Lecture Notes : RME-051: IC Engines and Compressors : Unit-1

Lecture # 01 : Introduction to IC Engines, Engine's Classification and Terminology

Engine / Heat Engine

A device, where phase / form transformation of energy takes place, is termed as engine. Heat Engines is the engine that converts thermal energy into mechanical energy or work as output. In the fuels, energy is stored in chemical form and get liberated upon combustion. Engine utilize this heat energy and generates mechanical work as output.

There are two type of engines : External Combustion Engine and Internal Combustion Engine; based on condition of combustion. If the combustion of fuel takes place at atmospheric conditions (in open, not in controlled condition), the engines are known as External Combustion Engine and when combustion of fuel takes place inside the cylinder (at controlled condition, temperature and pressure – not atmospheric), the engines are termed as Internal Combustion Engines (IC Engines).

IC Engines are of Rotary / Reciprocating or Wankle type. Reciprocating IC Engines may be of 2-stroke / 4-stroke Engines (on the basis of strokes required to complete the cycle of operation) and of Spark Ignition (SI) Engines or Compression Ignition (CI) Engines (on the basis of initialization of combustion).

Nomenclature

Bore

Nominal inner diameter of cylinder is called bore. It is represented by 'd' in mm.

Piston

The cross-sectional area of piston or cylinder bore is called Piston Area. It is represented by 'A' in mm^2.

Stroke

The nominal distance by which the piston moves between two successive reversals of its direction of motion is known as Stroke or Stroke Length. It is represented by 'L' in mm. It is the distance between dead centers, i.e. between Top Dead Centre (TDC) and Bottom Dead Centre (BDC) in case of vertical engine or between the Inner Dead Centre (IDC) and Outer Dead Centre (ODC), in case of horizontal engine. In one stroke, piston moves from one dead centre to another and crank rotates by 180^0 (half rotation).

Dead Centre :

The extreme position on either side of piston movement, beyond which reversal of direction of motion takes place, are termed as dead centre. It is the point at which velocity of piston is zero. These are Top Dead Centre (TDC) and Bottom Dead Centre (BDC) in case of vertical engine or Inner Dead Centre (IDC) and Outer Dead Centre (ODC) in case of horizontal engine.

Displacement Volume / Swept Volume

The volume swept by the piston in cylinder during its suction stroke or movement from TDC to BDC is called Swept Volume (V_s). It is $V_s = A \times L = (\pi/4)\, d^2\, L$ mm^3 (or in cubic cm; cc; 1000 cc = 1 Liter)

Clearance Volume

The volume of combustion chamber is called clearance volume. The volume of entrapped charge (or air) in combustion chamber, when the piston is at TDC (or IDC), is termed as Clearance Volume (V_c).

Total Cylinder Volume

It is the sum of swept volume and clearance volume (V_T). $V_T = V_s + V_c$

Compression Ratio

It is the ratio of total cylinder volume when the piston is at BDC (or ODC) to the volume when the piston is at TDC (or at IDC). It is represented by 'r'.

$$CR = r = V_T / V_c = (V_c + V_s) / V_c = V_1 / V_2$$

Cut-off Ratio

It is the ratio of volume at which fuel injection is stopped to the volume at which fuel injection is started.

$$\rho = V_3 / V_2$$

COMPONENTS OF AN ENGINE

An engine comprises of a few hundred components : small and big; stationary and moving, metallic and non-metallic, casted and forged and made by other processes. The components of an engine can be grouped under two categories.

- Stationary or Structure forming components
- Moving or Mechanism forming components

The stationary components constitute the structural parts and the moving components synthesize the mechanism parts of an engine. Important components among these are listed below.

1. **Cylinder block**
   It consists of three parts the cylinder in which the piston slides up & down, the ports or openings for the valves & the passages for the flow of cooling water.

Figure 2.51 Engines vary, here is a four cylinder inline design. (Source: Ford Media)

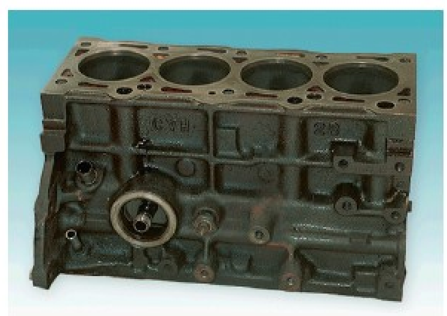


Figure 2.52 Cast iron engine block

2. **Cylinder head:**

   The top of the cylinder is covered by a spout ate canst piece known as the cylinder head. It consists of combustion chamber, spark plug & valves.

3. **Crankcase:**

   It is attached to the bottom face of the cylinder block. It acts as the base of the cylinder. It supports the crank shaft & cam shaft in suitable bearings& provides the arms for supporting the engine on the frame. Cylinder block. Cylinder head & crank case these three parts form the foundation & main stationary body of the engine.

4. **Piston:**

   It is just like a cylindrical plug that moves up & down in the cylinder. It is equipped with piston rings to provide a good seal between the cylinder wall & piston. It converts chemical energy obtained by the combustion of fuel in to mechanical power. It is connected to the small end of the connecting rod by means of position pin.

5. **Piston Rings:**

   Piston rings are fitted in to the grooves of the position to monition good seal between the piston & cylinder wall.

6. **Piston Pin:**

   It is also known as gudgeon pin. It connects the piston & the small end of connecting rod.

7. **Connecting Rod:**

   It is connection between the piston & crank shaft. It joints the piston pin with crank pin. Small end of the connecting rod is connected to the potion pin & big end to the crack pin. The function of the connecting rod is to convert liner motion of the piston in to rotary motion of crank shaft.

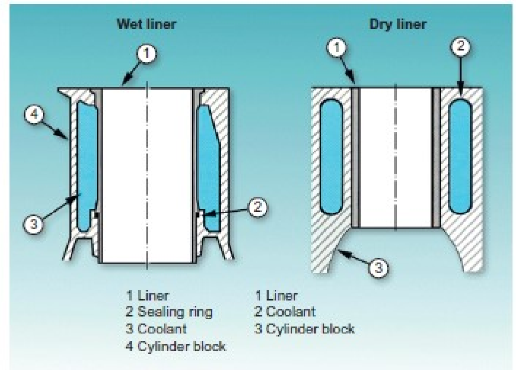


Figure 2.53 Wet and dry liners

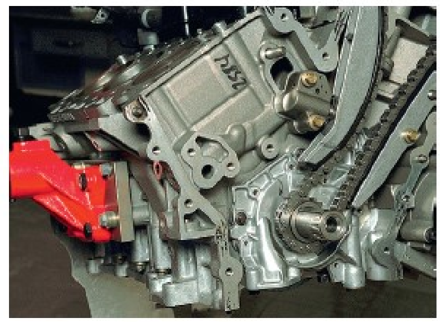


Figure 2.54 Modern engine block

Figure 2.69 Con rod features: 1, front of engine; 2, identification marks; 3, big end cap; 4, oil spray hole for cylinder wall lubrication

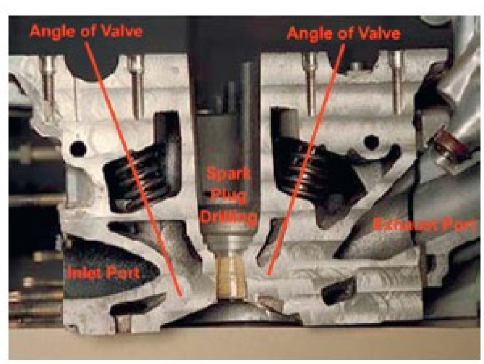


Figure 2.90 Cross-section of a cylinder head

8. **Crank Shaft:**
   It is the first part of the power transmission system on to which the reciprocating motion of the piston is converted in the rotary motion with the help of connecting rod.
9. **Fly Wheel:**
   A flywheel is a fairly heavy steel wheel attached to the roast & of the crank shaft. It maintains smooth rotation of the crank shaft.
10. **Valve:**
    Valve is a device to close & open a passage. Two valves are provided on a cylinder inlet valve & exhaust valve. Fuel is admitted in to the cylinder by the inlet valve & burned gasses escape by the exhaust valve.
11. **Cam Shaft:**
    It is simply a shaft in which cams are mounted. It is driven by the crankshaft. When it rotate, the cam mounted on it gives motion to the valve up & down to open & closed the valve.
12. **Spark Plug:**
    It gives sparks at the end of the compression stroke to burn the air fuel mixture inside the cylinder. It is screwed in the cylinder head & projects in to the combustion chamber.
13. **Ports:**
    There are three ports in two stroke cycle engine. Fresh charge is admitted in crankcase through inlet port. It is transferred in the cylinder above the piston through the transfer port. The exhaust gases leave the cylinder through the exhaust port. All the three ports are closed and opened by the movement of the piston
14. **Injector:**
    It is fitted at the top of the cylinder & projects in combustion chamber that injects fuel in CC.

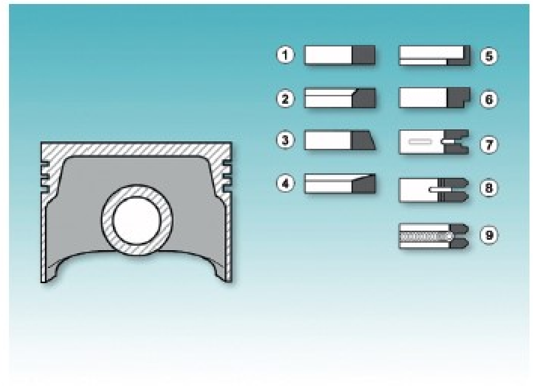


Figure 2.64 Piston rings: 1, rectangular; 2, internally chamfered; 3, taper faced; 4, trapezoidal; 5, L shaped; 6, stepped; 7, slotted oil control; 8, oil ring with expander; 9, oil ring with spiral expander

Figure 2.65 Compression and oil control rings

Figure 2.75 Crankshaft: 1–5 main journals

Figure 2.1 Internal combustion engine internal components: 1, crankshaft; 2, connecting rods; 3, pistons; 4, valves; 5, camshafts

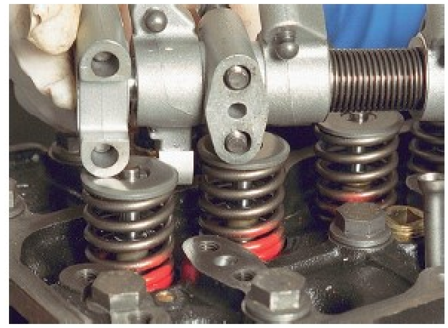


Figure 2.86 Overhead valve (OHV) head

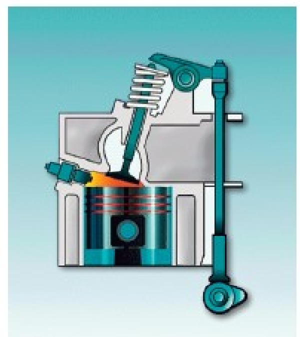


Figure 2.87 Combustion chamber wedge design

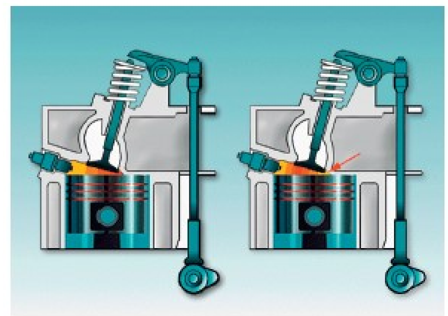
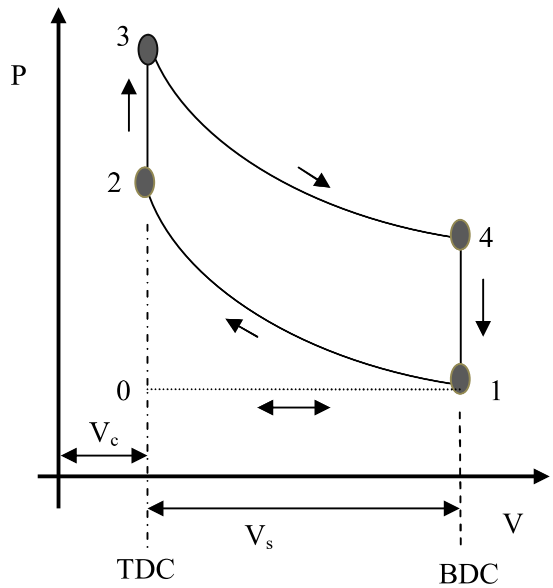


Figure 2.88 Engine knock can cause damage

Cycle of Operation

CYCLE OF OPERATION

Otto Cycle



Processes in Air Standard Otto Cycle (1-2-3-4-1)

In case of Air Standard Otto Cycle, working medium is only air, having no fuel. Heat is added at constant volume from heat source and rejected to heat sink, again at constant volume. The processes of Air Standard Otto Cycle are as follows :

1-2 : Isentropic Compression
2-3 : Constant Volume Heat Addition
3-4 : Isentropic Expansion
4-1 : Constant Volume Heat Rejection

Efficiency of Otto Cycle

The efficiency of the cycle is as follows:

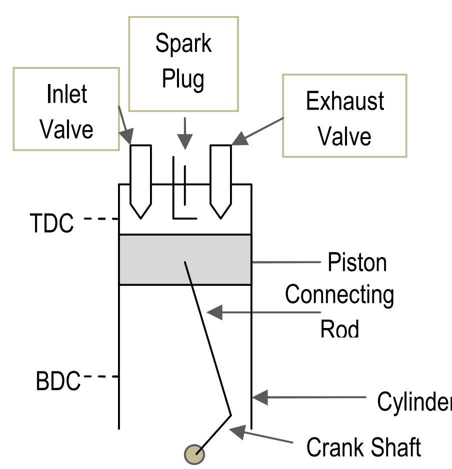
Net Work Done = Heat Supplied – Heat Rejected

Thermal Efficiency = Work Done / Heat Supplied

Thermal Efficiency ➔ $\eta_{Otto} = 1 - \frac{1}{r^{\gamma-1}}$ Where, r = Compression Ratio = V_1 / V_2

Construction Details of 4-stroke SI Engine: Components

Cylinder	Cylinder Head / Block
Piston	Combustion Chamber
Piston Rings	Inlet Manifold
Exhaust Manifold	Valves
Carburetor	Spark Plug
Cylinder Liner	Connecting Rod
Crank Shaft	Cam and Cam Shaft
Gudgeon Pin	Fly Wheel
Crank Case	Gasket
Mufflers	



Working of 4-stroke SI Engine

Let, piston is at TDC and is coming downward (to BDC). Intake Valve is open and exhaust valve is closed. Charge (mixture of petrol and air in prescribed ratio) is prepared by carburetor and is supplied from carburetor to cylinder through inlet manifold.

When piston moves downward, volume inside the cylinder (free space where charge is to be sucked) increases and thus pressure get reduces. Outside the cylinder, the pressure is atmospheric. Hence, partial vacuum is created and owing to this pressure difference charge enters into the cylinder. This is known as Suction process and at the end of this process, piston reaches to BDC.

Now, piston starts moving upward (from BDC to TDC). Inlet valve and exhaust valve, both are closed. Charge is now compressed. Compression is done to increase temperature so that upon spark, combustion of entire mixture / charge can take place instantaneously. In case of SI Engines, temperature after compression remains below the self ignition temperature of fuel. Just before the end of compression (when piston is about to reach at TDC), spark is given (by Spark Plug; SP) to initiate the combustion of fuel. This is known as Compression.

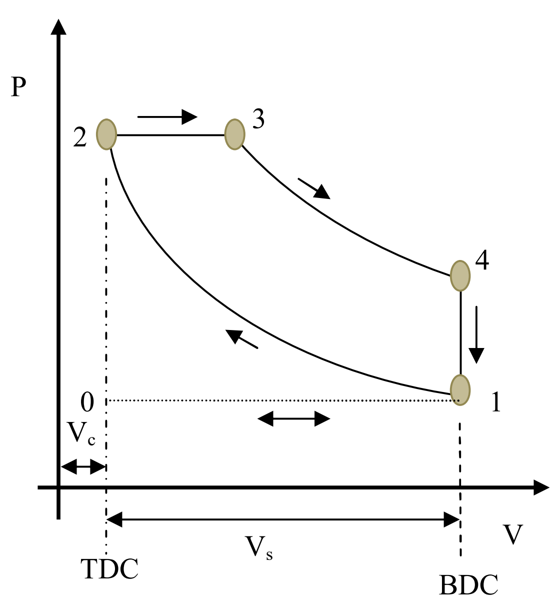
When combustion of charge takes place, an explosive force is generated instantaneously and the only movable part is piston that stats moving downward (from TDC to BDC) under the influence of this generated explosive force. It gives power. During this time, both the valves (inlet and exhaust valve) are closed. This is known as Power.

Now, burnt gases are to be removed from the cylinder. Exhaust valve opens and piston starts moving upward (from BDC to TDC). Burnt flue gases moves from cylinder to exhaust manifold through exhaust valve and escaped to atmosphere through muffler or silencer. This is known as Exhaust.

In this way, piston completes four strokes (movements from one dead centre to another) in two rotation of crank to complete one cycle of operation. In actual cycle, the processes are :

0-1 : Suction	1-2 : Compression	2-3 : Heat Addition
3-4 : Power / Expansion	4-1 : Heat Rejection	1-0 : Exhaust

Diesel Cycle



Processes in Air Standard Diesel Cycle (1-2-3-4-1)

In case of Air Standard Diesel Cycle, working medium is only air, having no fuel. Heat is added at constant pressure from heat source and rejected to heat sink at constant volume. The processes of Air Standard Diesel Cycle are as follows :

1-2 : Isentropic Compression
2-3 : Constant Pressure Heat Addition
3-4 : Isentropic Expansion
4-1 : Constant Volume Heat Rejection

Efficiency of Diesel Cycle

The efficiency of the cycle is as follows:

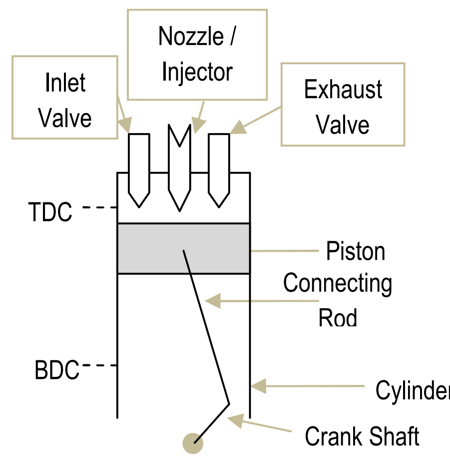
Thermal Efficiency = Work Done / Heat Supplied

Thermal Efficiency ➔ $$\eta_{Diesel} = 1 - r^{\gamma-1}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$$

Where, r = Compression Ratio = V_1 / V_2 ; and, ρ = cut-off ratio (V_3 / V_2)

Construction Details of 4-stroke CI Engine : Components

Cylinder	Cylinder Head / Block
Piston	Combustion Chamber
Piston Rings	Inlet Manifold
Exhaust Manifold	Valves
Injector	Connecting Rod
Crank Shaft	Cam and Cam Shaft
Gudgeon Pin	Fly Wheel
Crank Case	Gasket
Mufflers	Cylinder Liner
Fuel Injection Pump	



Working of 4-stroke CI Engine

Let, piston is at TDC and is coming downward (to BDC). Intake Valve is open and exhaust valve is closed. Air from air cleaner is supplied to cylinder through inlet manifold. Fuel is supplied by Fuel Injection Pump at correct timing in metered quantity.

When piston moves downward, volume inside the cylinder (free space where charge is to be sucked) increases and thus pressure get reduces. Outside the cylinder, the pressure is atmospheric. Hence, partial vacuum is created and owing to this pressure difference, air enters into the cylinder. This is known as Suction process and at the end of this process, piston reaches to BDC.

Now, piston starts moving upward (from BDC to TDC). Inlet valve and exhaust valve, both are closed. Air is now compressed. Compression is done to increase temperature so that upon injection of fuel (diesel), combustion of entire mixture (air + diesel) can take place instantaneously. In case of CI Engines, temperature after compression remains above the self ignition temperature of fuel (diesel). Thus, compression ratio required in CI Engines is more than SI Engines. Just before the end of compression (when piston is about to reach at TDC), diesel is injected into the cylinder (by Nozzle, supplied from FI Pump in correct quantity) and combustion of fuel and air starts. This is known as Compression.

When combustion of mixture takes place, an explosive force is generated instantaneously and the only movable part is piston that stats moving downward (from TDC to BDC) under the influence of this generated explosive force. It gives power. During this time, both the valves (inlet and exhaust valve) are closed. This is known as Power.

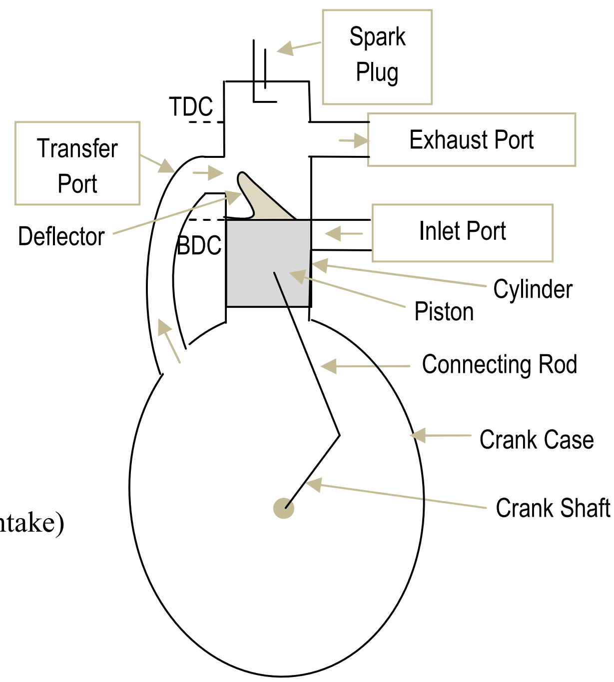
Now, burnt gases are to be removed from the cylinder. Exhaust valve opens and piston starts moving upward (from BDC to TDC). Burnt flue gases moves from cylinder to exhaust manifold through exhaust valve and escaped to atmosphere through muffler or silencer. This is known as Exhaust.

In this way, piston completes four strokes (movements from one dead centre to another) in two rotation of crank to complete one cycle of operation. In actual cycle, the processes are :

0-1 : Suction	1-2 : Compression
2-3 : Heat Addition (Constt. Pressure)	3-4 : Power / Expansion
4-1 : Heat Rejection (Constt. Volume)	1-0 : Exhaust

Construction Details of 2-stroke SI Engine : Components

Cylinder	Cylinder Head / Block
Piston	Combustion Chamber
Piston Rings	Inlet Manifold
Exhaust Manifold	Mufflers
Carburetor	Spark Plug
Cylinder Liner	Connecting Rod
Crank Shaft	Gasket
Gudgeon Pin	Fly Wheel
Crank Case	Ports (Exhaust, Transfer & Intake)



Working of 2-stroke SI Engine

Let, charge is in the cylinder and piston is moving upward.

Piston is moving Upward (BDC to TDC) : First, piston closes Transfer port. Upon further upward movement of piston closes exhaust port. The charge that came inside the cylinder (when transfer port was open) gets now compressed. It completes Compression. At the end of compression (just prior), spark is given by the spark plug that starts combustion. At the same time, when piston is moving upward (when it closes transfer port and exhaust port), it opens intake port and partial vacuum is created in crank case. Owing to this pressure difference, charge comes inside (from carburetor to crank case). It completes partial Suction.

Piston is moving Downward (TDC to BDC) : Now, explosive force (generated owing to combustion) pushes piston to move down. It gives Power (Expansion). Downward movement of piston opens exhaust port that allow burnt gases to move out (from cylinder to atmosphere via exhaust port and exhaust manifold). Further downward movement of piston opens transfer port. Downward movement of piston compresses the charge which is available in crank case and thus it allows the movement of charge from crank case to cylinder via transfer port. It completes the Suction. The charge which enters into cylinder from transfer port, strikes on deflector and deflector changes its director to upward that helps in escaping of burnt gases.

In this way, piston completes two strokes (movements from one dead centre to another) in one rotation of crank to complete one cycle of operation. In actual cycle, the processes are :

0-1 : Suction	1-2 : Compression	2-3 : Heat Addition
3-4 : Power / Expansion	4-1 : Heat Rejection	1-0 : Exhaust

In short, all of these are completed as :

- Piston moves from TDC to BDC (Downward)

  Expansion, Suction (b), Exhaust, Heat Rejection
- Piston moves from BDC to TDC (Upward)

  Compression, Suction (a), Heat Addition
- Suction is in two parts (Charge):

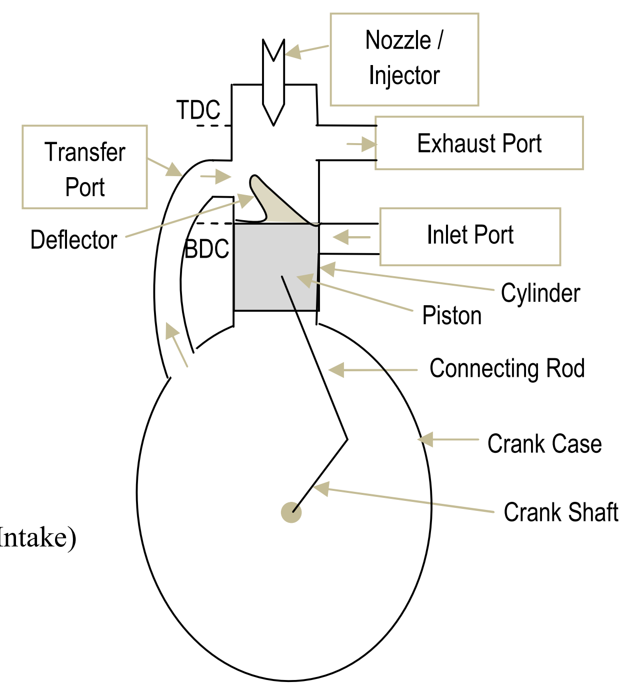
  (a) From Carburetor to Crank Case via Inlet Port; and

  (b) Crank Case to Cylinder through Transfer Port

In case of 2-strok SI Engines, dilution of fresh charge may occur and fresh charge may escape out to atmosphere after getting mix with burnt gases.

Construction Details of 2-stroke CI Engine: Components

Cylinder	Cylinder Head / Block
Piston	Combustion Chamber
Piston Rings	Inlet Manifold
Exhaust Manifold	Fuel Injection Pump
Injector	Connecting Rod
Crank Shaft	Cylinder Liner
Gudgeon Pin	Fly Wheel
Crank Case	Gasket
Mufflers	Ports (Exhaust, Transfer & Intake)



Working of 2-stroke SI Engine

Let, charge is in the cylinder and piston is moving upward.

Piston is moving Upward (BDC to TDC) : First, piston closes Transfer port. Upon further upward movement of piston closes exhaust port. The air that came inside the cylinder (when transfer port was open) gets now compressed. It completes Compression. At the end of compression (just prior), fuel is injected by the injector (or nozzle) that starts combustion. At the same time, when piston is moving upward (when it closes transfer port and exhaust port), it opens intake port and partial vacuum is created in crank case. Owing to this pressure difference, air comes inside (from air cleaner to crank case). It completes partial Suction.

Piston is moving Downward (TDC to BDC) : Now, explosive force (generated owing to combustion) pushes piston to move down. It gives Power (Expansion). Downward movement of piston opens exhaust port that allow burnt gases to move out (from cylinder to atmosphere via exhaust port and exhaust manifold). Further downward movement of piston opens transfer port. Downward movement of piston compresses the air which is available in crank case and thus it allows the movement of air from crank case to cylinder via transfer port. It completes the Suction. The air which enters into cylinder from transfer port, strikes on deflector and deflector changes its director to upward that helps in escaping of burnt gases. Scavenging is a process of supplying extra air to remove burnt / flue gases from the cylinder.

In this way, piston completes two strokes (movements from one dead centre to another) in one rotation of crank to complete one cycle of operation. In actual cycle, the processes are :

0-1 : Suction	1-2 : Compression	2-3 : Heat Addition
3-4 : Power / Expansion	4-1 : Heat Rejection	1-0 : Exhaust

In short, all of these are completed as :

- Piston moves from TDC to BDC (Downward)

  Expansion, Suction (b), Exhaust, Heat Rejection
- Piston moves from BDC to TDC (Upward)

  Compression, Suction (a), Heat Addition
- Suction is in two parts (Air):

  (a) From Air Cleaner to Crank Case via Inlet Port; and

  (b) Crank Case to Cylinder through Transfer Port

In case of 2-strok CI Engines, dilution of fresh air with burnt gases may occur.

Difference between SI and CI Engines

S. No.	Parameter	SI (Spark Ignition) Engines	CI (Compression Ignition) Engines
1	Cycle of Operation	Otto Cycle or Constant Vol. Cycle	Diesel Cycle or Constant Pr. Cycle
2	Heat Addition	At Constant Volume	At Constant Pressure
3	Fuel Used	Petrol (Volatile)	Diesel
4	Charge that enters into cylinder	Mixture of air and petrol in vapour form (in proper ratio)	Only air
5	Method of Ignition	Compressed charged is ignited by Spark	Ignition takes place owing to high compression (Temp. of air after compression becomes more than self ignition temp. of diesel)
6	Compression Ratio	Low (1:6 to 1:12)	High (1:14 to 1:22)
7	Weight of Engine	Less	More
8	Spark Plug / Nozzle	It has Spark Plug	It has Nozzle / Injector
9	Carburetor / Fuel Injection Pump	It has Carburetor	It has Fuel Injection (FI) Pump
10	Cut-off Ratio	Not Applicable	Exists

Difference between 2-stroke and 4-stroke IC Engines

S. No.	Parameter	2-stroke	4-stroke
1	Completion of Thermodynamic Cycle	Cycle completes in one rotation of crank i.e. per 360^0 rotation of crank	Cycle completes in two rotations of crank i.e. per 720^0 rotation of crank
2	Power or Expansion	in two movement of piston between the dead centres or per rpm of crank, ideally double power is to be generated (practically – 1.6 times) wrt 4-stroke engine	in four movement of piston between dead centres or per two rpm of crank
3	Torque or Power developed	Per rpm of crank, more uniform torque is generated, for same size engine – less power is generated	Per two rpm of crank, less uniform torque is generated, for same size engine – more power is generated
4	Pick-up	Fast as power is generated per rpm of crank	Slow as power is generated per two rpm of crank
5	Flywheel requirement	Less weight flywheel is required as power is generated per rpm of crank	More flywheel weight is required as power is generated per 2 rpm of crank
6	Construction Details	It has ports (inlet port, transfer port and exhaust port)	It has two valves (inlet and exhaust valve)
7	Piston (Deflector)	Piston has deflector	No deflector is provided
8	Mileage / Fuel Economy	Poor as fuel is supplied per rpm of crank	Better as fuel is supplied per two rpm of crank
9	Pollution	More	Less
10	Application	Where high torque / power is important, e.g. – Tractors, Ships	Where fuel economy is important, e.g. – Automobiles
11	Initial Cost	Less	More
12	Volumetric Efficiency	Poor	Better
13	Thermal Efficiency	Better (higher value)	Poor (lower value)

Valve Timing Diagram

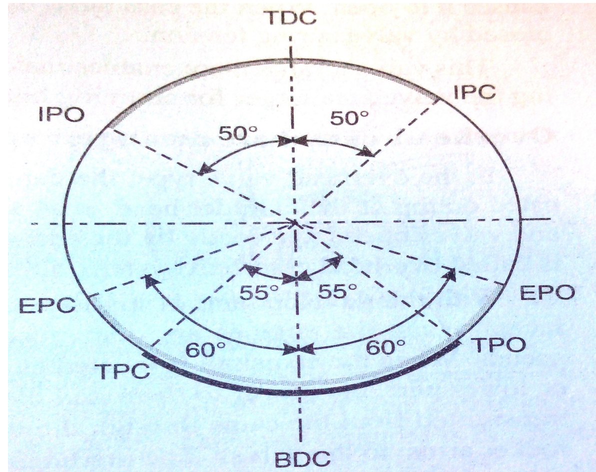


Fig. 3.17 Port timing diagram

The time valves in a 4-stroke engine cycle actually open and close can be measured by angles. These angles can be easily read using a valve-timing diagram. This intake valve opens 12° before the piston reaches top dead center. And it closes 40° after bottom dead center. The exhaust valve opens 47° before bottom dead center - and stays open - until 21° past top dead center.

This gives exhaust gases more time to leave. By the time the piston is at 47° before bottom dead center on the power stroke, combustion pressures have dropped considerably and little power is lost by letting the exhaust gases have more time to exit.

When an intake valve opens before top dead center and the exhaust valve opens before bottom dead center, it is called lead. When an intake valve closes after bottom dead center, and the exhaust valve closes after top dead center, it is called lag. On the exhaust stroke, the intake and exhaust valve are open at the same time for a few degrees around top dead center. This is called valve overlap. On this engine, it is 33°.

Different engines use different timings. Manufacturer specifications contain the exact information.

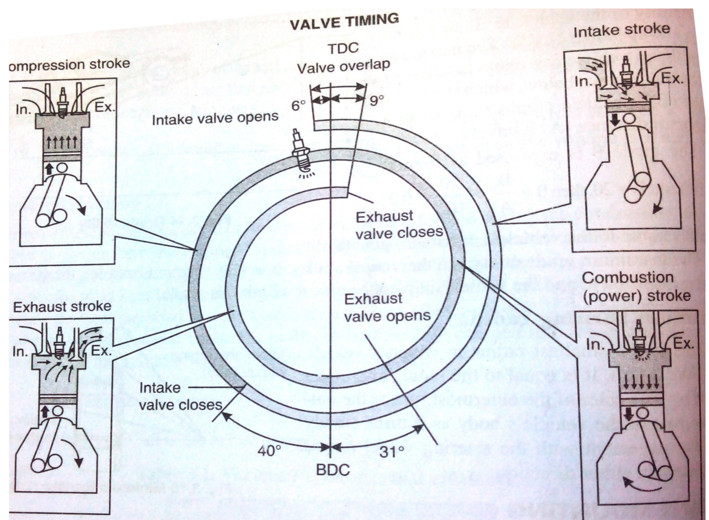
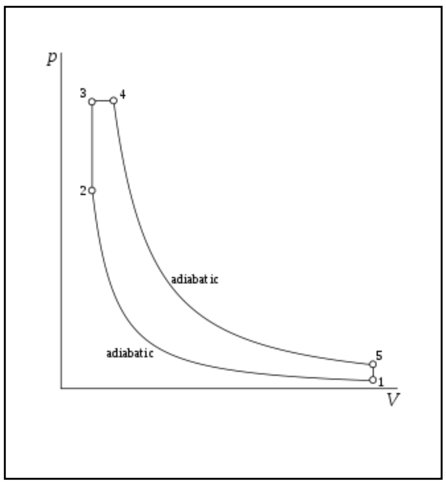
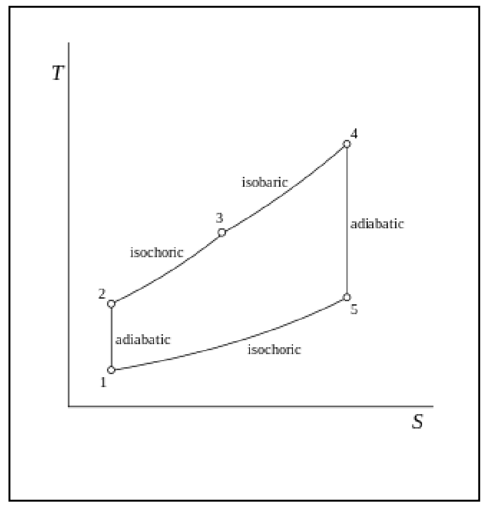


Fig. 3.16 Valve timing diagram

Dual Cycle

The **dual combustion cycle** (also known as the **mixed cycle**, **Trinkler cycle**, **Seiliger cycle** or **Sabathe cycle**) is a thermal cycle that is a combination of the Otto cycle and the Diesel cycle, first introduced by Russian-German engineer Gustav Trinkler. Heat is added partly at constant volume and partly at constant pressure, the advantage of which is that more time is available for the fuel to completely combust. Because of lagging characteristics of fuel this cycle is invariably used for Diesel and hot spot ignition engines. It consists of two adiabatic and two constant volume and one constant pressure processes. Efficiency lies between Otto and Diesel cycle.





Pressure-Volume diagram of Sabathe cycle   Temperature-Entropy diagram of Sabathe cycle

The dual cycle consists of following operations:

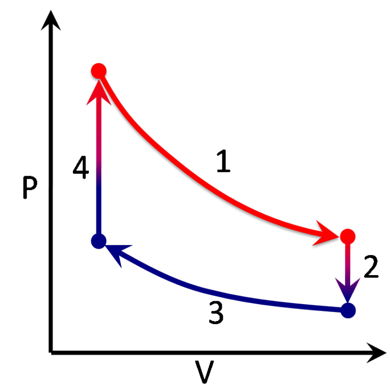
- Process 1-2: Isentropic compression
- Process 2-3: Addition of heat at constant volume.
- Process 3-4: Addition of heat at constant pressure.
- Process 4-5: Isentropic expansion.
- Process 5-1: Rejection of heat at constant volume.

The cycle is applicable for automobile sector.

Stirling Cycle

The **Stirling cycle** is a thermodynamic cycle that describes the general class of Stirling devices. This includes the original Stirling engine that was invented, developed and patented in 1816 by Robert Stirling with help from his brother, an engineer.[1]

The **idealized** Stirling cycle consists of four thermodynamic processes acting on the working fluid (See diagram to right):



1. **Isothermal expansion**. The expansion space is heated externally, and the gas undergoes near-isothermal expansion.
2. **Constant-volume** (known as **isovolumetric** or **isochoric**) heat removal. The gas is passed through the regenerator, thus cooling the gas, and transferring heat to the regenerator for use in the next cycle.
3. **Isothermal compression**. The compression space is intercooled, so the gas undergoes near-isothermal compression.
4. **Constant-volume heat addition**. The compressed air flows back through the regenerator and picks up heat on the way to the heated expansion space.

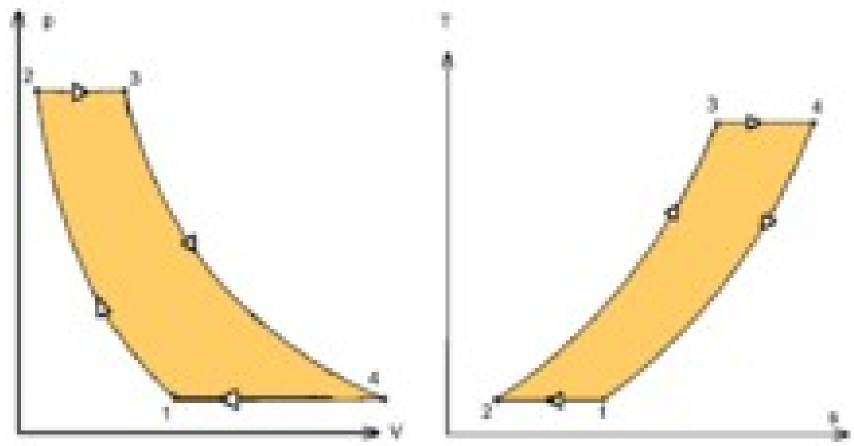
The ideal Otto and Diesel cycles are not totally reversible because they involve heat transfer through a finite temperature difference during the irreversible isothermal heat-addition and heat-rejection processes. The irreversibility renders the thermal efficiency of these cycles less than that of a Carnot engine operating within the same limits of temperature. Another cycle that features isothermal heat-addition and heat-rejection processes is the Stirling cycle, which is an altered version of the Carnot cycle in which the two isentropic processes featured in the Carnot cycle are replaced by two constant-volume regeneration processes.

The cycle is reversible, meaning that if supplied with mechanical power, it can function as a heat pump for heating or cooling, and even for cryogenic cooling. The cycle is defined as a closed regenerative cycle with a gaseous working fluid. "Closed cycle" means the working fluid is permanently contained within the thermodynamic system. This also categorizes the engine device as an external heat engine. "Regenerative" refers to the use of an internal heat exchanger called a regenerator which increases the device's thermal efficiency.

The cycle is the same as most other heat cycles in that there are four main processes: compression, heat addition, expansion, and heat removal. However, these processes are not discrete, but rather the transitions overlap. The Stirling cycle is a highly advanced subject that has defied analysis by many experts for over 190 years. Highly advanced thermodynamics is required to describe the cycle. Professor Israel Urieli writes: "...the various 'ideal' cycles (such as the Schmidt cycle) are neither physically realizable nor representative of the Stirling cycle".

Ericsson Cycle

The **Ericsson cycle** is named after inventor John Ericsson, who designed and built many unique heat engines based on various thermodynamic cycles. He is credited with inventing two unique heat engine cycles and developing practical engines based on these cycles. His *first* cycle is now known as the closed Brayton cycle, while his second cycle is what is now called the Ericsson cycle.



The following is a list of the four processes that occur between the four stages of the ideal Ericsson cycle:

- Process 1 -> 2: Isothermal compression. The compression space is assumed to be intercooled, so the gas undergoes isothermal compression. The compressed air flows into a storage tank at constant pressure. In the ideal cycle, there is no heat transfer across the tank walls.
- Process 2 -> 3: Isobaric heat addition. From the tank, the compressed air flows through the regenerator and picks up heat at a high constant-pressure on the way to the heated power-cylinder.
- Process 3 -> 4: Isothermal expansion. The power-cylinder expansion-space is heated externally, and the gas undergoes isothermal expansion.
- Process 4 -> 1: Isobaric heat removal. Before the air is released as exhaust, it is passed back through the regenerator, thus cooling the gas at a low constant pressure, and heating the regenerator for the next cycle.

Comparison with Carnot, Diesel, Otto, and Stirling cycles

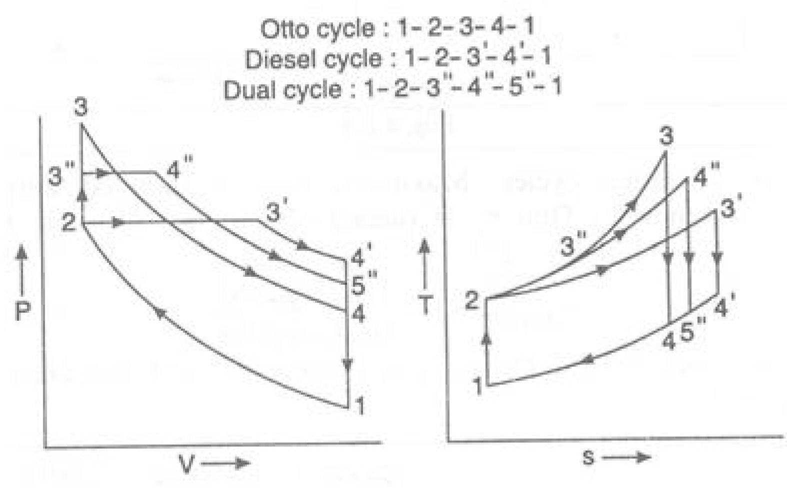
The ideal Otto and Diesel cycles are not totally reversible because they involve heat transfer through a finite temperature difference during the irreversible isochoric/isobaric heat-addition and isochoric heat-rejection processes. The aforementioned irreversibility renders the thermal efficiency of these cycles less than that of a Carnot engine operating within the same limits of temperature. Another cycle that features isobaric heat-addition and heat-rejection processes is the Ericsson cycle. The Ericsson cycle is an altered version of the Carnot cycle in which the two isentropic processes featured in the Carnot cycle are replaced by two constant-pressure regeneration processes.

The Ericsson cycle is often compared to the Stirling cycle, since the engine designs based on these respective cycles are both external combustion engines with regenerators. The Ericsson is perhaps most similar to the so-called "double-acting" type of Stirling engine, in which the displacer piston also acts as the power piston. Theoretically, both of these cycles have so called *ideal* efficiency, which is the highest allowed by the second law of thermodynamics. The most well known ideal cycle is the Carnot cycle, although a useful *Carnot engine* is not known to have been invented. The theoretical efficiencies for both, Ericsson and Stirling cycles acting in the same limits are equal to the Carnot Efficiency for same limits.

Comparison of Otto, Diesel and Dual Cycles

The **comparison of Otto, Diesel and Dual cycles** can be made on the basis of compression ratio, maximum pressure, maximum temperature, heat input, work output etc.

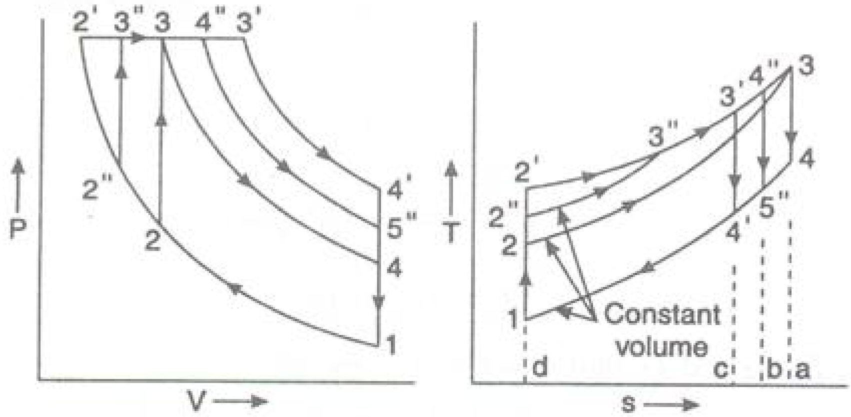
(a) **For same compression ratio and same heat input:**
When compression ratio is kept constant process (1-2) remains the same for all the three cycles. But process (2-3), which shows the heat addition is different for those cycle. If same heat is transferred in all three cycles, the temperature attained is maximum for Otto cycle and minimum for Diesel cycle.



The work done during the cycle is proportional to the area inside the bounded region. The area is maximum for Otto cycle and minimum for Diesel cycle. Thus, for same heat input, efficiency of Otto cycle will be the maximum while that of Diesel cycle will be the minimum.

(b) For same maximum pressure and same heat input:

For the same maximum pressure 3.3'. and 3" must be on same pressure line and for the same heat input the area 2-3-a-d-2, 3' -3' –c-d-2 and 2"3"4" b – d – 2" should be equal. It is obvious from figure that heat rejected by otto cycle 1-4 – a – d – 1 is more than 1-5" – b – d – 1 and 1 – 4' – c – d – 1.

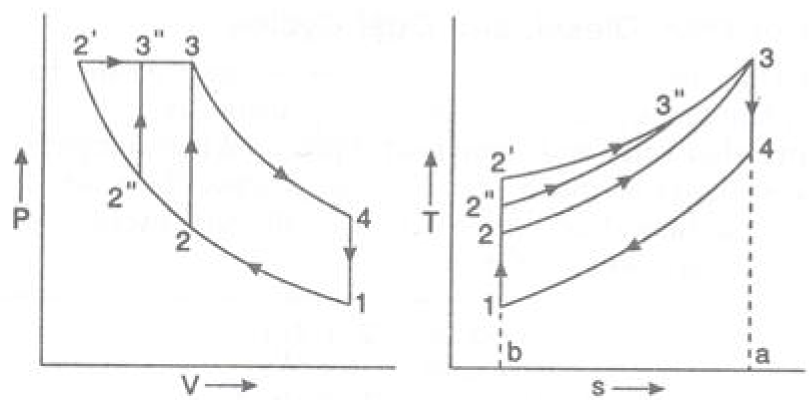


Since $\prod_{thermal} = Q_s - Q_R / Q_s$

The Diesel cycle is more efficient that Dual cycle, which in term is more efficient that Otto cycle.

(iii) For same pressure and temperature:

It is clear from the figure that the heat rejected by all three cycles, Otto, Diesel and Dual cycle remains the same (area 4-a – b - 1 - 4). But the heat supplied is different for all three cycles. Maximum heat is supplied during diesel cycle (area 2'-3-a-b-2') and minimum for Otto cycle (area 2 – 3 – a – b - 2) while for Dual cycle it is in between the two (area 2' – 3" – 3 – a – b – 2")



since, $\prod_{thermal} = 1 -$ Heat rejected / Heat supplied

Hence, for the above conditions the Diesel cycle is more efficient than Dual cycle, which in turn is more efficient than Otto cycle.(Internet)

Lecture # 7-8

Fuel Air Cycles and Actual Cycles

FUEL - AIR CYCLES : INTRODUCTION

The basic problem in the air-cycle analysis is that it is based on highly simplified approximations. This is why the results obtained from such analysis are much greater than the actual performance. For example, an engine with CR=7 has a thermal efficiency (based on air cycle analysis) equals to 54% while the actual value does not exceed 30%. This is mainly due to the following reasons:

1. Non-instantaneous burning of the fuel.
2. Non-instantaneous operation of the valves.
3. Over simplifications in using the values of the properties of the working fluids.
4. Incomplete combustion of the fuel.
5. Assuming constant specific heat of the working fluid.
6. Assuming the working fluid to be only air.

Fuel-Air cycle is defined as the theoretical cycle that is based on the actual properties of the cylinder gases. The Fuel-Air cycle takes into account the following:

1. The actual composition of the cylinder gases (air + fuel + water vapor + residualgases).
2. The variation of the specific heat of these gases with temperature.
3. The incomplete mixing (in-homogeneous) of fuel and air at higher temperatures(@ above 1600^0K

The variations in the number of molecules present in the cylinder as the temperature and pressure change. Besides these, the fuel-air cycle analysis are based on the following assumptions:

1. No change in the fuel or air chemical composition before combustion.
2. The process is frictionless and adiabatic.
3. Charge is in chemical equilibrium after combustion.
4. Combustion process is instantaneous.
5. Fuel is completely vaporized and perfectly mixed with the air (for SI only).

The basic advantage of the fuel-air cycle analysis is that while the air cycle studies the effect of CR only on other parameters, with fuel-air cycle we can also study the effect of CR, F/A, inlet pressure and temperature, variable specific heat and other factors on engine performance

The actual cycles for IC engines differ from the fuel-air cycles and air-standard cycles in many respects. The actual cycle efficiency is much lower than the air-standard efficiency due to various losses occurring in the actual engine operation. The major losses are due to:

1. Variation of specific heats with temperature
2. Dissociation of the combustion products

3. Progressive combustion
4. Incomplete combustion of fuel
5. Heat transfer into the walls of the combustion chamber
6. Blowdown at the end of the exhaust process
7. Gas exchange process An estimate of these losses can be made from previous experience and some simple tests on the engines and these estimates can be used in evaluating the performance of an engine.

COMPARISON OF THERMODYNAMIC AND ACTUAL CYCLES

The actual cycles for internal combustion engines differ from thermodynamic cycles in many respects. These differences are mainly due to:

1. The working substance being a mixture of air and fuel vapor or finely atomized liquid fuel in air combined with the products of combustion left from the previous cycle.
2. The change in chemical composition of the working substance,
3. The variation of specific heats with temperature,
4. The change in the composition, temperature and actual amount of fresh charge because of the residual gases.
5. The progressive combustion rather than the instantaneous combustion.
6. The heat transfer to and from the working medium.
7. The substantial exhaust blowdown loss, i.e., loss of work on the expansion stroke due to early opening of the exhaust valve,
8. Gas leakage, fluid friction etc., in actual engines.

Remaining points viz. (v) to (viii) are in fact responsible for the difference between fuel-air cycles and actual cycles. Most of the factors listed above tend to decrease the thermal efficiency and power output of the actual engines.