# IC ENGINES



## 2.1 INTRODUCTION

The machines that produce power or energy are called engines. The engines work as prime movers meaning ñproducers of motionò. There are other machines which are run by prime movers. Engines have become well known these days because of widespread popularity of automobile ï the cars, trucks, buses and motor cycles are machines that are used for transport almost by everybody and everywhere. Doubtless no other engineering wonder can claim such wider use and engines provide the power for automobile. There are of course other uses of these engines also.

Engines in general are reciprocating and rotary, the latter are commonly recognized as turbines, though there are some which are not turbine.

An engine which was first introduced perhaps used a hot air which expanded on top of a piston. It was steam at high pressure which was then used against the piston which was pushed and moved in a cylinder linearly. The engine piston was connected to a crank through connecting rod caused the crank to rotate about its axis. Thus rotary motion is generated. An engine would definitely need an expanding medium which will push the piston when expanding. The expanding medium will have to be at higher temperature and pressure. The heat required for increasing the temperature and pressure of expanding medium can be given to the medium outside the cylinder in which the piston moves. In such a case the engine is called *external combustion engine*. The *steam engine* and *hot air engine* are examples. Fuel is burnt out of engine and heat is supplied to working fluid which enters the cylinder of the engine with high energy due to temperature and pressure.

In internal combustion engine the fuel is burnt in the cylinder in confined space between walls and top of the cylinder. The heat causes the gases, which become mixture of air and product of combustion, to expand and thus creates thrust on piston to cause its linear motion in the cylinder.

### Objectives

After studying this unit you should be able to know

- how internal combustion engines are classified, cycles these engines work,

how many times the piston has to move to and fro to complete a

s are used in these engines, and

- if there are any harmful effects.

Figure 2.1 shows a so called reciprocating engine which is a machine consisting of following parts :

(a) Cylinder,

(b) Piston,

(c) Connecting rod, and

(d) Crank.

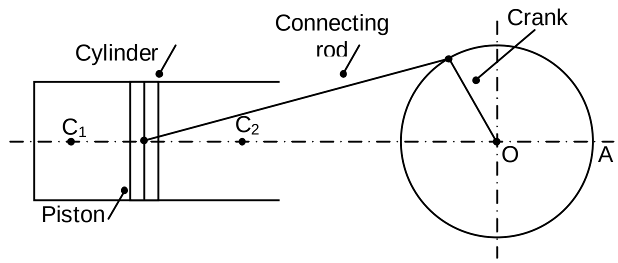



**Figure 2.1 : Reciprocating Engine**

The piston is pushed to right in the cylinder. The connecting rod is then pushed and in turn it causes the crank to rotate about its centre O. The engine shaft at (perpendicular to plane of paper) rotates and give power to any. The piston reciprocates between two extreme positions $C_1$ and $C_2$, called *dead centres*. When piston is at $C_1$, there is clearance between the piston and head of the cylinder. The volume of this space is called clearance volume. The volume between $C_1$ and $C_2$ is called *swept volume* or stroke volume. The linear distance between $C_1$ and $C_2$ is known as *stroke* and apparently stroke is two times the radius of the crank.

Apparent requirement of the engine arise in our mind. Firstly there should be an arrangement for drawing in the fuel and fresh air so that fuel may burn on top of the piston. This will provide motive force. This will also allow maximum expansion of gases in the cylinder in which case piston will be at $C_2$ and crank will be along $OA$. The other requirement is that the expanded gases should leave the cylinder to make new charge to enter. That means proper openings are to be provided both for entry of fresh charge and exit of spent gases. Whether both openings are to be provided at the head or top of the cylinder or exit opening may be provided at end near $C_2$. The other question is which form of the fuel is to be pushed into the cylinder and how it is to be ignited. We shall proceed to learn the IC Engines in still greater detail.

## 2.2 CLASSIFICATION OF IC ENGINES

The IC Engines are classified in several ways. The criteria of classifications are : Fuel, Cycle of operation, Method of ignition, Number of strokes of piston to complete cycle.

The necessary operations have already been spelt out in last section. Here we enumerate gain starting from the piston position at $C_1$, which is called *top dead centre*.

**Step 1**

The suction, the charge is inducted and cylinder is completely filled, the piston reaching $C_2$ which is called *bottom dead centre*.

**Step 2**

ed to clearance volume, resulting in high
s here.

ressure gas expands, piston is pushed to bottom dead centre under great pressure and torque is generated on crank. It is also called power stroke.

**Step 4**

The exhaust, the residual gases are pushed out of the cylinder by motion of the piston.

For these four steps to complete the piston may move between TDC and BDC two times or four times. During one to and fro motion the crank rotates once (i.e. one rotation) but if piston has two to and fro motions the crank rotates two times (i.e. two rotations). We will take up this type of classification at a later stage. Table 2.1 describes the engine classification based on fuel while other variables are also mentioned.

**Table 2.1 : IC Engine Classification Based on Fuels**

| Sl. No. | Fuel Type | Specific Fuel | Ideal Cycle | Piston Strokes | Ignition | Governing |
|---|---|---|---|---|---|---|
| 1. | Gas | Coal gas, Producer gas | Otto cycle | Four | Spark or Heated tube | Hit and miss, Throttle |
| 2. | Petrol | Petrol, Benzol, Alcohol | Otto cycle | Four or Two | Spark | Throttle |
| 3. | Light Oil | Paraffin | Ottocycle | Four or Two | Spark or Hot Tube | Throttle |
| 4. | Heavy Oil | Diesel or Paraffin | Diesel or Dual cycle | Four or Two | Self | Change of point of cut off |

The fuel, and ideal cycles have already been discussed in the last unit.

Which fuel is to be used in which cycle will depend upon the highest temperature achieved after compression, which will in turn depend upon the compression ratio. The compression ratio of course is to be fixed during design stage. If compression ratio is around 8 or 8.5 then the highest temperature may not be such that can cause the ignition and a separate device to initiate ignition may be required. A spark plug which strikes a spark at desired moment is very commonly used in IC Engine where highest temperature may not cause self ignition. The other igniting devices are porcelain or ceramic tube which may be heated from outside or may retain heat from previous combustion.

A petrol engine works on Otto cycle in which highest temperature is not high enough to cause self ignition. Hence a spark plug ignition is used. In this case the charge sucked in the cylinder of the engine contains a mixture of vapourized petrol and air. In earlier engine a carburetor was used for vapourizing the petrol and allow the vapours to mix with air in its passage. In new design the liquid petrol is injected in air stream through intel manifolds (the air passages attached to the body of the engine. The injection occurs at several points hence the system is known as *multipoint fuel injection* (MPFI). The control of quantity of fuel becomes much more convenient and accurate in MPFI than in carburetor system.

In a diesel engine which works on Diesel standard air cycle and burns diesel fuel the compression ratio is higher than 14. The resulting temperature and pressure are much higher than in petrol engine. The fuel is allowed to enter in the clearance space at high pressure and temperature (675$^o$C) is greater than the self ignition temperature (400$^o$C) of fuel. The fuel burns and expansion occurs causing a great force on the piston. Since compression produces require temperature for ignition the engine is also called compression ignition (CI) engine. For pushing the fuel inside the cylinder at high pressure r is used and process is called injection. The amount of fuel to be y the injector itself.

and air through separate passages are entered through a single value the cylinder.

The heat generated due to combustion results in very high temperature. Such temperature may cause damage to all metallic parts such as cylinder and valves. The lubricants used in engine, between several moving parts (such as piston and cylinder) may lose their viscosity at high temperature. It is, therefore, necessary that some of the heat generated in the cylinder must be removed. The heat is removed by air surrounding the cylinder. The air is particularly made to move faster over entire cylinder and in many air cooled engine the external surface of cylinder is enlarged by making extended surfaces called fins. Smaller IC Engines are normally air cooled. Engines of motor cycles are the example. In many cases the heat is removed by circulating water around cylinder and on top of cylinder head. For this purpose special water jackets are made around cylinder and in the head of the cylinder. It may be mentioned here that the valves which control the inlet and exit of the gases are situated in the cylinder head. Special arrangements are made for oil to splash on the inside of the piston to carry away the extra heat.

*Governing* is yet another characteristic associated with types of engine, as mentioned in Table 2.1. Governing is varying of the power of the engine according to load, while the speed of engine may be required to be maintained within certain limits. The actual governor (i.e. the mechanism) may be practically the same but the way the fuel supply to the cylinder is regulated may differ. Following methods are used.

*Hit and Miss* method consists of completely cutting off the supply of fuel to the cylinder. During such cut off period no power is generated. The mechanism of governor operates either on exhaust valve or on gas valve in gas engines. In former the residual gases do not exit hence no suction effect is created and new charge does not enter. In latter the gas does not enter hence no combustion takes place. Only the air is exited. The second method which is used in small gas engine offers the advantage of fixed air to gas ratio for all power strokes. Idle cycles, however, generate uneven torque on crank.

This method is now not preferred.

*Quantitative Method* controls the quantity of fuel by throttling the air fuel mixture. The throttle is placed in the passage of air fuel mixture in which A/F ratio does not change due to throttling. However, since the weight of the charge varies the final pressure will vary ($pV = mRT$). This will result in lower thermal efficiency but the combustion will be complete even at light loads on the engine. In gas engine the gas and air may be separately throttled. In Table 2.1 it has been mentioned as throttle governing and is commonly used in petrol engines.

*Quantity Governing* may perhaps be the best method in diesel engines in which quantity of air is kept unaltered but the quantity of oil to be injected is varied. The fuel quantity is controlled by one of the following methods :

(a) Varying the stroke of the oil pump,

(b) By passing the part of the fuel to the oil tank, or

(c) Delaying the closing of the suction valve of the fuel pump.

The variation of the quantity of fuel will change the cut-off ratio in the ideal diesel air cycle. However, since the air intake remains unchanged, the maximum pressure is always the same. Yet the pressure after the explosion will reduce if fuel supply has been reduced. The combustion is less efficient but theoretical efficiency is likely to increase with diminishing cut-off.

operation have to be performed in the

(a) Suction of charge which could be a mixture of vapourized fuel and air or only air. When whole cylinder (swept volume of cylinder) has been filled the suction operation is complete.

(b) Compression of charge in an adiabatic process, when the whole volume of the charge has been compressed into clearance volume compression is complete.

(c) Combustion of fuel either at constant volume or at constant pressure. Even at constant pressure piston moves a very small distance. In constant volume combustion piston does not move.

(d) Expansion of gases all through the stroke volume. During this expansion the gases perform work on the piston which is transmitted to crank.

(e) Heat rejection at constant volume, the piston does not move.

(f) Exhaust of spent gases from the cylinder so that fresh charge may be sucked in.

Out of above 6 operations, two (i.e. number *c* and *e*) do not require piston displacement (or every little in one case). The other four require piston to move all the way from top to bottom and from bottom to top. The question faced by the designer of the engine will be in how many piston strokes he should complete the four operations ï the suction, compression, expansion and exhaust.

Two answers have evolved. You can complete these operations either in two strokes (1 crank revolution) or in four strokes (2 crank revolution) resulting in 2-stroke and 4-stroke engine.

### 2.3.1 Four Stroke Otto Cycle Engine

These are petrol engines. Four operations i.e. suction, compression, expansion and exhaust are performed separately in four strokes of the piston. The operations, each of which is a process are shown in Figures 2.2(a), (b), (c) and (d) and they occur in this order. The cylinder, along with head having inlet (*A*) and exit (*E*) valves is shown in Figure 2.2.

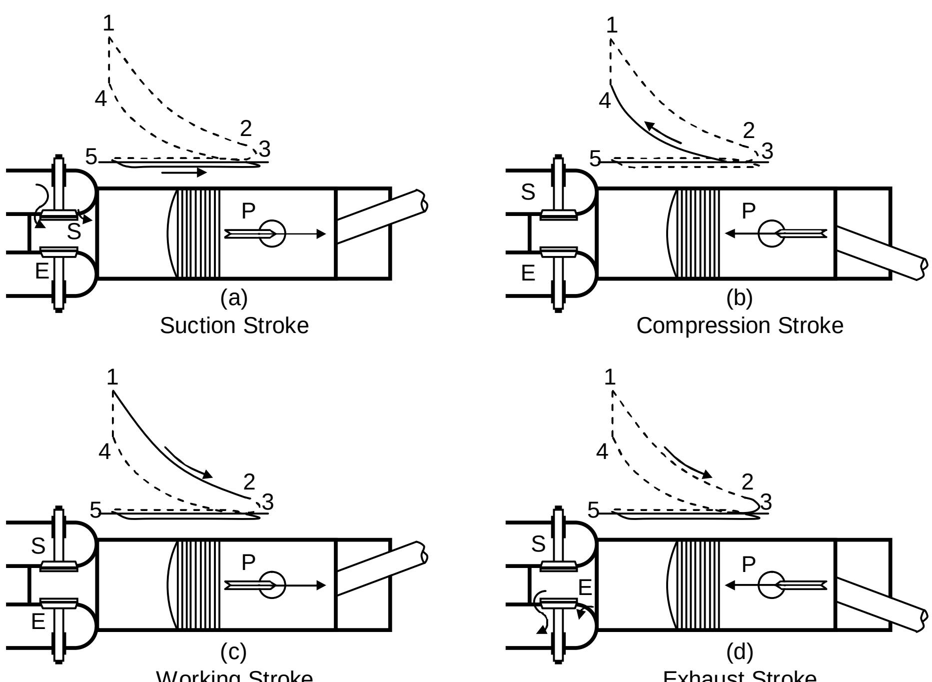



**Figure 2.2 : 4-Stroke Operation**

exhaust valve ($E$) is closed and suction valve $S$ is opened. The nd fuel is sucked in the cylinder as piston $P$ moves away from top or e (TDC or IDC). The suction stroke is complete when the piston reaches end of the stroke, bottom or outer dead centre (BDC or ODC). On the top of the cylinder the process is shown by the line S3 in the indicator diagram (also see Figure 2.2).

**Compression Stroke**

In Figure 2.2(b), both the suction and exhaust valves ($S$ and $E$) are closed. The piston starts moving from BDC to TDC and charged is compressed. The compression ends at 4 and the compression process is shown by 3-4. Just near the end of the stroke (i.e. point 4) the charge is ignited by the spark. 1S is indicator diagram of Figure 2.2(b), also see Figure 2.2.

**Expansion Stroke**

Both the suction and exhaust valves are kept closed and due to addition of heat the gas expands from 1 to 2 (indicator diagram) and piston move from TDC to BDC, as shown in Figure 2.2(c).

**Exhaust Stroke**

The suction valve remains closed and exhaust valve is open. As the piston moves from BDC to TDC it pushes the gases out through exhaust valves. The process is shown as 2-S in the indicator diagram.

### 2.3.2 Four Stroke Diesel Cycle

The spark plug in the petrol engine is screwed into head of the cylinder. In a diesel engine an injector is placed instead of spark plug. Injector pushes fuel into cylinder at right time.

The suction and exhaust valves like petrol engine are present in diesel engine also.

**Suction Stroke**

The exhaust valve is closed. Suction valve opens and air is sucked in along S-3 when the piston moves from TDC to BDC.

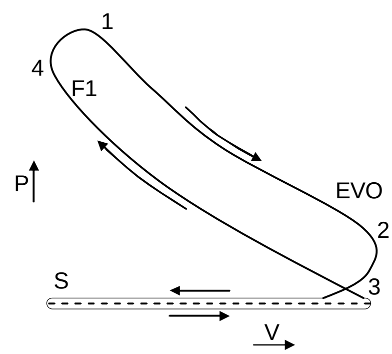



**Figure 2.3 : Indicator Diagram of 4-Stroke Diesel Engine**

**Compression Stroke**

Both the valves are closed and air is compressed along 3-4. The piston moves from BDC to TDC. The fuel injection begins slightly before end of compression as shown by F1 and continues until sometimes after the piston has started return.

**Expansion Stroke**

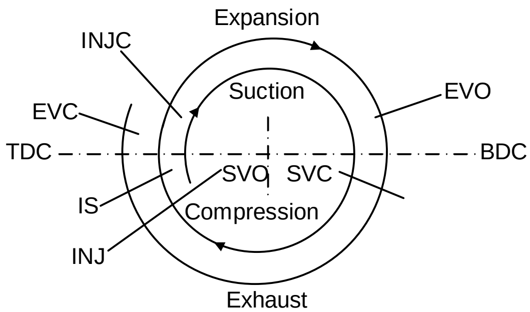
The temperature just before point 4 is sufficiently high to cause fuel to ignite and combustion continues until injection stops at cut off (point 1). Both the valves remain closed. The gases expand from 1 to 2. Piston moves from TDC to BDC. During the process before piston reaches BDC the exhaust valve opens.



**Exhaust Stroke**

f expansion i.e. slightly before piston
on from BDC toward TDC pushing gases
ion valve opens at the end of exhaust stroke
ust valve closes slightly after that.

Valve setting diagram of Figure 2.4 also shows the four operations of 4-stroke cycle. The diagram is applicable to both diesel and petrol engines. 1S is applicable to petrol engine to which INJ and INJC are not applicable. INJ and INJC are applicable to diesel engine to which 1S is not applicable.




SVO = Suction valve opens
SVC = Suction valve closes
IS = Ignition by spark
INJ = Injection begins
INJC= Injection closes
EVO = Exhaust valve opens
EVC = Exhaust valve closes

**Figure 2.4 : Valve Setting Diagram**

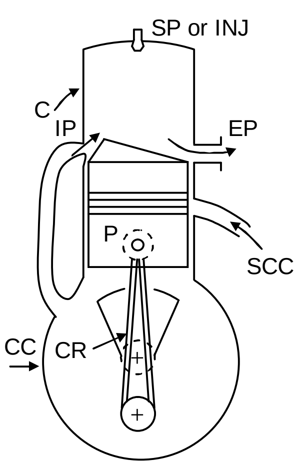
### 2.3.3 Two Stroke Cycle Engine

The four operations of suction, compression, expansion and exhaust are completed in only two strokes of the piston or one revolution of crank. The expansion, exhaust and intake occur in the same stroke. The exhaust begins close to the end of expansion stroke and suction begins immediately after. In both petrol and diesel engines suction and exhaust takes place through ports in the cylinder which are almost at the same level. When piston is moving to BDC it first begins to uncover the top of exhaust port and piston top is so shaped that it facilitates the flow of gases through exhaust port. Before the piston has completely uncovered the exhaust port, the initial port is uncovered and fresh charge (either mixture of petrol vapour and air or only air) enters the cylinder through inlet port which is diametrically opposite to the exhaust port. The piston top is so shaped that it helps the charge to rise up in the cylinder.

In moving from BDC to TDC the piston compresses the charge and just before it reaches the TDC the spark ignities the charge or fuel is injected depending upon engine operating on Otto cycle or Diesel cycle.

The charge or air is compressed slightly in crankcase which facilitates the suction. There is a separate suction port into crackcase which is closed during charge intake into cylinder.

Figure 2.5 shows the scheme of a two stroke engine. See the shape of the top of piston in particular which allows incoming charge to move up while helping the outgoing gases to push out. Yet there is always a risk that some fresh charge may also leave through exhaust or some spent gas may not leave the cylinder. The removal of exhaust gases from the cylinder is known as scavanging. The engine shown in Figure 2.5 is crank case scavanged. In a uniflow scavanged engine the exhaust ports are provided all around the cylinder at BDC but the charge enters at the top. The inlet valve may be spring loaded and cam operated.




C = Cylinder
CC = Crank case
CR = Connecting rod
P = Piston
EP = Exhaust port
IP = Inlet port
SCC = Suction in crank case
SP = spark plug
INJ = Injector

**Figure 2.5. : A 2-Stroke Engine**

### 2.3.4 Advantages of Spark Ignition Engine

These engines operate on Otto cycle with compression ratio varying between 6 : 1 to 12 : 1 with final pressure between 1030 to 2060 kPa. They employ carburettor, gas mixing system or fuel injection system. Commonly used fuels are petrol, compressed gas, coal gas, coke oven gas and producer gas. They are commonly used in automobiles, small air craft and tractors. Throttle governing is employed.

The initial cost of these engines is low. Their specific weight is low and they require less cranking torque. Wide variation in speed and load is obtainable, with fairly low specific fuel consumption they result in high mechanical efficiency.

### 2.3.5 Advantages of Compression Ignition Engine

These engines operate on diesel or dual combustion cycle, use less valatile fuel (diesel being very common) and have compression ratio vary between 11 : 1 to 22 : 1. The compression pressure is between 2760 to 4830 kPa. Generally no ignition device is required. Governing is qualitative by controlling quantity of fuel.

These engines produce high thermal efficiency at low specific fuel consumption even at partial loads. Preignition does not occur, less CO is produced and hydrocarbon emission is also low at low and moderate loads. The engine is suited to both 2 and 4-stroke operation. The low compression 2-stroke engines offer advantage of low initial cost and higher mechanical efficiency because of absence of valves.

### 2.3.6 Advantages of 2-Stroke Engine

The major advantage is 50 to 80% greater output per unit piston displacement and same speed as 4-stroke engine. The cost of these engines is low because the construction is valveless. The $NO_x$ emission is low in SI engines. The overall weight is less.

## 2.4 ENGINE PERFORMANCE

Power in engine is produced by burning fuel which gives heat. The heat supplied by fuel is divided as follows :

Heat supplied by fuel = Heat converted into useful work +
Heat rejected to cooling water +
Heat rejected to surrounding +
Heat carried away by exhaust gases

The power produced in the cylinder of the engine is called *indicated power*. The indicated power is also calculated from *indicator diagram Brake power* is that which is obtained from shaft of the engine. The difference between indicated power and brake power is the power lost in friction of various moving parts. This friction power is required to move the engine when it is not producing any power. *Indicated power* can be calculated from mean effective pressure obtainable from indicator diagram.

$$IP = (mep)\, l\, A n \quad \ldots (6.3)$$

where, m. e. p = mean effective pressure

$l$ = Length of stroke

$n$ = number of power stroke per second which is equal to revoluation per second in 2-stroke engine and half this number in 4-stroke engine

...ction of cylinder.

...al ways but the easiest is applying a belt ... in the belt can be increased or decreased. If ... $T_2$ (Newton) and $D$ is the diameter ... $N$ rpm, then

$$\text{BP} = (T_1 - T_2)\,\frac{D}{2}\,\frac{2\pi N}{60} \quad \ldots (2.1)$$

(See Figure 2.6)

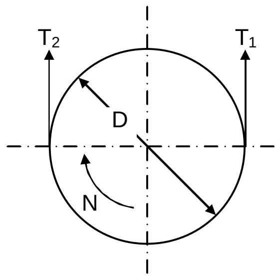



**Figure 2.6 : Pulley on Engine Shaft**

**Mechanical Efficiency** of the engine is the ratio of BP to IP.

$$\eta_m = \frac{\text{BP}}{\text{IP}} \quad \ldots (2.2)$$

Specific Output **is defined as ratio of B.P to swept (stroke) volume**

$$\text{Specific Output} = \frac{\text{BP}}{Al} \quad \ldots (2.3)$$

It can be easily understood that at the beginning of each suction stroke there is some volume of remaining gases in clearance space. As the piston moves toward BDC these gases will also expand. Of course simultaneously new change will enter. Due to expansion of residual gases the volume of new charge will not be exactly equal to the stroke volume. This deficiency is taken care of by defining volumetric efficiency.

$$\text{Volumetric efficiency, } d_v = \frac{\text{Actual volume of charge in haled at suction condition}}{\text{stroke volume}}$$

Other efficiencies are defined as under.

$m$ = mass of fuel supplied per sec.

$$\text{Indicated thermal eff.} = \eta_i = \frac{IP}{m \times (CV)} \quad \ldots (2.4)$$

$$\text{Brake thermal eff.} = \eta_b = \frac{BP}{m \times (CV)} \quad \ldots (2.5)$$

$$\text{Relative eff.} = d_r = \frac{d_b}{\text{Eff. of cycle}} \quad \ldots (2.6)$$

tion $= \dfrac{m}{BP} \times 3600$ kg/BP/Hr . .

An IC Engine rotates at 2400 rpm. The 4-stroke engine has a cylinder bore diameter of 100 mm and crank radius of 100 rpm. From indicator diagram m.e.p is found as 100 kPa. If mechanical efficiency is 80% find B.P.

**Solution**

Stroke, $l = 2 \times$ crank radius

$l = 2 \times 100 = 200$ mm $= 0.2$ m

$$A = \frac{\pi}{4} d^2 = \frac{\pi}{4} (0.1)^2 = 7.854 \times 10^{-3} \text{ m}^2$$

$n$ = number of power stroke per sec.

$$= \frac{\text{rpm}}{2 \times 60} = \frac{2400}{2 \times 60} = 20$$

$IP$ = mep A$l$ n

$= 100 \times 10^3 \times 7.854 \times 10^{ï3} \times 2.0 \times 20$

$= 3141.6$ W or 3.14 kW . . . (i)

$$\eta_m = \frac{BP}{IP}$$

$\therefore$ $BP = \eta_m \times IP$

$= 0.8 \times 3.14$

or $BP = 2.51$ kW . . . (ii)

**Example 2.2**

If the engine of Example 2.1 has a specific fuel consumption of 315 kg/BP/hr and calorific value of the fuel is $46 \times 10^3$ J/kg, Find brake thermal efficiency. If compression ratio is 6, find relative efficiency. Use $\alpha = 1.4$.

**Solution**

With compression ratio of 6, it can be assumed that the 4-stroke engine works on Otto cycle.

$\therefore$ Cycle efficiency $\eta_a = 1 - \dfrac{1}{(r)^{\gamma - 1}}$

$$= 1 - \frac{1}{(6)^{1.4-1}} = 1 - \frac{1}{(6)^4}$$

or $\eta_a = 51.2\%$ . . . (i)

$$m = \text{mass of fuel per sec} = \text{Specific Fuel consumption} \times \frac{BP}{3600}$$

$$= 315 \times \frac{2.51}{3600} = 0.22 \text{ kg}$$

$$= \frac{2.51\ (\text{kW})}{0.22 \times 46} = 0.248 \quad \ldots$$

$$\text{Relative efficiency, } \eta_r = \frac{\eta_b}{\eta_a} = \frac{24.8}{51.2} = 0.48 \quad \ldots$$

(iii)

$$\eta_r = 48\% .$$

## SAQ 1

(a) Define different efficiencies and explain volumetric efficiency.

(b) Compare 2-stroke and 4-stroke engines.

(c) A single cylinder four stroke diesel engine, having swept volume of $850 \times 10^{-6}$ m$^3$ is tested at 300 rpm. When a braking torque of 50 Nm is applied, analysis of the indicator diagram results in mean effective pressure of 0.8 MPa. Calculate B. P. and mechanical efficiency.

(d) Compare petrol and diesel engine.

(e) What is the difference between indicated and brake power of an engine? Define mechanical efficiency. By monitoring an engine it is found that the engine requires 10 kW will all cylinders simply inhaling and exiting air. The engine produces 98 kW on full load. Find the mechanical efficiency at

  (i) full load,

  (ii) half load, and

  (iii) quarter load.

## 2.5 OCTANE AND CETANE NUMBERS

Self ignition temperature (SIT) of a fuel is the temperature at which the fuel ignities on its own without spark. If large amount of mixture in an engine cylinder auto ignities rapid rise in pressure occurs causing direct blow on engine structure accompanied by thudding sound. This causes vibrations in the engine. The phenomenon is called *knocking*.

If however, a small pocket of fuel-air mixture auto ignities, pressure waves are generated which travel with speed of sound across the cylinder. These pressure waves are of such small duration that indicator diagram mechanism fails to record them. These waves interact within themselves and with the cylinder walls, creating characteristics *ping* sound. The phenomenon is called *pinking*. The engine runs rough, overheats and loses efficiency due to knocking and pinking.

The processes of knocking and pinking are related to the nature of the fuel and relative merits of the fuel are decided on the basis of their antipinking and antiknock property. The merit is measured by *octane number* such that a fuel of high octane number will be liable to less pink or knock as compared to a fuel of low octane number in the same engine. It is the same fuel will into show same tendency to pink or knock in all

n SI engines is a mixture of isooctane and *n*-heptane. Iso-octane has knock and this fuel is arbitrarily assigned an octane number of 100 (*ON* = 100)-*n*-heptane has maximum knocking tendency with *ON* = 0. The octane number of a given fuel is percentage of iso-octane in the mixture of iso-octane and n-heptane. Thus a fuel other than mixture of iso-octane and n-heptane if assigned an *ON* of 80 will knock under standard operating condition similar to the mixture of 80% iso-octane and 20% *n*-heptane.

The tendency to knock increases with increase in compression ratio. The highest compression upto which no knocking occurs in a given engine is called *highest useful compression ratio* (HUCR).

Certain chemical compounds when added to the fuel successfully suppress the knocking tendency. Tetraethyl lead [Pb $(C_2 H_5)_4$] also commonly called TEL and tetramethyl lead [Pb $(CH_3)_4$] also referred to as TML are effective dopes in the automobile fuel to check knocking. However, because of lead poisoning effects TEL and TML are not being used. Some organic auto knocking agents have been developed.

In CI engine air alone is compressed to a compression ratio of 15 to 20 (commonly). The fuel is injected under a pressure of 120 to 210 bars about $20^o$ to $35^o$ before TDC. As the fuel evaporates the pressure in the cylinder drops. The ignition begins a little while latter. The time between beginning of injection and the beginning of combustion is known as *delay period* which consists of time for atomization, vapourization and mixing alongwith time chemical reaction prior to auto-ignition. The combustion of fuel continues in the expansion and is called *after burning.* Increased delay period causes accumulation of atomized fuel in the combustion chamber and as the pressure and temperature continue to rise at one instant the bulk of fuel autoignities. This would result in high forces on the structure of the engine causing vibration and rough running.

The CI engine fuel rating is based on ignition delay and is measured in terms of cetane number. *Cetane* fuel [$C_{16} H_{10}$] has very low delay period and is arbitrarily assigned a cetane number of 100. Another fuel $\alpha$ *methyl-napthalene* [$C_{11} H_{10}$] has poor ignition quality and is assigned zero cetane number. The volume percenetage of cetane in a mixture of cetane and $\alpha$-methyl napthaline is the cetane number of the fuel that produces same delay period as the mixture under specified test conditions.

Additives such as methyl nitrate, ethyl thionitrate and amyl nitrate increase cetane number respectively by 13.5%, 10% and 9% if added to the extent of 0.5%.

## 2.6 POLLUTION

Pollution has become a catchword these days. Pollution deteriorates air quality whereby human health is badly affected. The plants, crops, concrete and steel structures are also damaged. Even the climatic changes are effected due to pollution which is understood as addition of such compounds and substances to environment components which will affect their functioning. Out of three components of environment- the air, water and the soil, the one which is most influenced by the IC Engines, is air. Although all the engines and industrial furnaces throwing polluting gases in the atmosphere have considerably increased the amount of pollutant yet they taken together have not exceeded 1%.

The most important product of combustion is $CO_2$. This gas is a greenhouse gas in that it causes atmospheric temperature to rise. More than 150 years ago $CO_2$ in air was only 250 ppm (parts per million). Now it is more than 350 ppm and has certainly caused average temperature of atmosphere to increase by half a degree. As it is today effect is felt in the warmth and change in climatic and rain patterns but if it continues like this may cause melting of ice cap. Water will flow to oceans and raise sea level thus drowning big chunks of land. Not much scope is available in this text to go into further details but there is fair

C engine in automobile has no indication of

ls, atomic oxygen and hydrogen, $SO_2$ and e exhaust of engines. CO is a poison which can kill. Nitrogen oxide and unburnt hydrocarbons produce an effect which is combination of smoke and fog and has been nick named as smog. Smog reduces visibility to almost zero. Many hydrocarbons (polynuclear aromatic) are known carceinogenic. Soot is also formed if fuels do not mix with air before combustion. Soot are particulate matter which remain suspended in the air and may cause respiratory problems and damage the vegetation.

$CO_2$ and CO in the exhaust vary opposite to each other. At stoichiometric A/F ratio $CO_2$ is maximum at 13% and CO very low at about 2%. When A/F is high (like nidling) CO is as high as 16% and $CO_2$ is lowest at 4 %. $NO_x$ is low even at A/F of 12 but becomes much at 0.4% if A/F is 16. in an automobile NOxis high during acceleration and during cruising. CO is high during deceleration.

Although all products of combustion can be calculated, yet, it is preferable that they are measured. Methods of measurement include chemical absorption in liquid or solid reagents or physical method based on thermal conductivity, infrared absorption, chromatography, paramagnetism and sonic velocity.

It has been recognized that all those pollutants mentioned above are also naturally added to environment. But economic activities of man have increased the atmospheric burden to a level where harmful effects have become most obvious. Out of several sources of the man has created, automobile seems to be greatest culprit of last century. There appears to be no respite from automobiles. Any country where the use of automobile is high (or very high) very large amount of $CO_2$ will be produced. USA produces 15% of all the $CO_2$ produced artificially. A survey conducted by environmental protection agency of USA in 1980 found that automobiles were responsible for 42% of all the artificial pollution. It was also found in the survey that CO, about half of hydrocarbon and one third of $NO_x$ due to transportation come from petrol engines. Diesel automobiles contributed only toward suspended particulate matter.

Besides several design changes brought in the automobile devices are also being used to reduce pollution. Changes have been brought in induction of charge, combustion in process, ignition system etc. Perhaps the most successful is exhaust treatment. The device called catalytic converter is capable of reducing CO, $NO_x$ and hydrocarbons. Three way single stages catalytic converter are successful but require precise fuel control. Catalyst consists of two metals reducing and oxidizing. $NO_x$ is to be reduced (removal of oxygen) where as CO and HC are to be oxidized (addition of oxygen). Rhodium, monel and ruthenium are used as reducing catalyst. Platinum and palladium are used to oxidizing catalyst.

## 2.7 SUMMARY

Internal combustion engine is a power producing device having fuel combustion inside its cylinder. It consists of a closed cylinder in which piston slides. Piston through a connecting rod is connected to a crank on the main shaft of the engine. The fuel is burnt in the confined space between piston and walls and head of the cylinder. The gases then expand, exert force on the piston and make it move to the other end (BDC). The motion and force through connecting rod are transmitted to the crank and power obtained at the engine shaft.

The processes of inletting the charge, its compression, expansion exiting out of the cylinder, each may be accomplished through one full travel of piston from one end of the cylinder to the other. This motion is one stroke and for two such strokes the cranks will move one full rotation. The admission and exhaust of charge and remaining gases will be through valves which will open and close, actuated by mechanism at the proper instants of are four stroke engines and produce power in one of four strokes or

wo stroke engines the admission of the charge and exhaust of burnt end of expansion stroke through openings (parts) provided in the lower region of the cylinder. Naturally it is possible that some charge may also exit or some burnt gases may remain in the cylinder. Yet the two stroke engine provide the advantage of producing same energy in two strokes or one revolution as the comparable four stroke engine will do in four strokes or two revolution and no power loss in valve mechanism. But exhaust of fresh charge without combustion is loss and polluting.

The engine performance is checked through the power produced at the shaft and is called brake power (BP). BP is compared with the power produced in the cylinder, called indicated power (IP). The ratio BP/IP is mechanical efficiency and difference (IP – BP) is power lost in friction. Another quantity to compare with BP is the heat produced by combustion of fuel (Heat of fuel). The ratio of BP/Heat of fuel is brake thermal efficiency. Since engine operates upon an ideal cycle it will have an air standard efficiency. Since engine operates upon an ideal cycle it will have an air standard efficiency which can have no relationship with mechanical efficiency. It is compared with brake thermal efficiency and ratio is called relative efficiency.

The exhaust from IC engines contain $CO_2$, CO, $NO_x$, $SO_2$ and unburnt hydrocarbons alongwith some soot. All these have bad effects. There is no way to avoid $CO_2$ but others can be reduced by design or devices. Hence attempts are made to reduce the polluting gases and smoke.

## 2.8 ANSWERS TO SAQs

**SAQ 1**

(c) BP = Torque × angular velocity

(W) = (Nm) × (rad/s)

$$BP = 50 \times \frac{2\pi \times 300}{60}$$

$$= 1570.8 \text{ W}$$

. . .

(i)

$$IP = \text{m.e.p} \times A \times l \times \frac{N}{2}$$

$$\text{mep} = 0.8 \times 10^6 \text{ N/m}^2, \ (Al) = \text{swept vol} = 850 \times 10^{-6} \text{ m}^3$$

$$N = \frac{300}{6} \text{ rps}$$

$$\therefore \quad IP = 0.8 \times 10^6 \times 850 \times 10^{-6} \times \frac{300}{120}$$

$$= 1700 \text{ W}$$

$$\therefore \quad \text{Mechanical Efficiency } \eta_m = \frac{BP}{IP} = \frac{1.57}{1.70}$$

$$\eta_m = 0.92 \quad \text{or} \quad 92\%.$$

(d) Petrol engines have low initial cost, low weight, and smaller size for same power as diesel engine. They require less cranking effort for starting and their

dour. For these reasons they are preferred
s noise is required. They are preferably

uel consumption at both full and part loads, less fire hazard, perhaps longer life. Though more suited to 2-stroke, yet not used in small size. Large marine engines are made 2-stroke. Diesel engines are good for continuous running like generator and long distance transport on road and in sea.

(e) Further note that IP = BP + FP

FP is power to overcome friction.

FP remains same under all load conditions.

Under full load condition the BP = 98 kW

$$\therefore \quad \text{IP} = 98 + \text{FP} = 98 + 10 = 108 \text{ kW}$$

$$\therefore \quad \eta_m = \frac{\text{BP}}{\text{IP}} = \frac{98}{108}$$

or $\eta_m = 0.907$ or 90.7% . . . (i)

At half load $\text{BP} = \frac{98}{2} = 49 \text{ kW}$

$$\therefore \quad \eta_m = \frac{49}{49 + 10} = \frac{49}{59}$$

$$\therefore \quad \eta_m = 0.83 \quad \text{or} \quad 83\%$$

At quarter load $\text{BP} = \frac{98}{4} = 24.5 \text{ kW}$

$$\therefore \quad \eta_m = \frac{24.5}{24.5 + 10} = \frac{24.5}{34.5}$$

or $\eta_m = 0.71\%$ or 71%.