valve is closed. The piston moves downwards towards bottom dead centre (BDC) position and the pressure inside the cylinder is reduced to a value below the atmospheric pressure. The vacuum thus created causes the charge to rush in and fill the space vacated by the piston. The charge consists of a mixture of air and petrol prepared by the carburettor.

The suction continues till the piston reaches its BDC position. The piston has now made one stroke and the crankshaft has turned through 180 °C, *i.e.*, has made half the revolution.

2. *Compression stroke* : (Fig. 3.5b) Both the valves (inlet and outlet) are closed and the movement of the piston is from BDC to TDC position. The charge inside the cylinder is compressed to the clearance volume; the volume decreases and there is a continuous rise both in temperature and pressure of the charge. Majority of the petrol engines use compression ratios between 5 to 1 and 8 to 1. Towards the end of compression, the approximate values of pressure and temperature are 6-12 bar and 250-300 °C respectively.

3. *Working, expansion or power stroke* : (Fig. 3.5c) When the piston reaches TDC position, the charge is ignited by causing an electric spark between the electrodes of a spark plug which is located in the cylinder head. During combustion, the chemical energy of the fuel is released and there is rise both in pressure and temperature of the gases at almost constant volume. The temperature of the gases increases to about 1800-2000 °C and the pressure reaches 30-40 bar.

With both valves closed, the gases at increased pressure and temperature expand, push the piston down the cylinder and work is done by the system. The reciprocating motion of the piston is subsequently converted into rotary motion of the crankshaft by connecting rod and crank. It is the rotary motion which is required to make wheels run, a cutting blade spin or a pulley rotate.

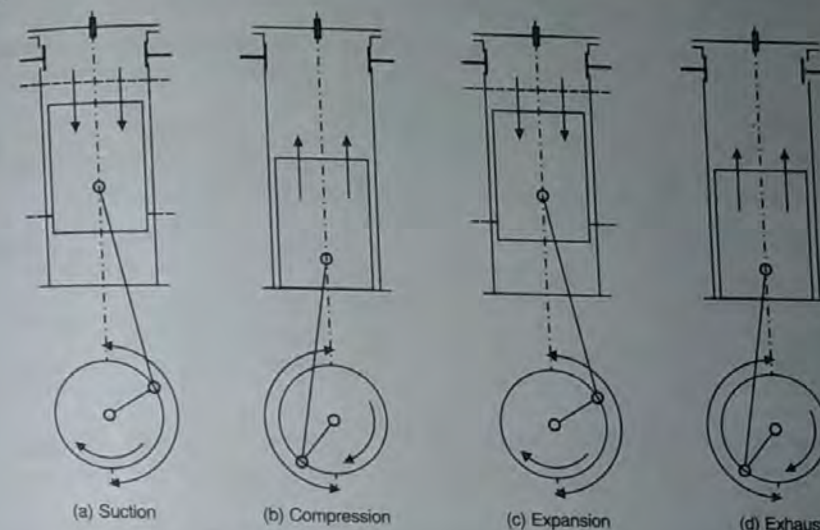

Fig. 3.5. Operation of a four stroke cycle petrol engine

During expansion, there is increase in volume of the gases and the pressure drops to as low as 3 bar.

4. *Exhaust Stroke* : (Fig. 3.5d) The inlet valve remains closed but the exhaust valve opens when the piston reaches BDC position towards the completion of power stroke. The pressure falls slightly above atmospheric pressure at constant volume. The piston moves upwards from BDC to TDC and this upward movement of the piston pushes the spent up gases into the atmosphere through exhaust valve and the exhaust manifold. Much of the noise associated with automobile engines is due to high exhaust velocity.

The exhaust stroke completes the cycle and the engine cylinder is ready to suck the fresh charge inside the cylinder once again and the cycle is repeated.

Since the beginning of suction stroke, the piston has made four strokes inside the cylinder : two up and two down. During the same period, the crank has turned two revolutions. Thus for a four stroke cycle, there is only one power stroke for every two revolutions of the crankshaft.

Theoretical and Actual $p-V$ Diagrams : The following assumptions have been made while carrying out the above operations :

(i) Suction and exhaust is at atmospheric pressure.

(ii) Opening and closing of the valves (both inlet and outlet) is instantaneous and at dead centres.

(iii) Compression and expansion processes are isentropic, *i.e.*, reversible adiabatic.

(iv) The combustion of fuel takes place instantaneously at constant volume.

(v) There is sudden drop in gas pressure to the atmospheric pressure at the end of expansion stroke.

Such a theoretical operation of the cycle can be represented by the $p - V$ plot as shown in Fig. 3.6a.

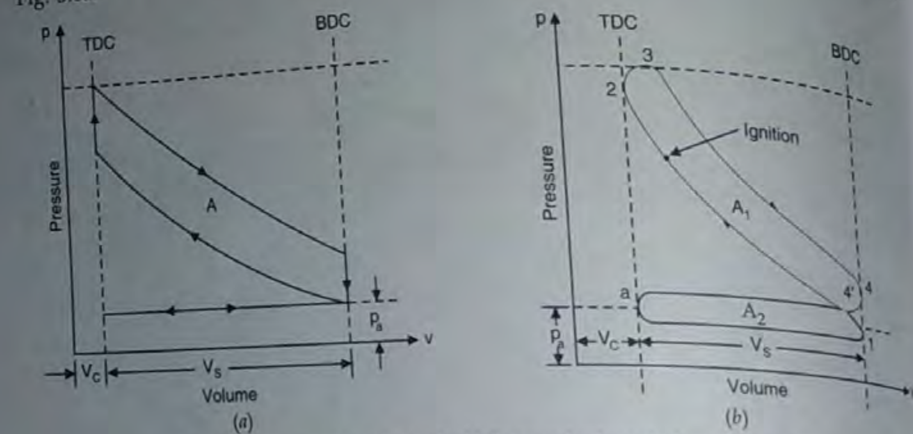

Fig. 3.6. Theoretical and actual p-V diagram for four stroke petrol engine

However, an actual cycle deviates considerably form the hypothetical one because of the following reasons :

(i) For efficient suction, the pressure inside the cylinder at suction is less than the atmospheric pressure. This pressure difference, called intake depression, is needed to overcome the resistance to the flow of charge through the restricted area of the inlet passages.

(ii) For proper exhaust of burnt gases, there has to be a net positive pressure from inside of cylinder to outside. Accordingly the exhaust line does not coincide with atmospheric pressure but is slightly above it.

(iii) Compression and expansion are not isentropic. Friction is always present, and there is considerable interchange of heat between the charge and the cylinder walls.

(iv) There is always a time lag between the ignition of charge and its actual combustion. Consequently, the combustion does not take place at constant volume and the pressure rise is not along a straight line.

(v) Opening and closing of the valves takes sometime and is never instantaneous. This is reflected in rounding off the corners of the $p - V$ plot.

(vi) Ignition of charge, and opening of the valves is never at dead centres. These events occur at some degree on either side of dead centres to get better charging and scavenging (pushing out of burnt gases) performance.

(vii) At high temperature, there is every likelihood of dissociation of products of combustion such as CO_2 and H_2O (steam). This splitting is an endothermic process and requires heat. Further, the value of exponent γ decreases with rise in temperature. Due to these aspects

the pressure and temperature attained during the actual cycle are lower than the theoretical values.

When these modifications are taken into account, the $p - V$ plot takes the form as shown in Fig. 3.6(b). The suction line $a - 1$ lies below the atmospheric pressure line, and the exhaust $1 - a$ lies slightly above the atmospheric line. The area enclosed by the exhaust and suction lines is called negative loop or pumping loop.

This represents the work required for the admission of fresh charge and for the removal of burnt gases. Net work is obtained by subtracting the pump loss from the gross output

Network per cycle = $(A_1 - A_2)$

The area $(A_1 - A_2)$ is always less than the area A of theoretical $p - V$ diagram.

3.5. FOUR STROKE DIESEL ENGINE

The engine completes its working cycle in four strokes of the piston, uses diesel oil as fuel and, therefore, is known as four-stroke diesel engine. Fig. 3.7 shows the different parts of the engine and illustrates its principle of operation. The piston reciprocates inside a cylinder, is connected to the crankshaft through connecting rod and the crank. The inlet (suction) and outlet (exhaust) valves are housed in the cylinder head. The cylinder head is also provided with a nozzle for injecting the fuel.

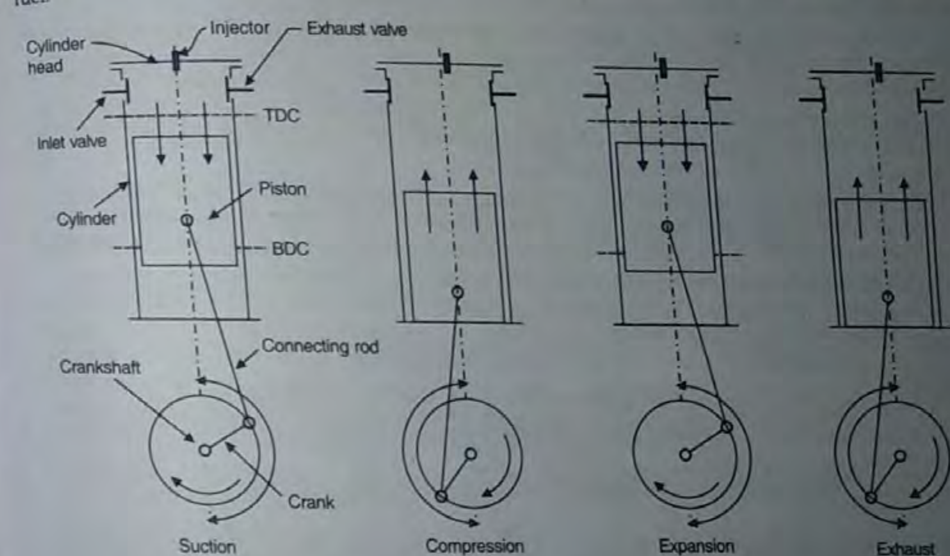

Fig. 3.7. Operation of a four stroke cycle diesel engine

The sequence of individual strokes is as follows :

1. *Intake or suction stroke* : Initially the piston is at top dead centre (TDC) position, the inlet valve is open and the outlet valve is closed. The piston moves downwards towards bottom dead centre position (BDC) and the pressure inside the cylinder is reduced to a value below the atmospheric pressure. The vacuum thus created causes the air from atmosphere to rush in and fill the space vacated by the piston. The suction stroke is completed when the piston reaches the BDC position. The piston has then made one stroke and the crankshaft has turned through 180°, *i.e.*, has made half the revolution.

2. *Compression stroke* : Both the inlet and outlet valves are closed and the movement of the piston is from BDC to TDC position (Fig. 3.7 b). The air inside the cylinder is compressed to clearance volume; the volume decreases and there is a continuous rise both in temperature and pressure of the air. Majority of the diesel engines use compression ratios between 15 : 1 and 20 : 1. Towards the end of compression, the approximate values of pressure and temperature are 60 bar and 600 °C respectively.

3. *Working expansion or power stroke* : When the piston reaches TDC position, a fine spray of diesel is injected into the combustion space containing the high temperature compressed air. The fuel vapours are raised to self ignition temperature and combustion occurs at approximately constant pressure.

The atomisation of fuel and its supply to the combustion space can also be accomplished by compressed air supplied from compressed air bottles. The air entering the combustion space is so regulated that the pressure theoretically remains constant during the burning period.

With both valves closed, the combustion products at increased pressure and temperature push the piston down the cylinder with a large force. Expansion of the gases takes place and work is done by the system. The reciprocating motion of the piston is subsequently converted into rotary motion of the crankshaft by connecting rod and crank.

The expansion stroke gets completed as the piston reaches its BDC position. During expansion, there is increase in volume of the gases and the pressure drops.

4. *Exhaust stroke* : The inlet valve remains closed while the exhaust valve opens. The piston moves upwards from BDC to TDC position and this upward movement of the piston pushes the spent up gases into the atmosphere through exhaust valve and the exhaust manifold.

The exhaust stroke completes the cycle and the engine cylinder is ready to suck fresh air inside the cylinder once again and the cycle is repeated. Much of the noise associated with automobile engines is due to high velocity of exhaust gases.

Since the beginning of suction stroke, the piston has made four strokes inside the cylinder : two up and two down. During the same period, the crank has turned two revolutions. Thus for a four stroke cycle, there is only one power stroke for every revolutions of the crankshaft.

The following assumptions have been made while carrying out the above operations.

(*i*) Suction and exhaust is at atmospheric pressure

(*ii*) Opening and closing of the valves (both inlet and outlet) is instantaneous and at dead centres.

(*iii*) Compression and expansion processes are isentropic, i.e., reversible adiabatic.

(*iv*) The combustion of fuel takes place at constant pressure during a small part of expansion stroke.

(*v*) There is a sudden drop in gas pressure to atmospheric pressure at the end of expansion stroke.

Such a theoretical operation of the cycle can be represented by the $p-V$ plot as shown in Fig. 3.8(*a*).

However, the actual cycle differs considerably from the hypothetical one due to the reasons mentioned in section 3.4 above. When those modifications are taken into account, then the plot takes the form as shown in Fig. 3.8 (b). The area enclosed by the exhaust and suction lines is called negative loop or pumping loop, and the actual pressure inside the cylinder is slightly less than the atmospheric pressure during suction stroke, and slightly higher than the atmospheric pressure during exhaust stroke (The corners are rounded off in the actual $p-V$ plot) represents the work required for the admission of fresh charge and for the removal of burnt gases. Net work is obtained by subtracting the pump loss from the gross output

Net work per cycle = $(A_1 - A_2)$

The area $(A_1 - A_2)$ is always less than the area A of the theoretical p–V diagram.

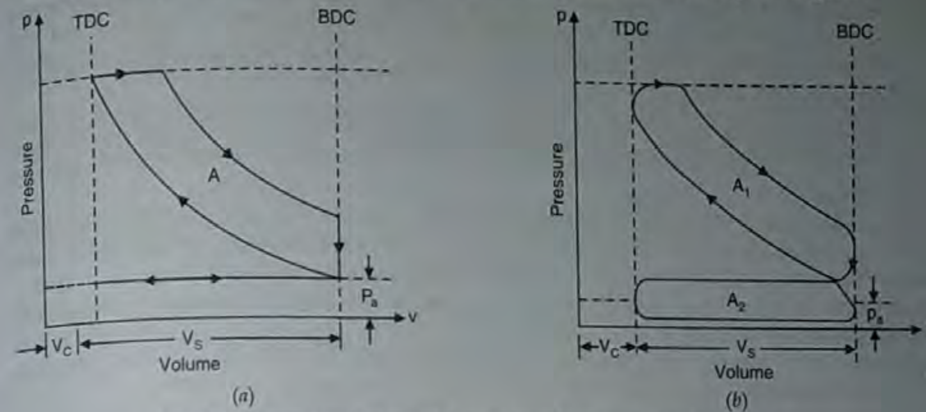

Fig. 3.8. Theoretical and actual p-V diagram for four stroke diesel engine

3.6. COMPARISON BETWEEN PETROL AND DIESEL ENGINES

Below are given the differences between the construction and operation of a diesel engine and a petrol engine of similar capacity and number of cylinders.

(*i*) *Basic cycles* : The petrol engine works on Otto cycle whereas a diesel engine works on Diesel cycle.

(*ii*) *Fuel used* : Petrol engine is a light oil engine and uses gasoline or petrol as fuel. Diesel engine is a heavy oil engine and uses diesel as fuel. The diesel has a high self ignition temperature compared to petrol

(*iii*) *Induction of fuel* : Mixture of petrol and air in required strength is prepared in the carburettor and inducted into the engine cylinder during the suction stroke of a petrol engine.

During suction stroke of a diesel engine, only air from the atmosphere is sucked in the engine cylinder. A fuel pump is used to inject fuel directly into the combustion space where it meets the air which has been compressed.

(*iv*) *Compression ratio* : Majority of petrol engines use compression ratio between 5 to 1 and 8 to 1. The upper limit is fixed by anti-knock rating of fuels.

The compression ratio in diesel engines lies between 15 : 1 and 20 : 1 ; the upper limit is fixed because of an increase in the weight of engine with increase in compression ratio.

(*v*) *Thermal efficiency* : For the same compression ratio, the efficiency of a diesel engine is lower than that of a petrol engine. However, this aspect is of not much practical significance since the petrol engines work with compression ratio not exceeding 8 whereas diesel engines can safely have compression ratio as high as 20. High compression ratio for a diesel engine is a must not only for high efficiency but also to prevent diesel knock – phenomenon of uncontrolled and rapid combustion.

(*vi*) *Ignition* : Petrol engines use a spark plug to ignite the charge (mixture of air and petrol) after it has been compressed. The combustion of fuel in diesel engines is due to high temperature of compressed air.

(*vii*) *Weight* : The cylinder walls of diesel engines have to be made thicker to sustain the high pressures attained due to higher compression ratios. The weight of a diesel engine amounts to between 30 to 50 % more than that of a petrol engine giving the same power output.

(*viii*) *Speed* : The petrol engines are high speed engines due to light weight, and the diesel engines run at comparatively low speeds due to heavy weight.

(*ix*) *Vibration and noise* : The vibration and noise level is higher with a diesel engine because of higher maximum pressure.

(*x*) *Load control* : The petrol engines are quantity control engines. The air-fuel mixture prepared by the mixture being inducted is controlled by the throttle valve in accordance with load on the engine.

The diesel engines are quality control engines. The composition of the mixture (air-fuel ratio) is changed by admitting more or less fuel with variation in engine load. The fuel pump regulates the supply of fuel injected into the combustion space.

(*xi*) *Power* : A petrol engine can be designated to give a better mean effective pressure mainly due to its improved combustion efficiency.

(*xii*) *Cost* : The initial cost of a diesel engine is higher, mainly due to the cost of the fuel pump. Since diesel is cheaper than petrol, the running cost of a diesel engine works out to be low. Further, the experience of most operators is that a diesel engine requires less maintenance than a petrol engine. However, a larger battery is necessary for a diesel engine.

(*xiii*) *Fire risk* : This is minimised in diesel engines owing to the higher ignition point of the fuel used.

(*xiv*) *Applications* : Petrol engines are used in cars, scooters and motor cycles.

Diesel engines are used in heavy duty vehicles like trucks, buses and locomotive engines.

3.7. TWO STROKE SYSTEM

The working cycle is completed in two strokes of the piston or in one revolution of the crankshaft as against two crankshaft revolutions in a four stroke cycle engine. The preparatory strokes (suction and exhaust) are combined with the working strokes (compression and expansion). The following two methods have been used to accomplish the desired objective.

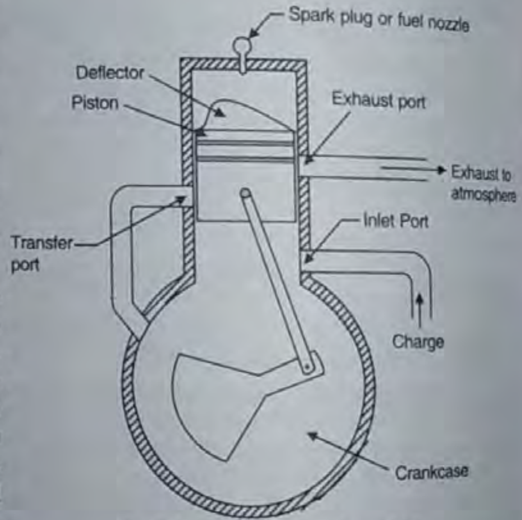

Fig. 3.9. Two-stroke cycle system

(*i*) Providing a separate pump outside the engine cylinder to compressible charge (air-fuel mixture from carburettor or air alone from atmosphere) before forcing it into the cylinder. The pump is an integral part of the engine and gets its motive power from the engine itself. The arrangement is referred to as *two channel system* and is used for large capacity multi-cylinder engines.

(*ii*) Crank-case compression system where the crankcase works as an air pump as the piston moves up and down. The charge (air-fuel mixture or air alone) is compressed by the pumping action of the underside of the piston before being supplied to the engine cylinder. The arrangement is referred to as *three-channel system* and is commonly used for single cylinder small power engines such as scooter and motor cycle engines.

Construction : Fig. 3.9 shows the arrangement of a typical three-port engine employing crank case compression. The piston which is closely fitted in the cylinder is connected to the crankshaft through connecting rod and crank. The top of the piston is usually crown-shaped and that assists in sweeping the spent-up gases towards the exhaust port with the help of fresh charge. The engine employs ports as against valves as provided in a four-stroke system. These ports are cut in the cylinder walls and are three in number : the transfer port, inlet or induction port and the exhaust port. The inlet and exhaust ports are located on one side, and the transfer port is provided on the other side. The cylinder top is provided with an electric spark plug in a petrol engine, or a nozzle for injecting the fuel in a diesel engine.

Working : The charge is led to the crankcase through the inlet port. The charge consists of a mixture of air and petrol prepared by the carburettor in case of petrol engine. The diesel engine admits only fresh air through the atmosphere. The transfer port takes the compressed charge from the crankcase to the engine cylinder. The spent up gases are discharged to the atmosphere through the exhaust port. The closing and opening of the ports is controlled by up and down motion of the piston inside the cylinder. The piston crown helps to prevent the loss of incoming fresh charge (charge being carried with the spent up gases) and uses its momentum for exhausting only the burnt gases. *Scavenging* is the term applied to the process of forcing the burnt gases through exhaust port by deflecting fresh charge across the cylinder.

Sequence of events : Fig. 3.10 explains the working principle and sequence of events in a two-stroke cycle system.

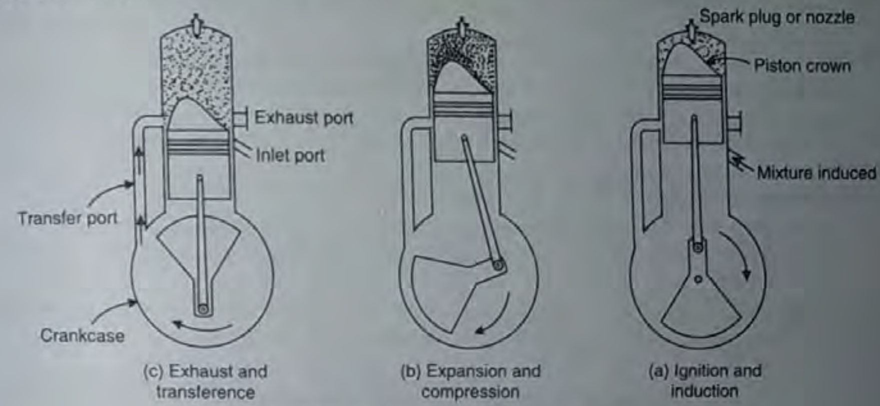

Fig. 3.10. Working of two-stroke cycle engine

Ignition and induction : In Fig. 3.10 (*a*), the piston occupies the almost TDC position towards the end of compression stroke. The compressed charge is being ignited by providing a spark, or fuel is being injected into the hot compressed air. The combustion of fuel occurs and thermal energy is released. There occurs a rise both in the pressure and temperature of combustion products.

At the same time, a partial vacuum (pressure lower than atmosphere) exists in the crank case and fresh charge is being inducted into the crank case through the inlet port which is uncovered by the piston.

Expansion and compression : (Fig. 13.10 *b*). The high pressure gases push the piston down, expansion takes place and power is developed. With downward movement of the piston, the charge in the crank case gets compressed by the underside of the piston to a pressure of about 1.4 bar absolute.

After completion of about 80% of expansion stroke, the piston uncovers the exhaust port. Some of the combustion products which are still above atmospheric pressure escape to the atmosphere. On its further downward motion, the piston uncovers the transfer port and allows the slightly compressed charge from the crank case to be admitted into the cylinder via the transfer port.

Exhaust and transference : (Fig. 3.10 *c*). The piston lies at its bottom dead centre position. The expanded gases are escaping through the exhaust port and simultaneously the slightly compressed charge from the crank case is being forced into the engine cylinder through the transfer port. The charge strikes the deflector on the piston crown, rises to the top of the cylinder and pushes out most of the burnt gases. During this scavenging action, a part of the fresh charge is likely to leave with the exhaust gases. The cylinder is completely filled with the fresh charge, although it is somewhat diluted due to its mixing with the burnt gases.

When the piston moves upward from its BDC position, it first covers the transfer port and stops the flow of fresh charge into the cylinder. A little later, the exhaust port too gets covered and actual compression of the charge begins and continues till the piston reaches TDC position. The cycle of the engine is thus completed within two strokes of the piston (one up and one down) and one revolution of the crank shaft.

3.8. COMPARISON BETWEEN TWO-STROKE AND FOUR-STROKE ENGINES

Merits of two-stroke engines

(*i*) For the same power output, a two stroke engine is simple in design, easy to manufacture and operate.

(*ii*) A two stroke cycle engine gives one working stroke for each revolutions of the crankshaft. The four stroke cycle engine gives one working stroke for every two revolutions of the crankshaft. As such, a two stroke engine develops theoretically twice the power developed by four stroke engine for the same engine speed and cylinder volume.

(*iii*) The number of working strokes is twice than that in a four stroke engine. Consequently, the turning moment is uniform and hence the need only for a lighter flywheel.

(*vi*) Less friction loss due to the absence of suction and exhaust strokes; consequently high mechanical efficiency. Absence of cams, cam shaft and rockers etc. also contributes towards high mechanical efficiency.

(*v*) Simpler construction and mechanism because of no valve and valve mechanism. The ports are easy to design and they are covered and uncovered by the movement of piston itself.

(*vi*) A two stroke engine occupies less space, needs lighter foundations and requires few spare parts.

(*vii*) The reversing of a two stroke engine can be achieved by a simple reversing gear mechanism.

(*viii*) The initial cost of a two stroke engine is less due to light weight and absence of valve mechanism.

(*ix*) The two stroke engines are much easier to start.

Demerits of two-stroke engines :

(*i*) Scavenging (driving out of burnt gases) is not complete due to short time available for exhaust. This results in the dilution of fresh charge.

(*ii*) Exhaust and inlet parts are uncovered (open) simultaneously during a certain period. Some fresh charge is likely to escape without giving any work output.

(*iii*) Thermal efficiency of a two-stroke engine is likely to be lower due to some charge escaping without burning, and poor scavenging. Consequently fresh charge is diluted which results

not only decrease in performance but also slow running, low combustion pressure and poor efficiency.

(*iv*) For the same stroke and clearance volume, the effective compression ratio is lower in a two stroke engine. This too lowers the engine efficiency.

(*v*) More wear and tear of moving parts due to double the number of power strokes.

(*vi*) The piston gets overheated due to firing in each revolution of crankshaft. Higher temperatures make the cooling and lubrication requirements quite severe.

(*vii*) Greater consumption of lubricating oil due to high operating temperatures.

(*viii*) Noisy exhaust due to sudden release of burnt gases.

3.9. APPLICATIONS OF TWO-STROKE ENGINES

Two stroke engines are generally used where low cost, compactness and light weight are the major considerations such as in scooters, motor cycles, mopeds and other light vehicles. The two-stroke opposed piston diesel engines are quite suitable for marine installations (ship propulsion) where the engine room is small.

3.10. PERFORMANCE ANALYSIS OF IC ENGINE

Engine performance is an indication of the degree of success with which the engine does the job assigned to it, *i.e.*, the conversion of chemical energy contained in the fuel into useful mechanical work. The engine performance is expressed in terms of certain parameters and a study needs to be made how those parameters are affected by the operating conditions, design concepts and modifications etc. The desired engine performance depends on power requirements of the apparatus or vehicle to which the engine has to be connected. A test run on the engine may be made

- to find the power output under certain conditions
- to determine the fuel economy
- to obtain detailed information about the various losses and for preparing heat balance.

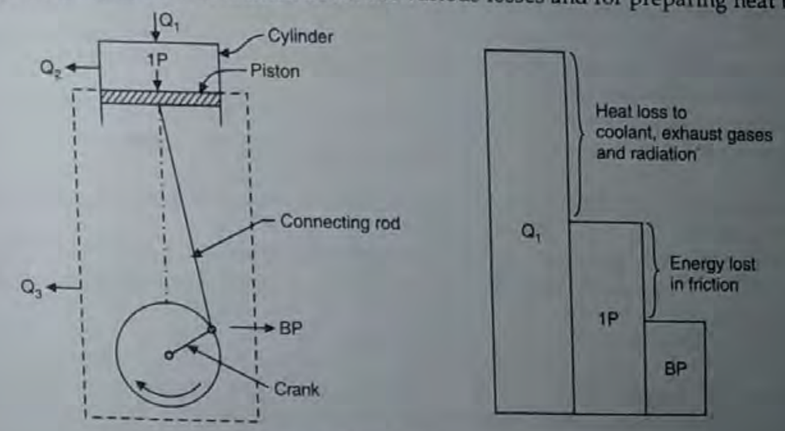

Fig. 3.11. Energy flow in an IC engine

Refer Fig. 3.11 for the energy flow through an IC engine.

When the mixture of air and fuel supplied is burnt inside the engine cylinder, the chemical energy gets converted into heat energy. The total heat thus generated cannot be converted into work and a substantial part is