1.1.1 Definition of 'Engine'

An engine is a device which transforms one form of energy into another form. However, while transforming energy from one form to another, the efficiency of conversion plays an important role. Normally, most of the engines convert thermal energy into mechanical work and therefore they are called 'heat engines'.

1.1.2 Definition of 'Heat Engine'

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)

1.1.3 Classification and Some Basic Details of Heat Engines

Engines whether Internal Combustion or External Combustion are of two types, viz.,

(i) Rotary engines

(ii) Reciprocating engines

A detailed classification of heat engines is given in Fig.1.1. Of the various types of heat engines, the most widely used ones are the reciprocating internal combustion engine, the gas turbine and the steam turbine. The steam engine is rarely used nowadays. The reciprocating internal combustion engine enjoys some advantages over the steam turbine due to the absence of heat exchangers in the passage of the working fluid (boilers and condensers in steam turbine plant). This results in a considerable mechanical simplicity and improved power plant efficiency of the internal combustion engine.

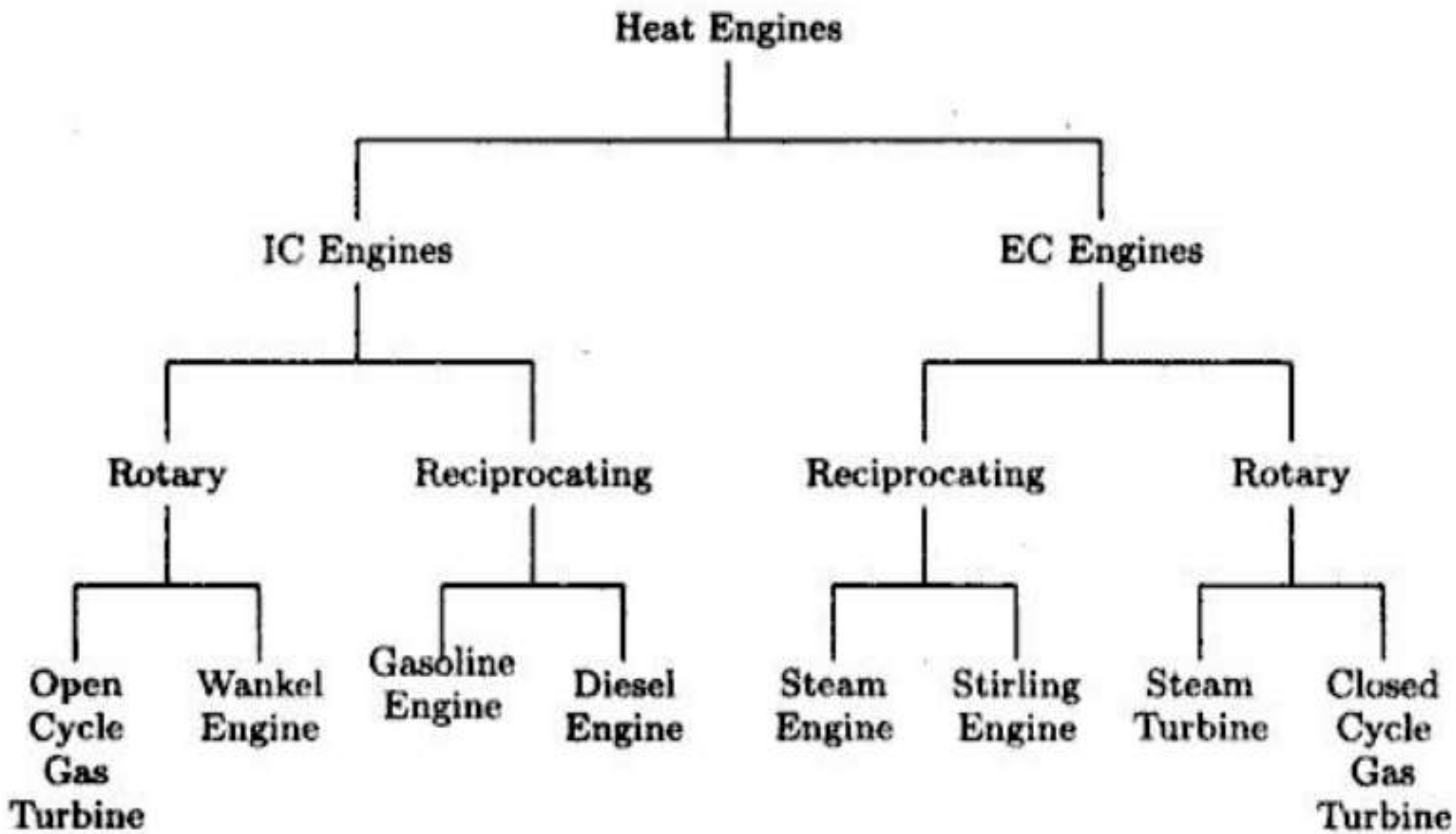

Fig. 1.1 Classification of Heat Engines

1.2.1 Engine Components

A cross section of a single cylinder spark-ignition engine with overhead valves is shown in Fig.1.2. The major components of the engine and their functions are briefly described below.

Cylinder Block : The cylinder block is the main supporting structure for the various components. The cylinder of a multicylinder engine are cast as a single unit, called cylinder block. The cylinder head is mounted on the cylinder block. The cylinder head and cylinder block are provided with water jackets in the case of water cooling or with cooling fins in the case of air cooling. Cylinder head gasket is incorporated between the cylinder block and cylinder head. The cylinder head is held tight to the cylinder block by number of bolts or studs. The bottom portion of the cylinder block is called crankcase. A cover called crankcase which becomes a sump for lubricating oil is fastened to the bottom of the crankcase. The inner surface of the cylinder block which is machined and finished accurately to cylindrical shape is called bore or face.

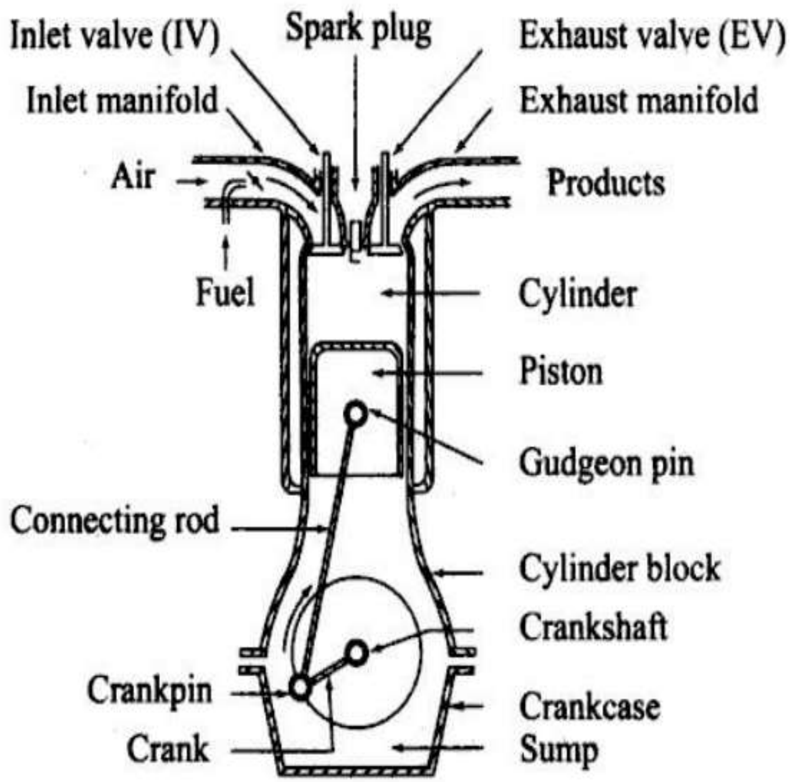

Fig. 1.2 Cross-section of a Spark-Ignition Engine

1.2.2 Nomenclature

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).

Stroke to Bore Ratio : L/d ratio is an important parameter in classifying the size of the engine.

If $d < L$, it is called under-square engine. If $d = L$, it is called square engine. If $d > L$, it is called over-square engine.

An over-square engine can operate at higher speeds because of larger bore and shorter stroke.

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 Fig.1.3.

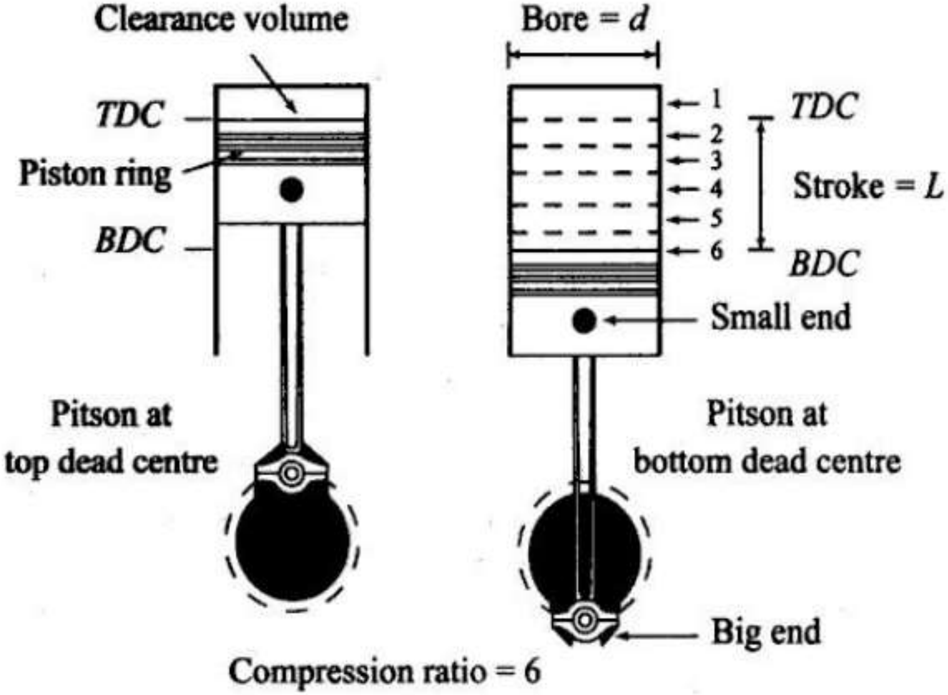

Fig. 1.3 Top and Bottom Dead Centres

Displacement or Swept Volume (V_s) : 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

$$V_s = A \times L = \frac{\pi}{4} d^2 L \qquad (1.1)$$

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

$$\text{Cubic capacity} = V_s \times K$$

Clearance Volume (V_C) : 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 V_C and expressed in cubic centimeter (cc).

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

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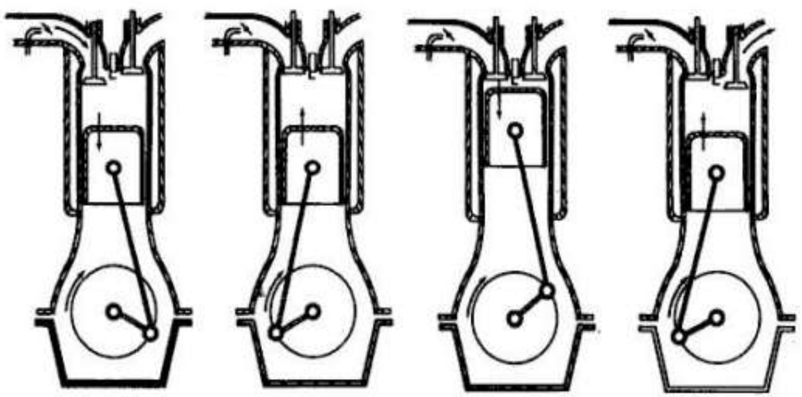
It is designated by the letter r.

$$r = \frac{V_T}{V_C} = \frac{V_C + V_s}{V_C} = 1 + \frac{V_s}{V_C} \qquad (1.2)$$

1.3.1 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° of crankshaft rotation and hence a four-stroke cycle is completed through 720° 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.

The details of various processes of a four-stroke spark-ignition engine with overhead valves are shown in Fig.1.4 (a-d). When the engine completes all the five events under ideal cycle mode, the p-V diagram will be as shown in Fig.1.5.



(a) Intake (b) Compression (c) Expansion (d) Exhaust

Fig. 1.4 Working Principle of a Four-Stroke SI Engine

1.3.2 Four-Stroke Compression-Ignition Engine

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. In the CI engine during suction stroke, air, instead of a fuel-air mixture, is inducted. Due to the high compression ratio employed, the temperature at the end of the compression stroke is sufficiently high to self ignite the fuel which is injected into the combustion chamber. In CI engines, a high pressure fuel pump and an injector are provided to inject the fuel into the combustion chamber. The carburettor and ignition system necessary in the SI engine are not required in the CI engine.

The ideal sequence of operations for the four-stroke CI engine as shown in Fig.1.6 is as follows:

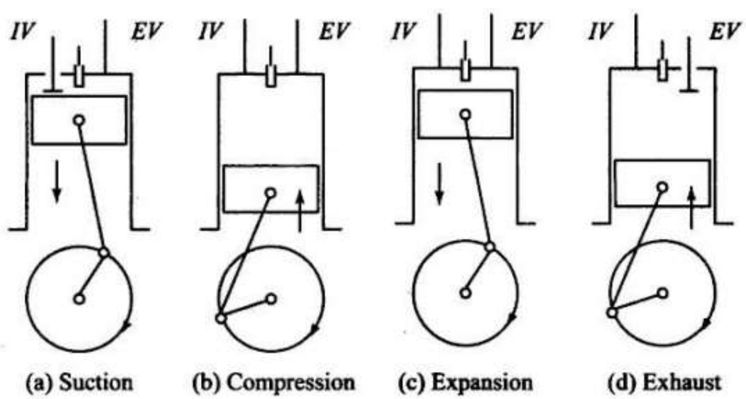


Fig. 1.6 Cycle of Operation of a CI Engine

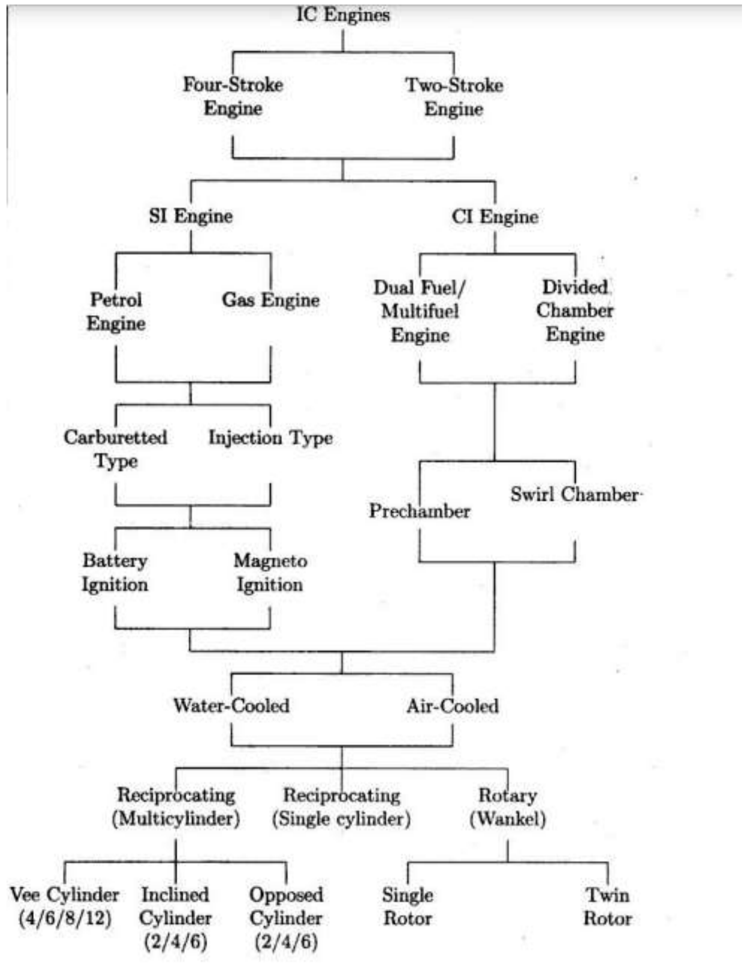


Fig. 1.11 Classification of Internal Combustion Engines

1.5.6 Cylinder Arrangements

Another common method of classifying reciprocating engines is by the cylinder arrangement. The cylinder arrangement is only applicable to multi-cylinder engines. Two terms used in connection with cylinder arrangements must be defined first.

(i) *Cylinder Row :* An arrangement of cylinders in which the centre-line of the crankshaft journals is perpendicular to the plane containing the centrelines of the engine cylinders.

(ii) *Cylinder Bank :* An arrangement of cylinders in which the centre-line of the crankshaft journals is parallel to the plane containing the centrelines of the engine cylinders.

A number of cylinder arrangements popular with designers are described below. The details of various cylinder arrangements are shown in Fig.1.12.

In-line Engine : The in-line engine is an engine with one cylinder bank, i.e. all cylinders are arranged linearly, and transmit power to a single crankshaft. This type is quite common with automobile engines. Four and six cylinder in-line engines are popular in automotive applications.

'V' Engine : In this engine there are two banks of cylinders (i.e., two in line engines) inclined at an angle to each other and with one crankshaft. Most of the high powered automobiles use the 8 cylinder 'V' engine, four in-line on each side of the 'V'. Engines with more than six cylinders generally employ this configuration.

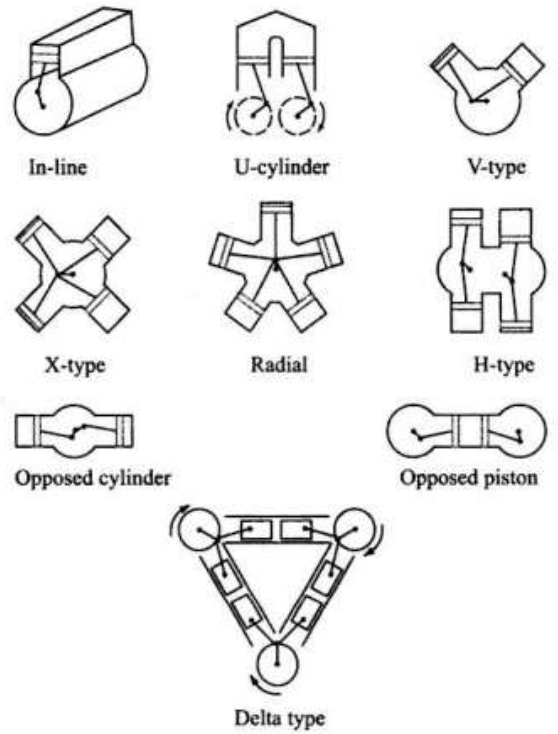


Fig. 1.12 Engine Classification by Cylinder Arrangements

Table 1.3 Application of Engines

IC Engine		EC Engine	
Type	Application	Type	Application
Gasoline engines	Automotive, Marine, Aircraft	Steam Engines	Locomotives, Marine
Gas engines	Industrial power	Stirling Engines	Experimental Space Vehicles
Diesel engines	Automotive, Railways, Power,Marine	Steam Turbines	Power, Large Marine
Gas turbines	Power, Aircraft, Industrial, Marine	Close Cycle Gas Turbine	Power, Marine

used widely in medium and large aircrafts till it was replaced by the gas turbine. Small aircrafts continue to use either the 'opposed cylinder' type or 'in-line' or 'V' type engines. The 'opposed piston' type engine is widely used in large diesel installations. The 'H' and 'X' types do not presently find wide application, except in some diesel installations. A variation of the 'X' type is referred to as the 'pancake' engine.

1.6 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 1.3 gives, in a nutshell, the applications of both IC and EC engines.

1.8 ENGINE PERFORMANCE PARAMETERS

The engine performance is indicated by the term *efficiency*, η. Five important engine efficiencies and other related engine performance parameters are given below:

(i)	Indicated thermal efficiency	(η_{ith})
(ii)	Brake thermal efficiency	(η_{bth})
(iii)	Mechanical efficiency	(η_m)
(iv)	Volumetric efficiency	(η_v)
(v)	Relative efficiency or Efficiency ratio	(η_{rel})
(vi)	Mean effective pressure	(p_m)
(vii)	Mean piston speed	$(\overline{s}_p)$
(viii)	Specific power output	(P_s)
(ix)	Specific fuel consumption	(sfc)
(x)	Inlet-valve Mach Index	(Z)
(x)	Fuel-air or air-fuel ratio	$(F/A$ or $A/F)$
(xi)	Calorific value of the fuel	(CV)

Figure 1.15 shows the diagrammatic representation of energy distribution in an IC engine.

1.8.1 Indicated Thermal Efficiency (η_{ith})

Indicated thermal efficiency is the ratio of energy in the indicated power, *ip*, to the input fuel energy in appropriate units.

$$[ht]\eta_{ith} = \frac{ip\ [\mathrm{kJ/s}]}{\text{energy in fuel per second } [\mathrm{kJ/s}]} \tag{1.3}$$

$$= \frac{ip}{\text{mass of fuel/s} \times \text{calorific value of fuel}} \tag{1.4}$$

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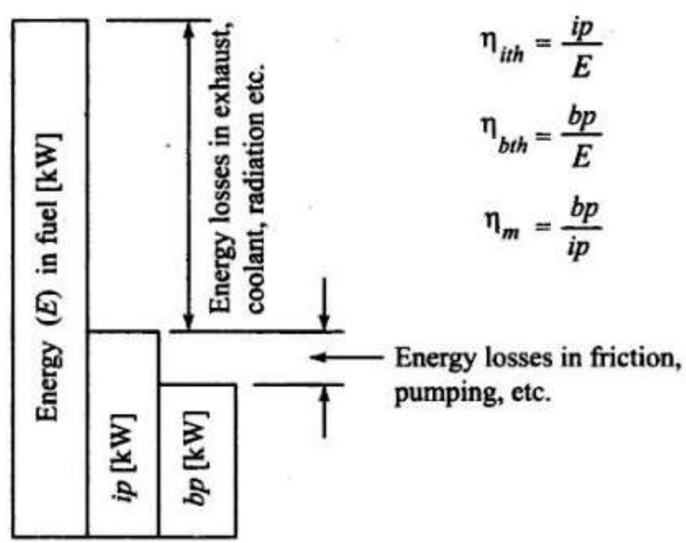

1.7 THE FIRST LAW ANALYSIS OF ENGINE CYCLE

Before a detailed thermodynamic analysis of the engine cycle is done, it is desirable to have a general picture of the energy flow or energy balance of the system so that one becomes familiar with the various performance parameters. Figure 1.13 shows the energy flow through the reciprocating engine and Fig.1.14 shows its block diagram as an open system.

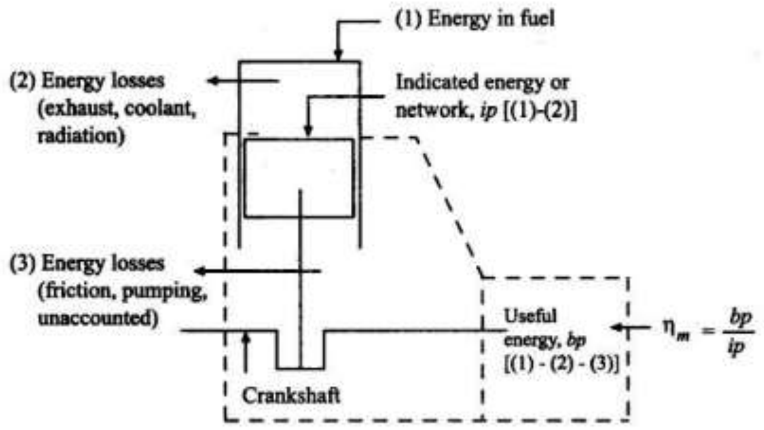

Fig. 1.13 Energy Flow through the Reciprocating Engine

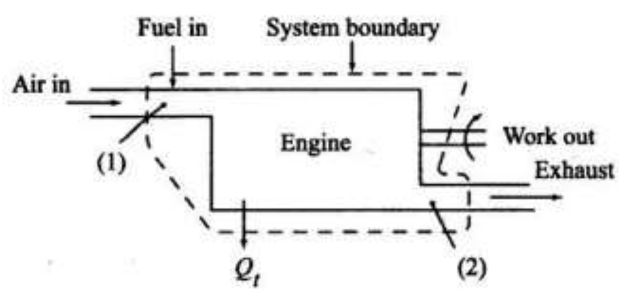

Fig. 1.14 Reciprocating Engine as an Open System

UNIT-2

CARBURETION

The process of formation of a combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion and the device which does this job is called a carburetor

FACTORS AFFECTING CARBURETION:

Of the various factors, the process of carburetion is influenced by

(i) the engine speed

(ii) the vapourization characteristics of the fuel

(iii) the temperature of the incoming air and

(iv) the design of the carburetor

- Since modern engines are of high speed type, the time available for mixture formation is very limited.
- For example, an engine running at 3000 rpm has only about 10 milliseconds (ms) for mixture induction during intake stroke.
- When the speed becomes 6000 rpm the time available is only 5 ms.

The temperature and pressure of surrounding air has a large influence on efficient carburetion

<u>AIR–FUEL MIXTURES</u>:

(i)chemically correct mixture

(ii) rich mixture and

(iii) lean mixture

1. chemically correct A/F is 15.12:1; usually approximated to 15:1
2. A mixture which contains less air than the stoichiometric requirement is called a rich mixture (example, A/F ratio of 12:1, 10:1 etc.).
3. A mixture which contains more air than the stoichiometric requirement is called a lean mixture (example, A/F ratio of 17:1, 20:1 etc.).

The carburetor should provide an A/F ratio in accordance with engine operating requirements and this ratio must be within the combustible range.

MIXTURE REQUIREMENTS AT DIFFERENT LOADS AND SPEEDS

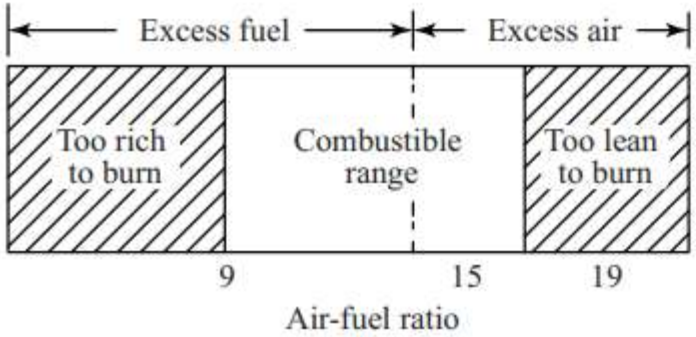

Fig. 7.1 Useful air-fuel mixture range of gasoline

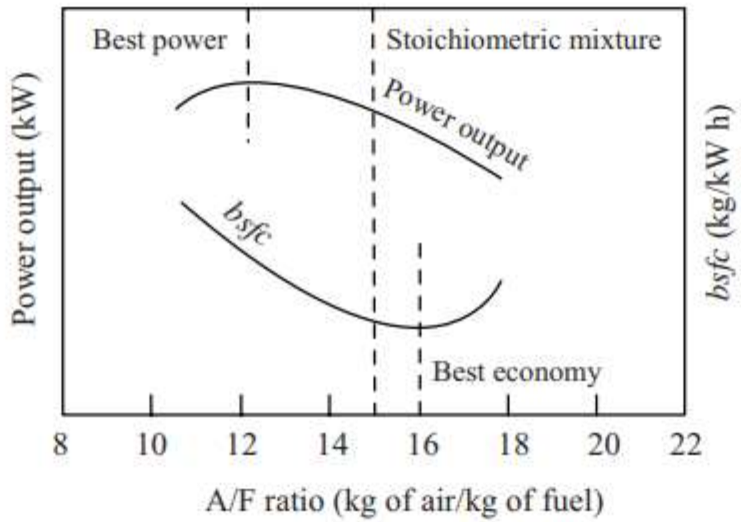

Fig. 7.2 Variation of power output and bsfc with air-fuel ratio for an SI engine

AUTOMOTIVE ENGINE AIR–FUEL MIXTURE REQUIREMENTS

(i) Idling (mixture must be enriched)

(ii) Cruising (mixture must be leaned)

(iii) High Power (mixture must be enriched)

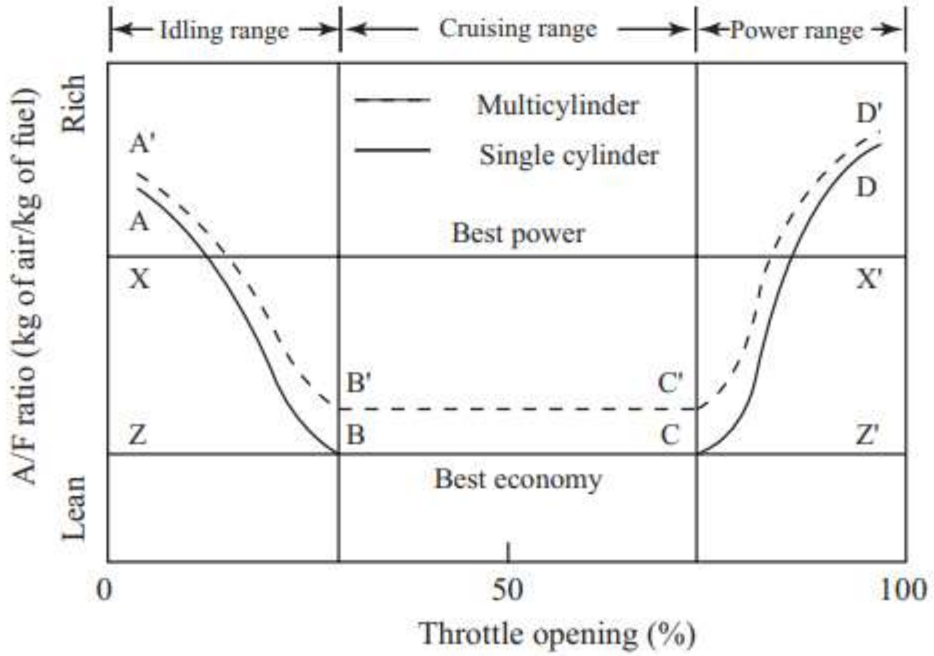

Fig. 7.3 Anticipated carburetor performance to fulfill engine requirements

THE SIMPLE CARBURETOR

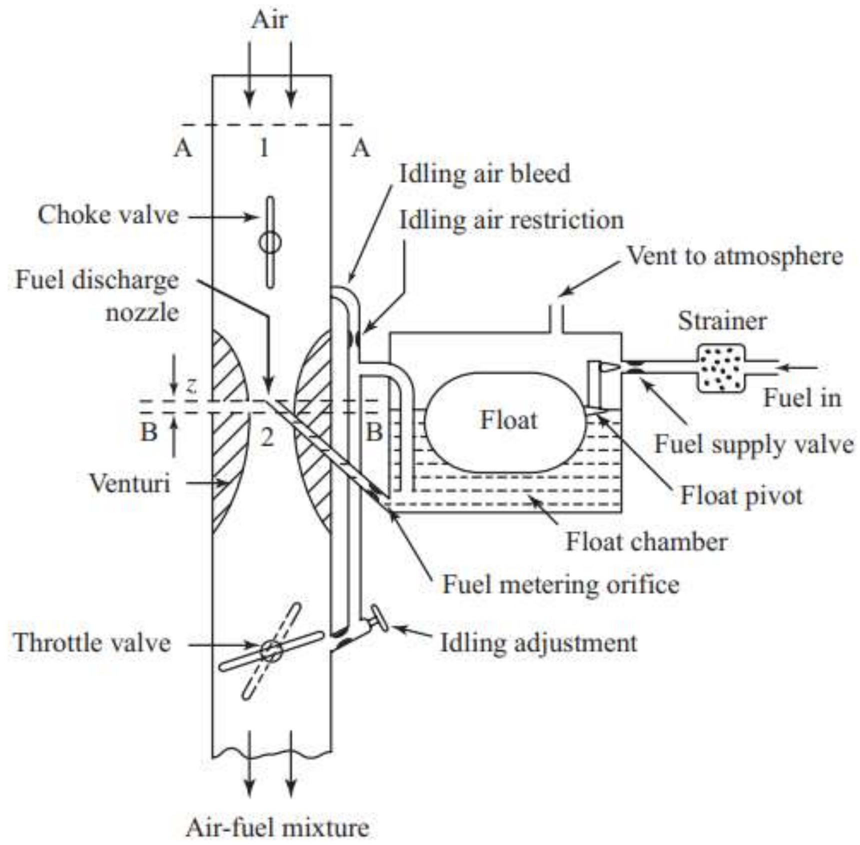

Fig. 7.7 Simple carburetor

ESSENTIAL PARTS OF A CARBURETOR

- A carburetor consists essentially of the following parts, viz.
- (i) fuel strainer
- (ii) float chamber
- (iii) main fuel metering and idling nozzles
- (iv) choke and throttle

HEAT REJECTION AND COOLING

- Internal combustion engines at best can transform about 25 to 35 per cent of the chemical energy in the fuel into mechanical energy. About 35 per cent of the heat generated is lost to the cooling medium, remainder being dissipated through exhaust and lubricating oil.

VARIATION OF GAS TEMPERATURE:

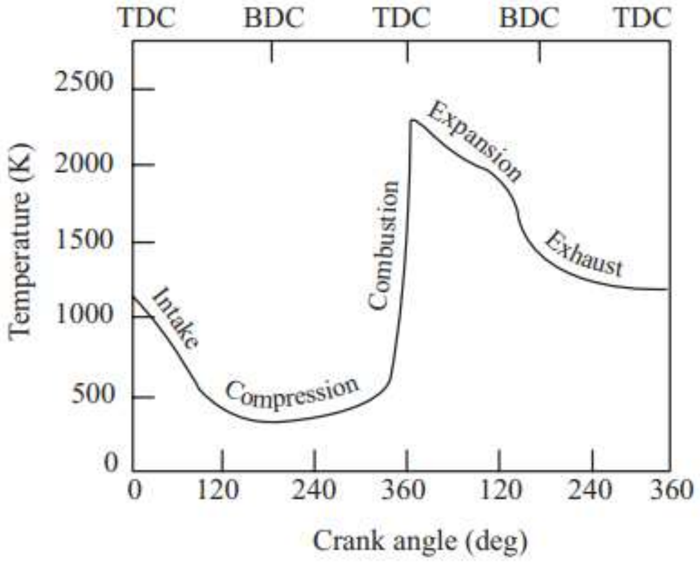

Fig. 13.1 Gas temperature variation during a cycle

PISTON TEMPERATURE DISTRIBUTION

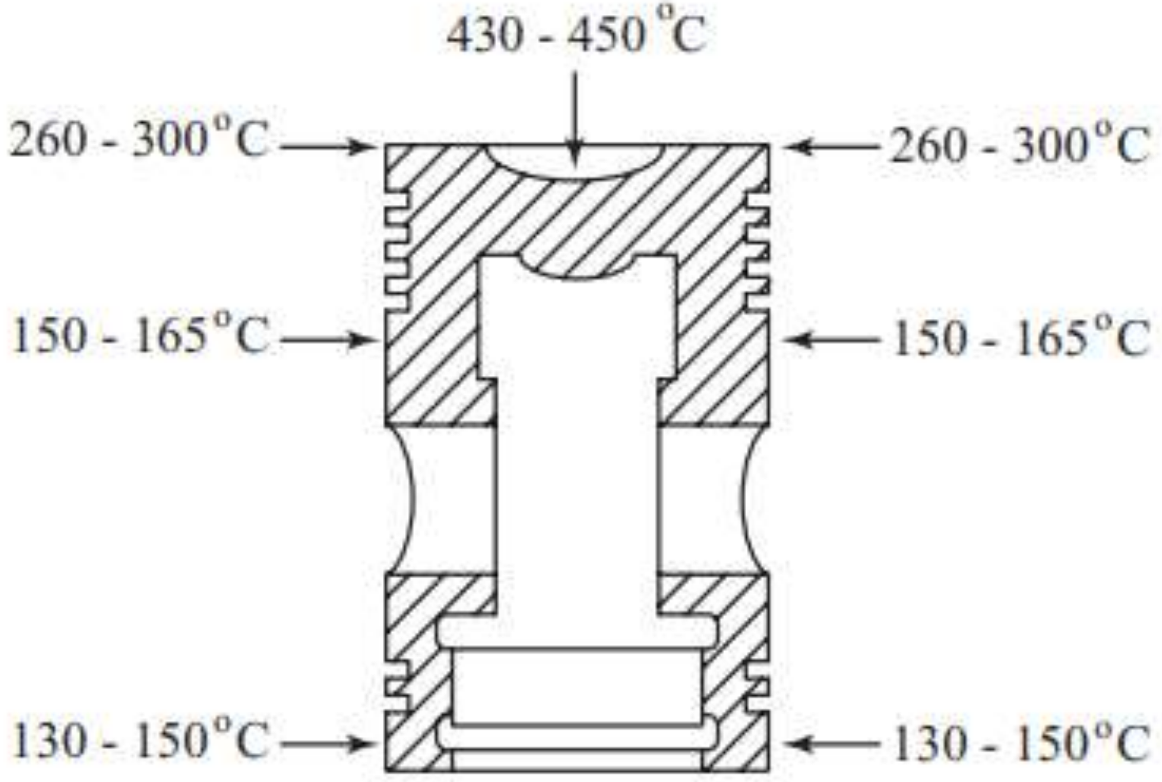

Fig. 13.2 Piston temperature distribution

CHARACTERISTICS OF AN EFFICIENT COOLING SYSTEM

The following are the two main characteristics desired of an efficient cooling system:

- (i) It should be capable of removing about 30% of heat generated in the combustion chamber while maintaining the optimum temperature of the engine under all operating conditions of the engine.
- (ii) It should remove heat at a faster rate when engine is hot. However, during starting of the engine the cooling should be minimum, so that the working parts of the engine reach their operating temperatures in a short time

TYPES OF COOLING SYSTEMS

- (i) liquid or indirect cooling system
- (ii) air or direct cooling system

LIQUID COOLED SYSTEMS

Water-cooling can be carried out by any one of the following five methods:

- (i) Direct or non-return system
- (ii) Thermosyphon system
- (iii) Forced circulation cooling system
- (iv) Evaporative cooling system
- (v) Pressure cooling system

Direct or Non-return System

- This system is useful for large installations where plenty of water is available.
- The water from a storage tank is directly supplied through an inlet valve to the engine cooling water jacket.
- The hot water is not cooled for reuse but simply discharged

Thermosyphon System

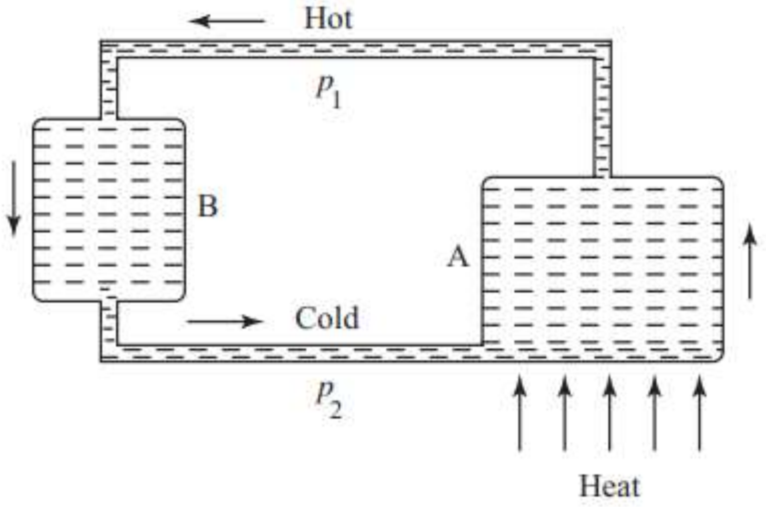

Fig. 13.7 Principle of thermosyphon system

Forced Circulation Cooling System

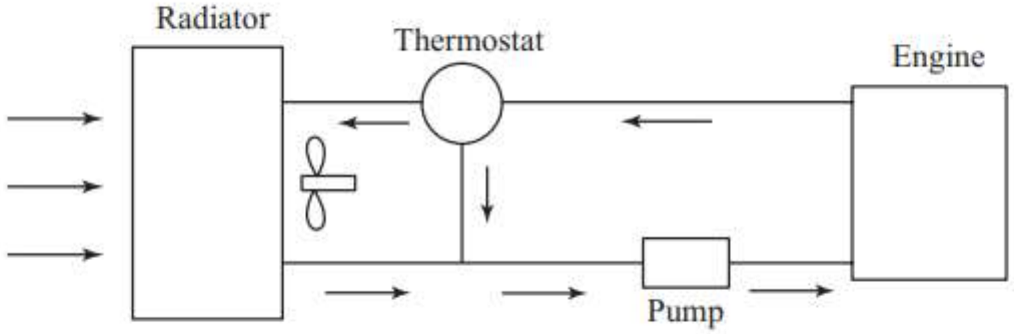

Fig. 13.8 Principle of Forced Circulation cooling system using the thermostat

Evaporative Cooling System

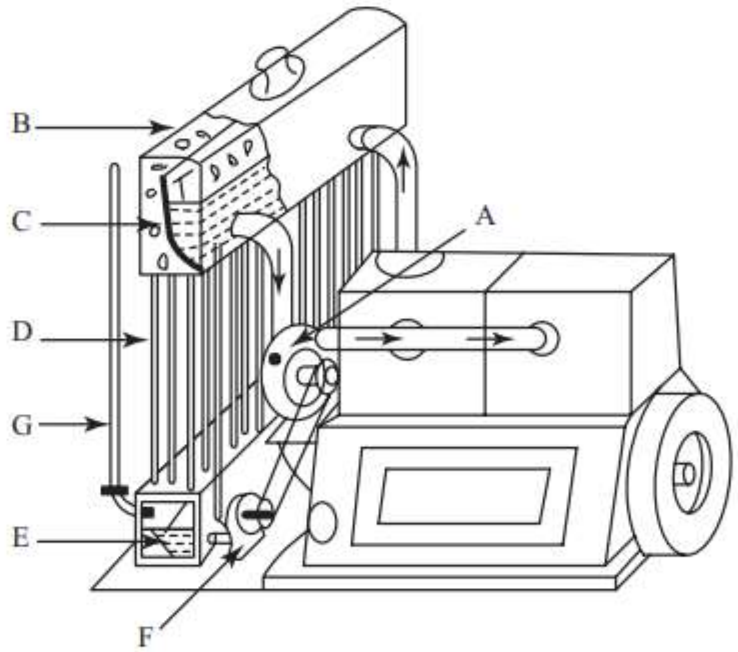

Fig. 13.13 Evaporative cooling with air-cooled condenser

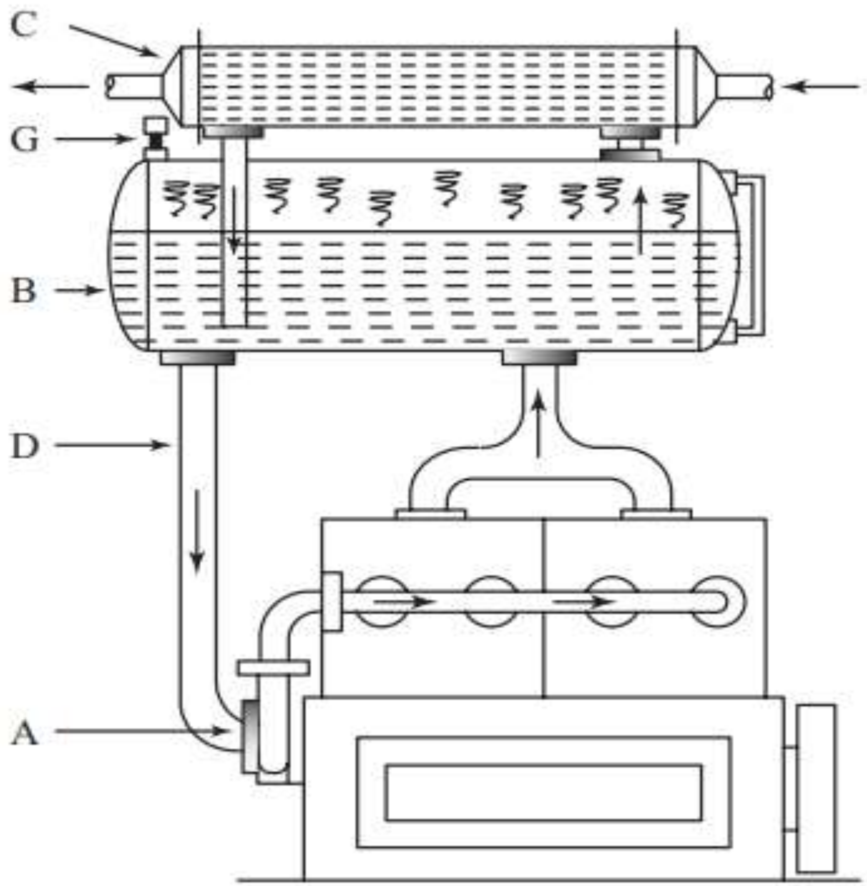

Fig. 13.14 Evaporative cooling with water-cooled condenser

Pressure Cooling System

Table 13.1 Boiling Point of Water at Various Pressures

Pressure (bar)	1.0	2.0	5.0	10.0
Temperature (°C)	100	121	153	180

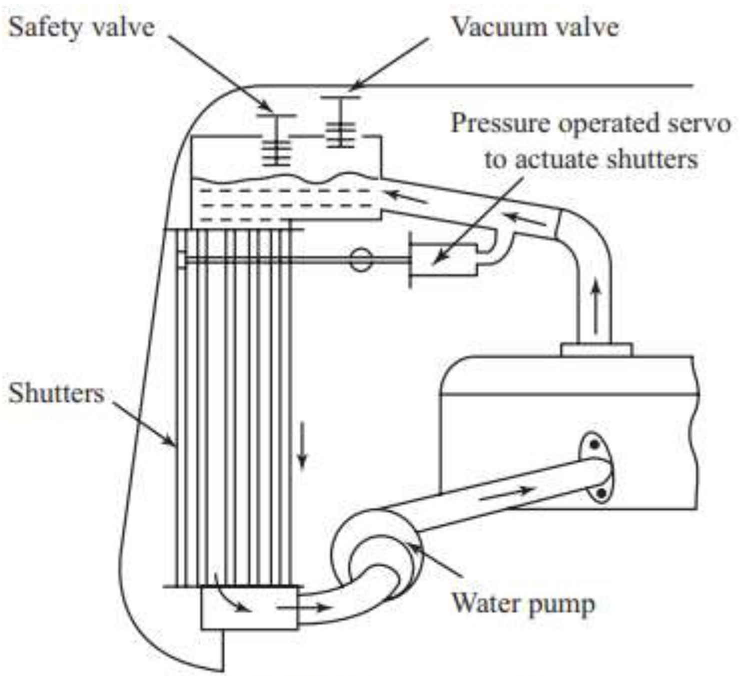

Fig. 13.15 Pressure cooling

AIR–COOLED SYSTEM

- Application :

- This method is mainly applicable to engines in motor cycles, small cars, airplanes and combat tanks where motion of vehicle gives a good velocity to cool the engine

- **Advantages of Liquid-Cooling System**
- (i) Compact design of engines with appreciably smaller frontal area is possible.
- (ii) The fuel consumption of high compression liquid-cooled engines are rather lower than for air-cooled ones.
- (iii) Because of the even cooling of cylinder barrel and head due to jacketing makes it possible to reduce the cylinder head and valve seat temperatures.
- (iv) In case of water-cooled engines, installation is not necessarily at the front of the mobile vehicles, aircraft etc. as the cooling system can be conveniently located wherever required. This is not possible in case of air-cooled engines.
- (v) The size of engine does not involve serious problems as far as the design of cooling systems is concerned.

In case of air-cooled engines particularly in high horsepower range difficulty is encountered in the circulation of requisite quantity of air for cooling purposes

Limitations

- (i) This is a dependent system in which water circulation in the jackets is to be ensured by additional means.
- (ii) Power absorbed by the pump for water circulation is considerable and this affects the power output of the engine.
- (iii) In the event of failure of the cooling system serious damage may be caused to the engine.
- (iv) Cost of the system is considerably high.
- (v) System requires considerable maintenance of its various parts.

Advantages of Air-Cooling System

- (i) The design of the engine becomes simpler as no water jackets are required. The cylinder can have identical dimensions and be individually detachable and therefore cheaper to renew in case of accident etc.
- (ii) Absence of cooling pipes, radiator, etc. makes the cooling system simpler thereby has minimum maintenance problems.
- (iii) No danger of coolant leakage etc.
- (iv) The engine is not subject to freezing troubles etc., usually encountered in case of water cooled engines.
- (v) The weight of the air-cooled engine is less than that of water-cooled engine, i.e., power to weight ratio is improved.
- (vi) In this case, the engine is rather a self-contained unit as it requires no external components like radiator, header, tank etc.
- (vii) Installation of air-cooled engines is easier

Limitations

(i) Can be applied only to small and medium sized engines

(ii) In places where ambient temperatures are lower

(iii) Cooling is not uniform

(iv) Higher working temperatures

(v) Produce more aerodynamic noise

(vi) Specific fuel consumption is slightly higher

(vii) Lower maximum allowable compression ratios

(viii) The fan, if used absorbs as much as 5% of the power developed by the engine compared to water-cooling

ENGINE FRICTION AND LUBRICATION

COMBUSTION

Combustion is a chemical reaction in which certain elements of the fuel like hydrogen and carbon combine with oxygen liberating heat energy and causing an increase in temperature of the gases.

COMBUSTION IN SPARK–IGNITION ENGINES

- STAGES OF COMBUSTION IN SI ENGINES

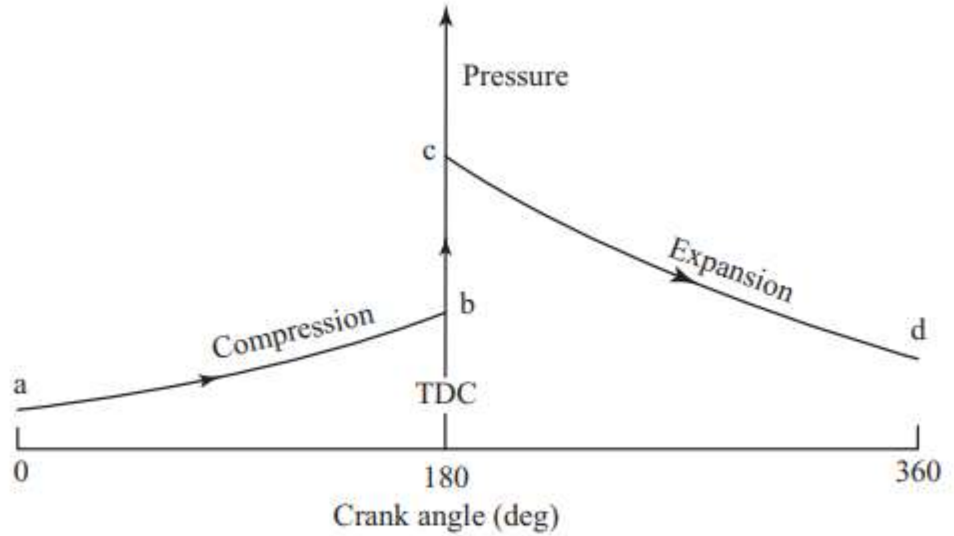

Fig. 11.1 Theoretical p-θ diagram

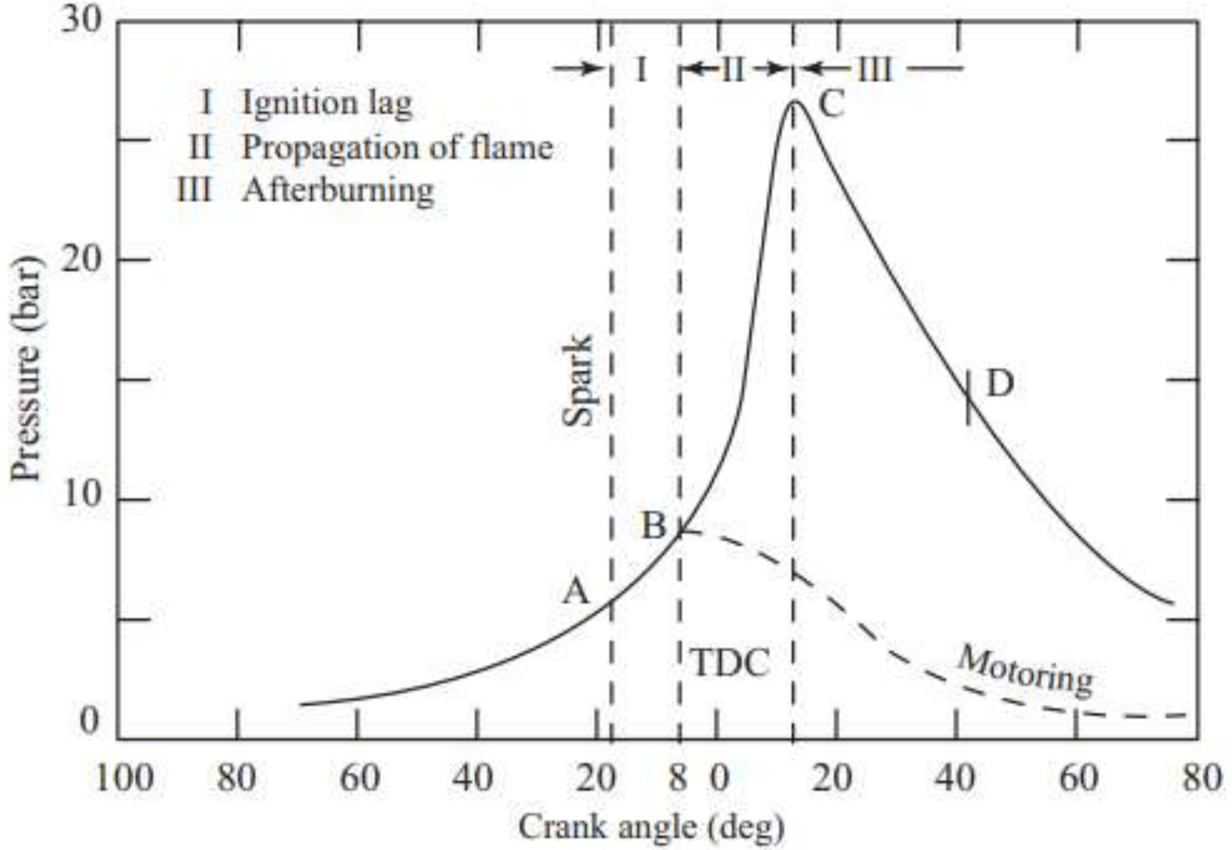

Fig. 11.2 Stages of combustion in an SI engine

- The first stage (A→B) is referred to as the ignition lag or preparation phase in which growth and development of a self propagating nucleus of flame takes place. This is a chemical process depending upon both temperature and pressure, the nature of the fuel and the proportion of the exhaust residual gas. Further, it also depends upon the relationship between the temperature and the rate of reaction.

- The second stage (B→C) is a physical one and it is concerned with the spread of the flame throughout the combustion chamber. The starting point of the second stage is where the first measurable rise of pressure is seen on the indicator diagram i.e., the point where the line of combustion departs from the compression line (point B). This can be seen from the deviation from the motoring curve

- The starting point of the third stage is usually taken as the instant at which the maximum pressure is reached on the indicator diagram (point C). The flame velocity decreases during this stage. The rate of combustion becomes low due to lower flame velocity and reduced flame front surface. Since the expansion stroke starts before this stage of combustion, with the piston moving away from the top dead centre, there can be no pressure rise during this stage

- FLAME FRONT PROPAGATION

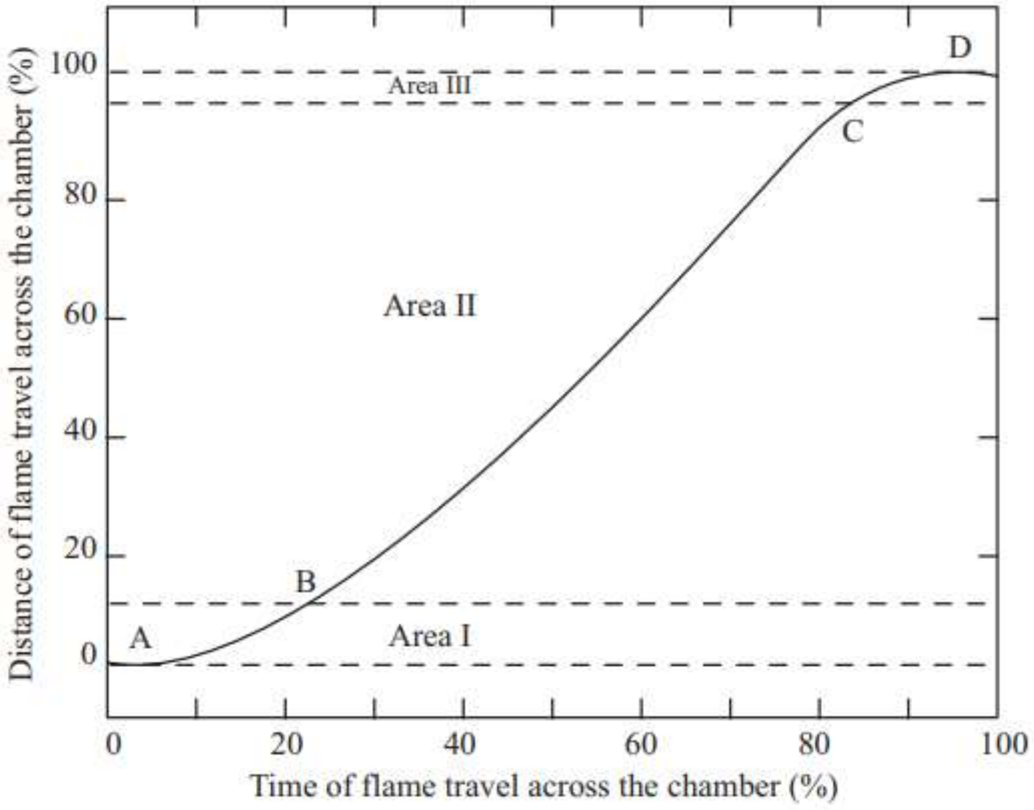

Fig. 11.3 Details of flame travel

- FACTORS INFLUENCING THE FLAME SPEED

Turbulence

Fuel-Air Ratio

Temperature and Pressure

Compression Ratio

Engine Output

Engine Speed

Engine Size

- THE PHENOMENON OF KNOCK IN SI ENGINES

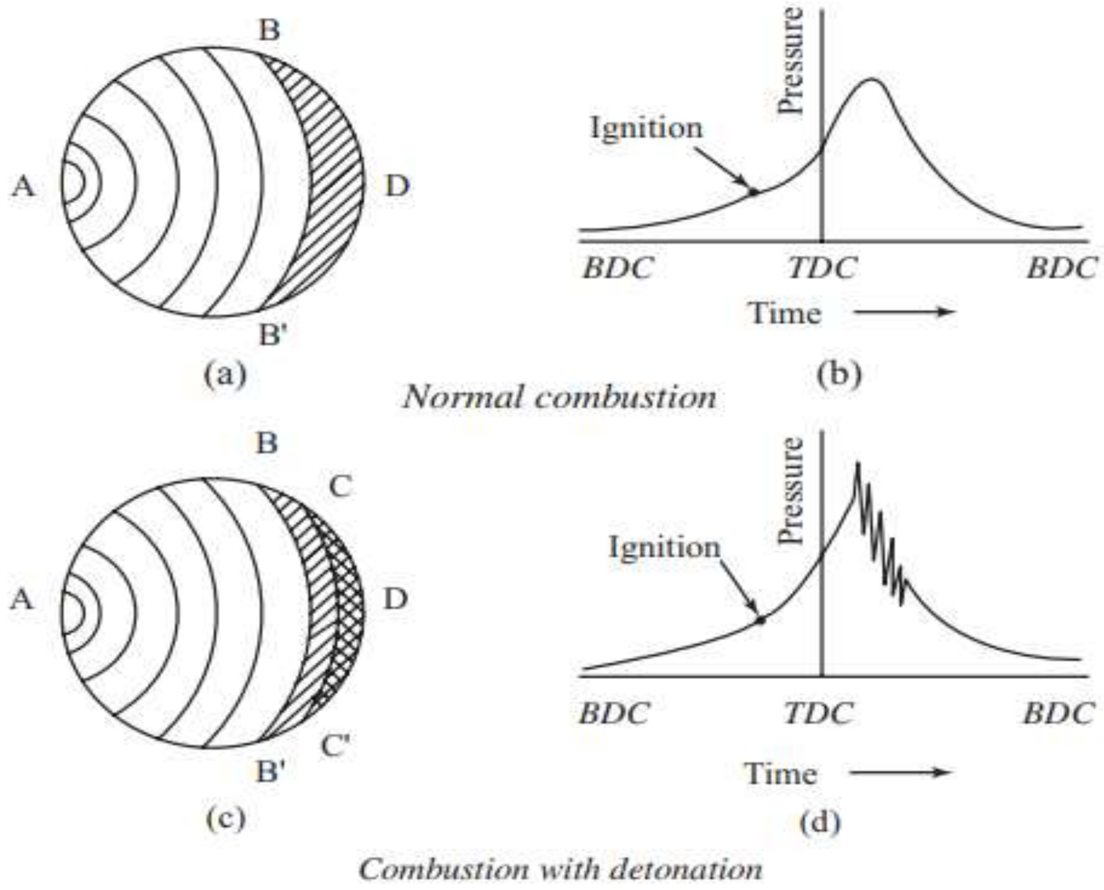

Fig. 11.6 Normal and abnormal combustion

- EFFECT OF ENGINE VARIABLES ON KNOCK
- Density Factors
    1. Compression Ratio
    2. Mass of Inducted Charge
    3. Inlet Temperature of the Mixture
    4. Temperature of the Combustion Chamber Walls
    5. Retarding the Spark Timing
    6. Power Output of the Engine

Time Factors

- Turbulence
- Engine Speed
- Flame Travel Distance
- Engine Size
- Combustion Chamber Shape
- Location of Spark Plug

Composition Factors

- Fuel-Air Ratio
- Octane Value of the Fuel

COMBUSTION CHAMBERS FOR SI ENGINES

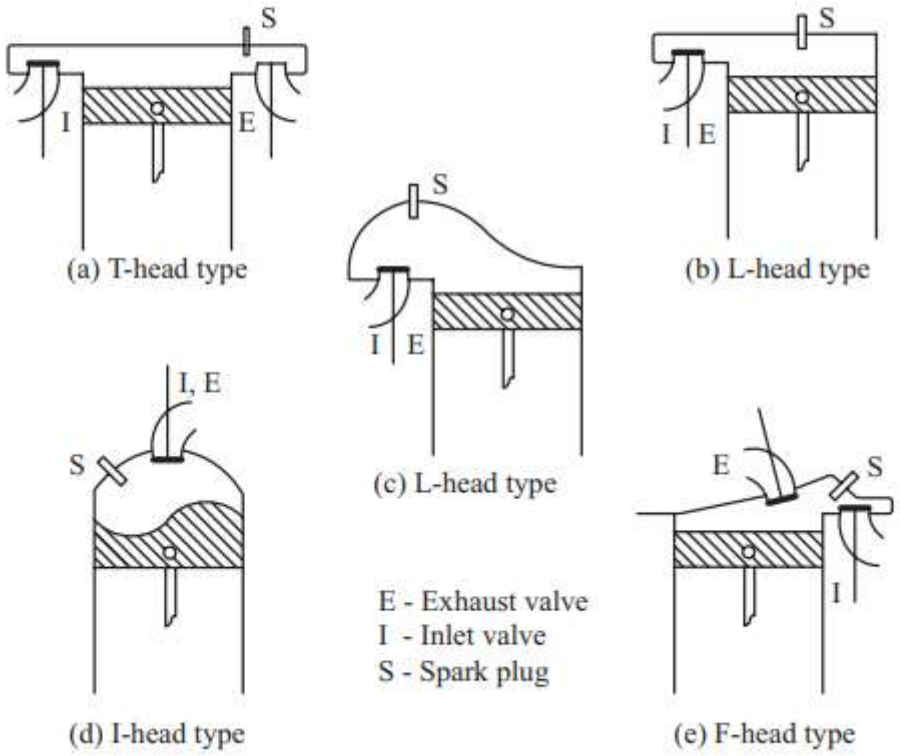

Fig. 11.8 Examples of typical combustion chamber

COMBUSTION IN COMPRESSION-IGNITION ENGINES