C. V. Raman Polytechnic, Bhubaneswar

Department of Mechanical Engineering

LECTURES NOTE

Subject- THERMAL ENGG -I

3RD SEM MECHANICAL

PREPARED BY

Dr Shubhashree Mohapatra

Assistant Professor

Mechanical Engineering

Chapter-1

Thermodynamic concept and terminology

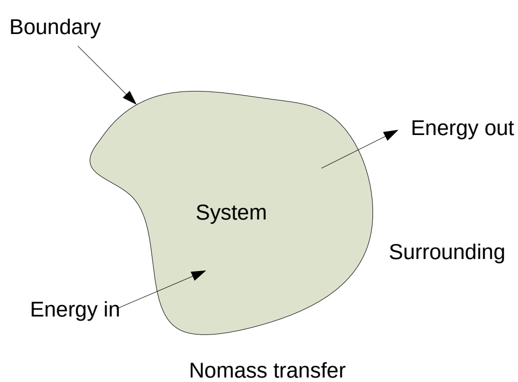
Thermodynamics is a science that deals with energy interaction with matter, which changes its macroscopic properties,

1.1. Thermodynamic system

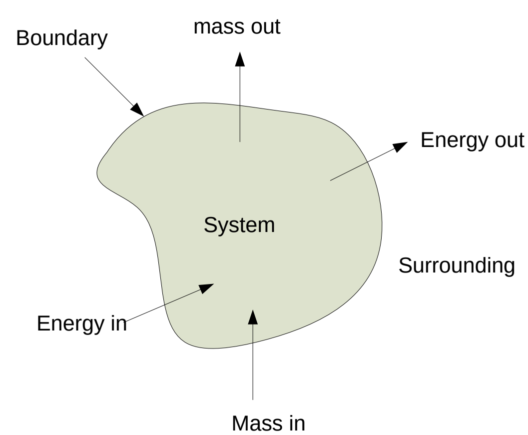
It is defined as quantity of a matter or a region in space where the attention is concentrated in the analysis of problem. Everything external to the system is called surrounding. System and surrounding are separated by the boundary. System and surrounding together can be called as universe.

Closed system: it is a system of fixed mass. No mass transfer across the boundary, only energy can transfer into or out of the system.

Ex: a certain quantity of fluid in a cylinder bounded by a piston is called a closed system. With movement of piston, energy transfer can occur in terms of heat and work, but there is no addition and loss of original mass of the working substance.



Closed system



Open system

Open system: In this system working substance or mass crosses the boundary. Energy may also crosses the boundary. Most of the engineering devices are open system.

Ex: An air compressor in which air enters at low pressure and leaves at high pressure and there is energy transfer across the boundary along with mass is an example of open system.

Isolated system: it is a system of fixed mass and no heat or work cross its boundary. It is a system where there is no interaction between system and its surrounding.

Homogeneous and Heterogeneous system: A quantity of mater homogeneous throughout in chemical composition and physical structure is called phase. Phase can be of solid, liquid or gas. A system consisting of a single phase is called homogeneous system, while system consisting of more than one phase is called heterogeneous system.

1.2. Thermodynamic properties

The state of a system may be identified by certain observable quantities such as volume, pressure, temperature etc. these quantities which identifies the state of a system is called properties. it is divided into two classes;

Extensive Property: these properties are related to mass. If mass is increased, value of extensive properties also increase. The properties of a system whose value for entire system is the sum of their values of individual part of system are called extensive properties. Example: volume, energy, total mass, size, length, entropy, enthalpy etc.
Intensive Properties: These are independent of mass in the system. The properties of a system whose value for entire system is not equal to the sum of their values of individual part of system are called intensive properties. Example: Temperature, pressure, density, melting point, boiling point, specific energy, specific volume etc.

1.3. Thermodynamic equilibrium:

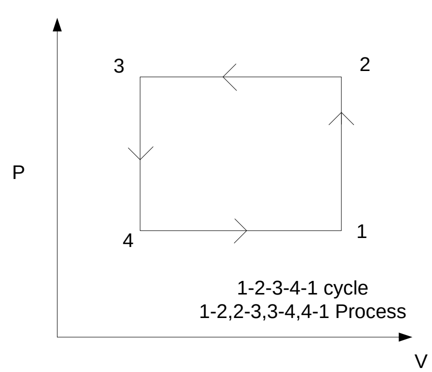
A system is said to be in thermal equilibrium where there is no change in macroscopic properties if the system is isolated from surrounding.

A system is said to be in thermodynamic equilibrium if the conditions for the following three type equilibrium is satisfied:
Mechanical Equilibrium: if there is no unbalanced force exist within the system and in between the system and surrounding, the system is said to be in mechanical equilibrium.
Chemical Equilibrium: if there is no chemical reaction or transfer of matter from one part of system to another, the system is said to be in a state of chemical equilibrium.
Thermal Equilibrium: when the system is in both mechanical and chemical equilibrium state and separated by a diathermic wall and there is no spontaneous change in any properties of the system, it is said to be in a state of thermal equilibrium state. There will be no temperature difference between the parts of the system or between the system and surrounding.

1.4. Thermodynamic Process, path, cycle, state, point function and path function

Thermodynamic state: when all the properties of a system have a definite value, the system is said to be in a definite state. It is a condition of a system specified by its properties.
Thermodynamic path: Any operation where one or more properties of a system changes is called change of state. The succession of state pass through during the change of state is called path. It is the loci of different intermediate states through which the system passes.
Thermodynamic process: when a system changes its state from one equilibrium state to another, the path of successive states through which the system has passed is known as process. If the process occurs slowly with infinitely small intermediate states it is called as reversible process. If the intermediate states are in non equilibrium states, it is known as irreversible process.

Thermodynamic cycle: it is the series of processes such that the system returns to its initial state. The final state is identical with the initial state.

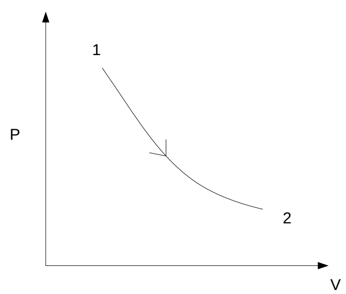


Point Function and Path function: the system properties whose value depends on end state or point are point function. Thermodynamic properties are point function since for a given state, there is a definite value for each property. Change in thermodynamic property of a system is independent of the path followed by the system during the change of state and depends only on initial and final point of the system. The differentials of the point function are exact differentials.

$$\int_{V1}^{V2} dV = V2 - V1 \;,\; \int_{P1}^{P2} dP = P2 - P1$$

Path functions are those properties whose value depends upon the path taken by the system. Thus, it is an inexact differential.

$\int_{1}^{2} \text{đ}w \neq W2 - W1$ rather it is W_{1-2}



Difference between point function and path function:

Sr. no.	Point Function	Path Function
1	Its values are based on the state of the system (i.e. pressure, volume, temperature etc.)	Its values are based on how that particular thermodynamic state is achieved.
2	No matter by which process the state is obtained, its values will always remain the same.	Different processes to obtain a particular state will give us different values.

3	Only initial and final states of the process are sufficient	We need to know exact path followed by the process
4	Its values are independent of the path followed	Its values are dependent on the path followed
5	It is an exact or perfect differential	It is an inexact or imperfect differential.
6	Its cyclic integral is always zero	Its cyclic integral may or may not be zero
7	It is property of the system	It is not the property of the system
8	Its examples are density, enthalpy, internal energy, entropy etc	Its examples are Heat, work etc.

Pressure (p):

A fluid exerts on a surface element dS of a wall a force of pressure perpendicular to dS, directed outwards with a norm equal to p dS, where by definition p is the pressure of the fluid.

The force of pressure, which is a force, a vector quantity the SI unit of which is the Newton, should not be confused with the pressure, a scalar quantity whose **SI unit is the Pascal(N/M^2)**. At thermodynamic equilibrium, the system must specifically be at mechanical equilibrium.

Temperature (T):

Temperature is a measure of the average kinetic energy of the atoms or molecules in the system. The unit of measurement in the International System of Units (SI) is the kelvin. Kelvin is, therefore, the unit used by scientists. It is frequent to see it referenced as a **Kelvin degree**.

The basic units (SI Units)

- Mass kg.
- Mole The mole is the amount of substance that contains as many atoms (or molecules) as there are atoms in 0.012 kg of carbon-12.
- Length—m.
- Time: second (s)
- SI unit of temperature is Kelvin (abbreviated as K). The Kelvin is defined as the fraction of 1/273.16 of the thermodynamic temperature of the triple point of water. The relation between Kelvin and Celsius temperature is K = C + 273.15 (The triple point of water is at 0.01 C).
- Force: 1 N = 1 kg m/s,
- Pressure, 1 Pa = 1 N/m^2 , 1 bar = 10^5 Pa, 1 atm. = 101.325 KPa.= 760 mm of HG In thermodynamics we are concerned with absolute pressure.

  Gauge pressure = absolute pressure – atmospheric pressure.

  Ordinary vacuum gauge pressure = atmospheric pressure – absolute pressure.

Volume (V):

The volume of a thermodynamic system typically refers to the volume of the working fluid, such as, for example, the fluid within a piston. Changes to this volume may be made through an application of work, or may be used to produce work. **SI unit of volume is M^3.**

Internal Energy :

• The molecule as a whole can move in x, y and z directions with respective components of velocities and hence possesses kinetic energy.

• There can be rotation of molecule about its center of mass and than the kinetic energy associated with rotation is called rotational energy.

• In addition the bond length undergoes change and the energy associated with it is called vibrational energy.

• The electron move around the nucleus and they possess a certain energy that is called electron energy.

• The microscopic modes of energy are due to the internal structure of the matter and hence sum of all microscopic modes of energy is called the internal energy.

Bulk kinetic energy (KE) and potential energy (PE) are considered separately and the other energy of control mass as a single property (U).

The total energy possessed by the body is given

by: E = KE + PE + U

Intensive & Extensive properties:

- An intensive property is one that does not depend on the mass of the substance or system.

- Temperature (T), pressure (P) and density (r) are examples of intensive properties. Intensive Property Examples;

The properties of matter that do not depend on the size or quantity of matter in any way are referred to as an intensive property of matter. Temperatures, density, color, melting and boiling point, etc., all are intensive property as they will not change with a change in size or quantity of matter. The density of 1 liter of water or 100 liters of water will remain the same as it is an intensive property.

- An extensive property of a system depends on the system size or the amount of matter in the system.

If the value of the property of a system is equal to the sum of the values for the parts of the system then such a property is called extensive property. Volume, energy, and mass are examples of extensive properties.

Extensive Property Examples;

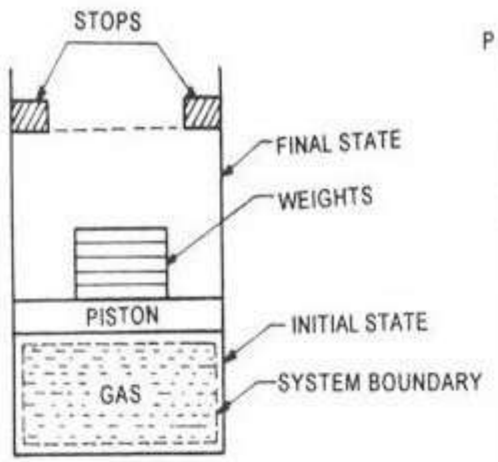
There are properties such as length, mass, volume, weight, etc. that depend on the quantity or size of the matter, these properties are called an extensive property of matter and their value changes if the size or quantity of matter changes. Suppose we have two boxes made up of the same material, one has a capacity of four litres while the other has a capacity of ten litres. The box with ten litres capacity will have more amount of matter as compared to that of a four- liter box.

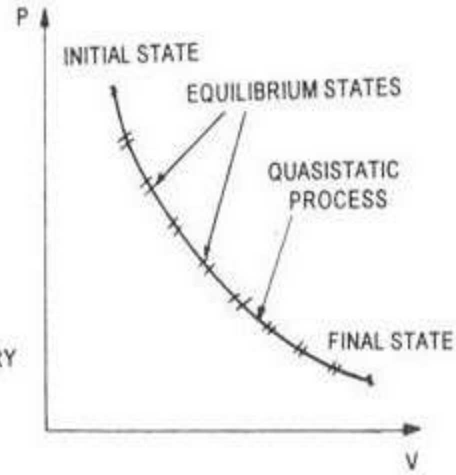
Quasi-static process:

When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times: Quasi-static or Quasi-equilibrium process

• The process proceeds slow enough to allow the system to the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts.

- The quasi-static or quasi-equilibrium process is also known as reversible process. A process which can be reversed in direction and the system retraces the same equilibrium states is known as reversible process.





Energy:

Energy possesses the ability to produce a dynamic, vital effect. Energy exists in various forms.

e.g. mechanical, thermal, electrical etc. One form of energy can transform to other by suitable arrangements.

SOURCES OF ENERGY:

The various sources of energy are:

- Fuels- I. Solids-Coal,Coke, Anthracite etc.
  2. Liquids-Petroleum and its derivates
  3. Gases-Natural gas, blast furnace gas etc
- Energy stored in water
- Nuclear energy
- Wind energy
- Solar energy
- Tidal energy
- Geothermal energy
- Thermoelectric power

Power:

Any Physical unit of energy when divided by a unit of time automatically becomes a unit of power. Power can be defined as rate of flow of energy and can state that a power plant is a unit built for production and delivery of flow of mechanical and electrical energy. With the advancement of technology the power consumption is rising steadily.

This necessitates that in addition to the existing source of power such as coal, water, petroleum etc. other source of energy should be searched out and new and more efficient ways of producing energy should be decided.

Work:

The work is said to be done by a force when it acts on a body moving in the direction of force.

Whenever a system interacts with its surroundings, it can exchange energy in two wayswork and heat. In mechanics, work is defined as the product of the force and the displacement in the direction of the force.

Work done when a volume is increased or decreased Consider a gas in a container with a movable piston on top. If the gas expands, the piston moves out and work is done by the system on the surroundings.

To calculate the work done in moving the piston,

- we know that the**, force = pressure x area** and then,
  work = pressure x area timex distance or, **work = pressure x change in volume**. So, **W = ∫ p dV**
- The differential work done (dW) associated with a differential displacement (dl) is given by
  dW = F .dl
- For a piston cylinder assembly, **dW = F dl = PA (dl) = P dV**
- If the gas is allowed to expand reversibly from the initial pressure P to final pressure P, then the work done is given by **W = ∫ p dV**

Displacement work:

Consider a piston cylinder arrangement as given in the Figure 2.4. If the pressure of the fluid is greater than that of the surroundings, there will be an unbalanced force on the face of the piston. Hence, the piston will move towards right.

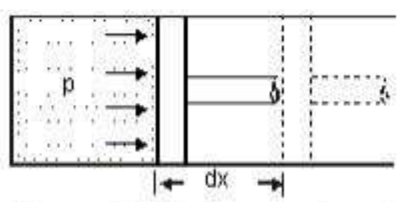


Figure 2.4 Displacement work

Force acting on the piston =Pressure x Area

= p.A

Work done =Force x distance

= pA x dx

= p.dV

Where, dV =change in volume.

This work is known as displacement work or pdV work corresponding to the elemental displacement dx . To obtain the total work done in a process, this elemental work must be added from the initial state to the final state.

IC Engines

Four stroke Spark ignition Engine

In this type of engine, the cycle operation is completed in four strokes of the piston or two revolutions of the crankshaft. During four strokes, there are five events to be completed, suction, compression, combustion, expansion and exhaust. Each stroke consists of 180° of crank shaft rotation and hence four strokes are completed through 720° of crank rotation.

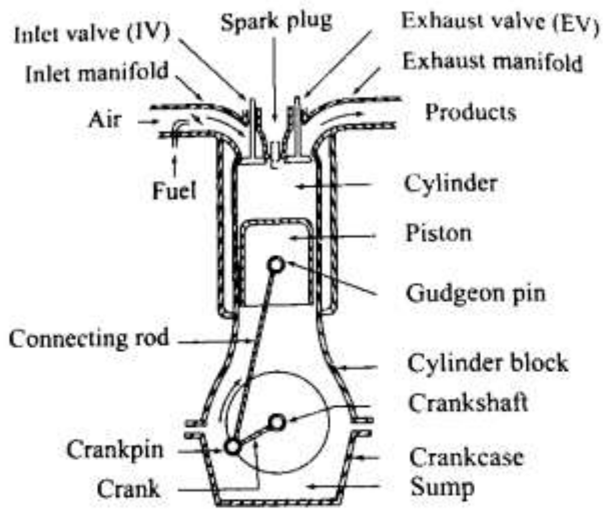


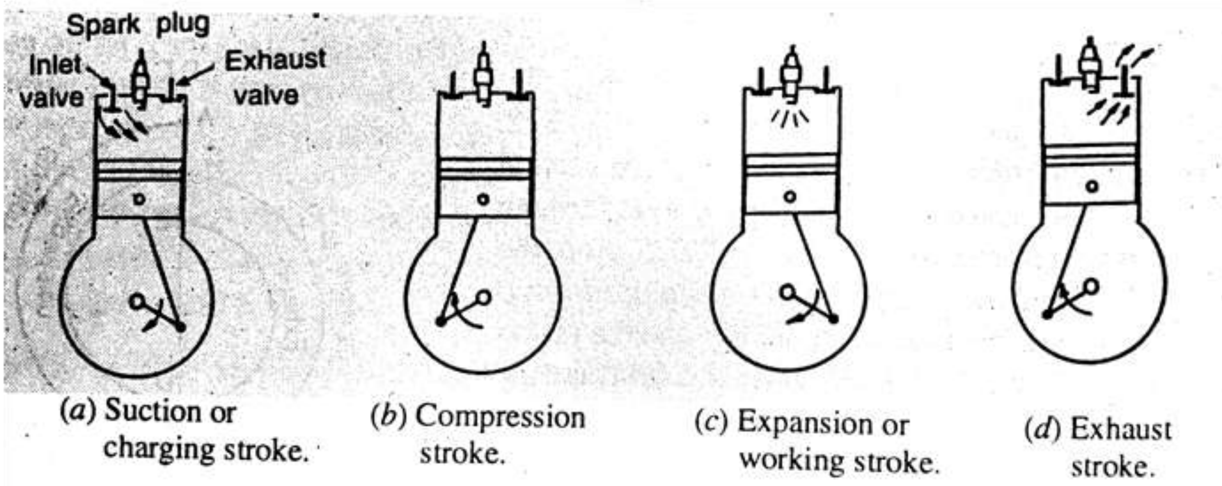
Fig. 1.2 Cross-section of a Spark-Ignition Engine

SI engine consists of following four strokes

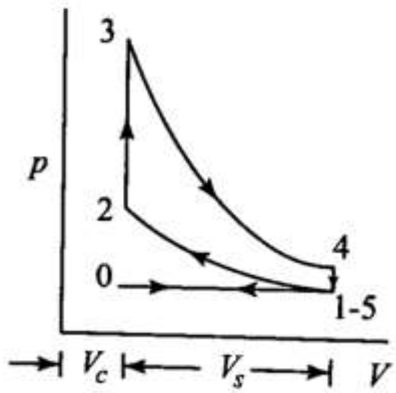
1. Suction
2. Compression
3. Expansion
4. Exhaust

Suction (0 – 1): It starts when piston is at top dead centre (TDC) and about to move downward. The inlet valve opens and exhaust valve closes. During suction, the charge consisting of fuel-air mixture is drawn into cylinder. When piston reaches at bottom dead centre (BDC), the suction valve closes.

Compression (1 – 2): the charge taken during suction stroke is compressed by return stroke of piston. During this stroke, both inlet and exhaust valves are closed. The air-fuel mixture is compressed into the clearance volume. At the end of the compression stroke, the mixture is ignited with the help of spark plug located on the cylinder head. During burning process, the chemical energy of fuel is converted into heat energy producing a temperature rise about 2000°C (2 – 3). The pressure at the end of this process is increased due to heat release from the fuel.



Four-stroke cycle petrol engine.



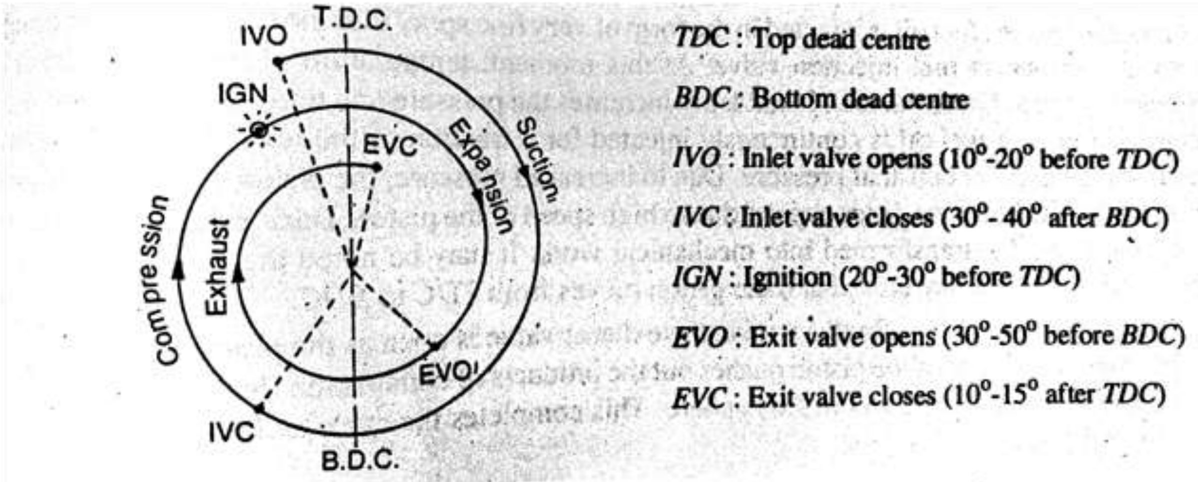
ig. 1.5 Ideal p-V Diagram of a Four-Stroke SI Engine

<u>Expansion stroke (3 – 4):</u> the high pressure burnt gases forces the piston towards BDC. Both the valves are closed. During this stroke, the power is produced. Here both pressure and temperature decreases.

<u>Exhaust stroke</u>: At the end of the expansion, the exhaust valve opens and inlet valve remained closed. The pressure falls to atmospheric level (4 – 5). The piston starts moving from BDC to TDC (5 – 0) and sweeps all the burnt gases out from the cylinder. The exhaust valve closes when the piston reaches at TDC. At the end of the exhaust stroke, some of the residual gases trapped in the clearance volume remain in the cylinder.

Valve timing diagram for four stroke Spark ignition Engine

The inlet valve opens before the piston reaches the TDC or before beginning of the suction stroke. Now the piston reaches at TDC and suction stroke starts. The piston reaches at bottom dead centre (BDC) and starts moving up. Here the inlet valve closes when the crank has moved a little beyond BDC. The ignition starts before the piston reaches to TDC during the compression stroke. When the piston reaches at TDC, the burnt gas pushes the piston towards the BDC, thus the expansion process starts. Before reaching the BDC, the exhaust valve opens and the burnt gases starts escaping from the cylinder. When the piston reaches at BDC, the piston starts moving up, it is called exhaust stroke. Before reaching the TDC, the inlet valve opens as the fresh charges helps to push the burnt gases. When the piston reaches at TDC, the suction stroke starts again. The exit valve closes when the piston moves little beyond the TDC during suction stroke. This is known as valves overlap as for some fraction of time both inlet and outlet valves are open.



Valve timing diagram for a four stroke cycle petrol engine.

Four stroke Compression ignition Engine

It is similar to four stroke SI engine but it operates at much higher compression ratio. In CI engine, during suction stroke, air is introduced to the engine chamber instead of air-fuel mixture. Due to high compression ratio, the temperature at the end of the compression is high enough to self ignite the fuel which is injected into the combustion chamber. In CI engine high pressure fuel pump and an injector is used.

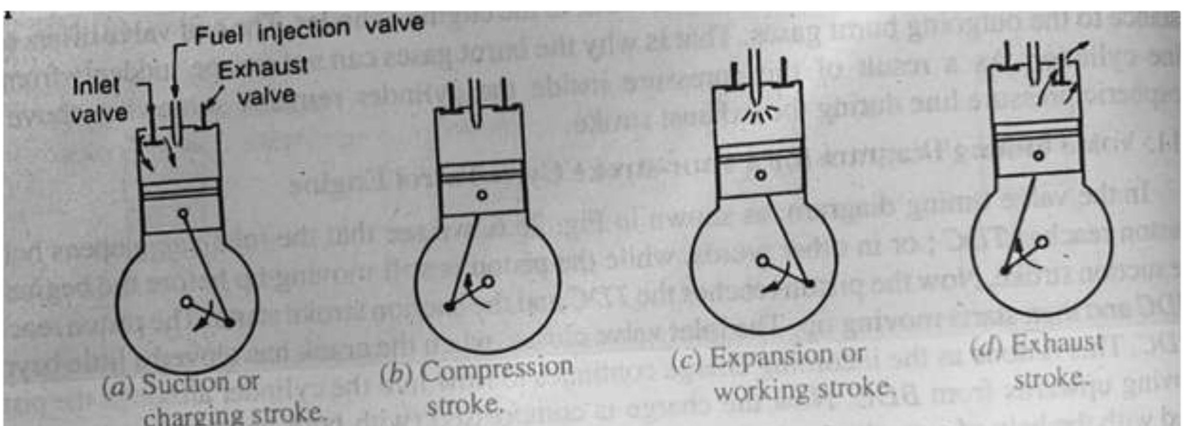
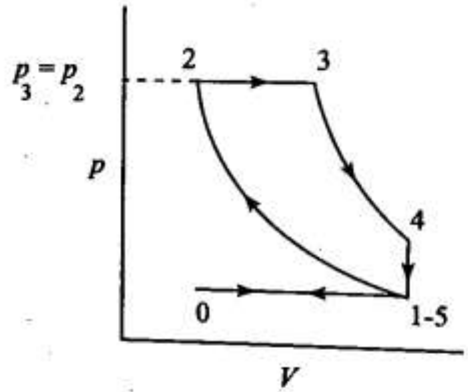


Fig. 26.7. Four stroke cycle diesel engine.



Ideal p-V Diagram for a Four-Stroke CI Engine

Suction: It starts when piston is at top dead centre (TDC) and about to move downward. The inlet valve opens and exhaust valve closes. Air is introduced during the suction stroke.

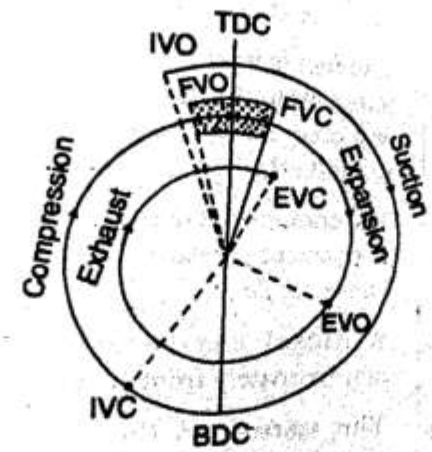
Compression: The air taken during suction stroke is compressed by return stroke of piston. During this stroke, both inlet and exhaust valves are closed. Fuel injection starts at the end of the compression stroke.

Expansion: The rate of injection of fuel occurs in such a way that combustion maintains the constant pressure in spite of the piston movement during expansion stroke increasing the volume. Heat assumed to have been added at constant pressure. After the injection of fuel is complete (Cut off point), the product of combustion expanded. Both the valves remained closed during this stroke.

Exhaust: The piston moves from BDC to TDC pushes out the product of combustion. The inlet valve is closed and exhaust valve is open during this stroke.

Valve timing diagram for four stroke Compression ignition Engine

The inlet valve opens before the piston reaches TDC or while the piston is still moving up before beginning of the suction stroke. When, the piston reaches the TDC, the suction stroke starts and air intake into the cylinder occurs. The piston reaches the BDC and then starts moving up. The inlet valve closes when the piston has moved a little beyond the BDC. Now the air is compressed with both the valve closed. Fuel valve opens just before the piston reaches to the TDC. The fuel is injected in the form of fine spray into the engine cylinder which get ignited due to the high temperature of the compressed air. The pressure increases due to burning of the fuel pushes the piston down toward the BDC and the expansion process starts. Fuel valve closes after the piston has moved a little beyond from the TDC. The exhaust valve opens before the piston reaches to the BDC and burnt gases starts escaping from the cylinder. After the piston reaches at the BDC, it starts moving up performing the exhaust stroke. Before reaching the TDC, the inlet valve opens, fresh air starts to enter into the cylinder and helps to push the remaining burnt air. Once the piston reaches the TDC, it starts to moving down performing suction stroke. The exit valve closes when the piston has moved a little beyond from the TDC.



TDC : Top dead centre

BDC : Bottom dead centre

IVO : Inlet valve opens (10° - 20° before *TDC*)

IVC : Inlet valve closes (25° - 40° after *BDC*)

FVO : Fuel valve opens (10° - 15° before *TDC*)

FVC : Fuel valve closes (15° - 20° after *TDC*)

EVO : Exhaust valve opens (39° - 50° before *BD*

EVC : Exhaust valve closes (10° - 15° after *TDC*

Fig. 26.9. Valve timing diagram for a four stroke cycle diesel engine.

<u>Comparison between SI AND CI engine</u>

Description	SI engine	CI engine
Basic cycle	Works on Otto cycle	Works on Diesel cycle
Fuel	Gasoline. Self ignition temperature is high	Diesel. Self ignition temperature is low
Introduction of fuel	A gaseous mixture of fuel-air mixture is introduced during suction stroke. A carburetor and ignition system is necessary.	Fuel injected directly to the combustion chamber at high pressure at the end of compression stroke. A fuel pump and injector is necessary.
Ignition	Requires an ignition system with spark plug in the combustion chamber.	Self ignition occurs
Compression ratio	6 to 10	16 to 20
Speed	Due to light weight and homogeneous combustion they are high speed engines	Due to heavy weight and heterogeneous combustion they are low speed engines
Thermal efficiency	low	high

2-stroke petrol engine/2-stroke SI engine

In this cycle, the suction, compression, expansion and exhaust takes place in two stroke of the piston or in one revolution of crank shaft.

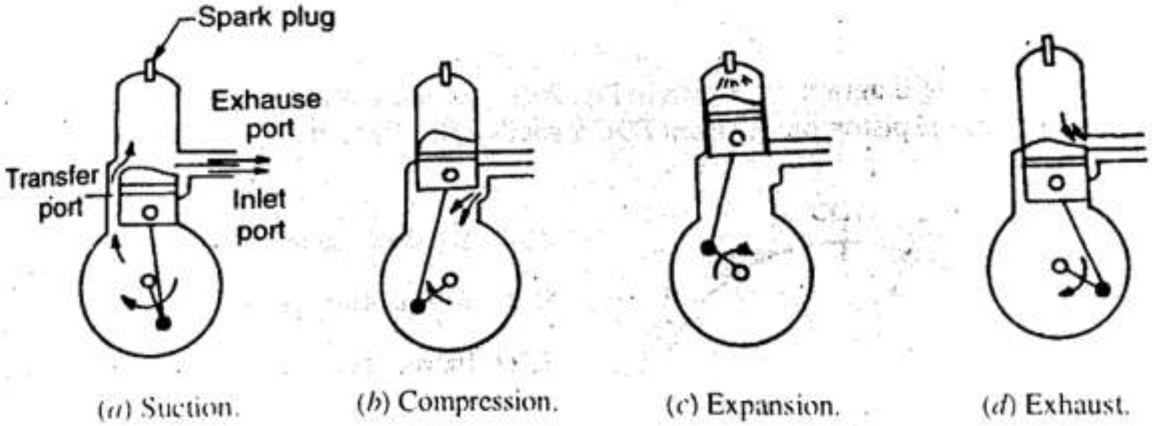


Fig. 26.10. Two-stroke cycle petrol engine.

Suction stroke: when the piston starts going towards BDC, it un covers both the transfer port and the exhaust port. The fresh fuel air mixture enters into the cylinder through the crank case.

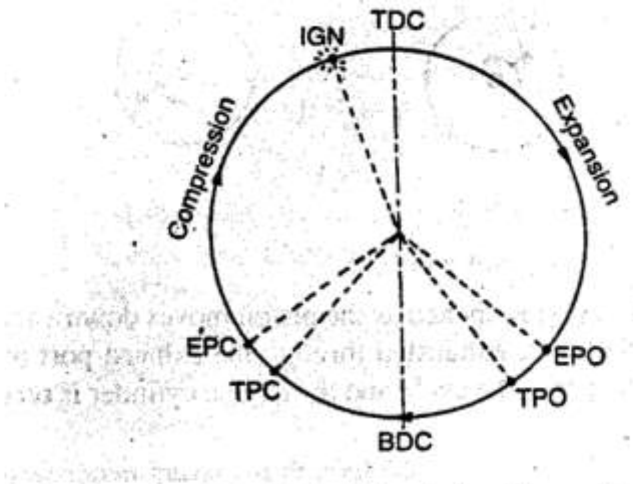
Compression stroke: when the piston starts moving up, it first covers the transfer port and the exhaust port. The fuel is compressed as the piston moves upward. In this stage the inlet port opens and the fresh fuel-air mixture enters into the crank case.

Expansion stroke: during the compression, before the piston reaches the TDC, the charge is ignited with the help of spark plug. It suddenly increases the pressure and temperature of the product and pushes the piston towards the BDC. Here the burnt gases start to expand. During this expansion, the heat energy produced is transferred into the mechanical work.

Exhaust stroke: in this stage, the exhaust port opens as the piston moves downward. The product of combustion started escaping from the cylinder through exhaust port into the atmosphere.

Valve timing diagram for two stroke Spark ignition Engine

After ignition, the expansion of the charge starts when the piston moves from TDC to BDC. The exhaust port opens just a little before the piston reaches to the BDC and burnt gases starts escaping from the cylinder. After a fraction of crank rotation, transfer port also opens before the piston reaches to the BDC and the fresh air-fuel mixture starts entering into the cylinder through the crank case. As the piston moves a little beyond the BDC, the transfer port closes and then the exhaust port closes. The stuck fresh air-fuel mixture in the cylinder is then compressed with both port closed. The ignition of charge occurs with the help of spark plug just before the piston reaches to the TDC. High pressure generated during combustion pushes the piston down ward and expansion takes place. Here, the exhaust port opens and burnt gases start escaping.



TDC : Top dead centre

BDC : Bottom dead centre

EPO : Exhaust port opens (35° - 50° before *BDC*)

TPO : Transfer port opens (30° - 40° before *BDC*)

TPC : Transfer port closes (30° - 40° after *BDC*)

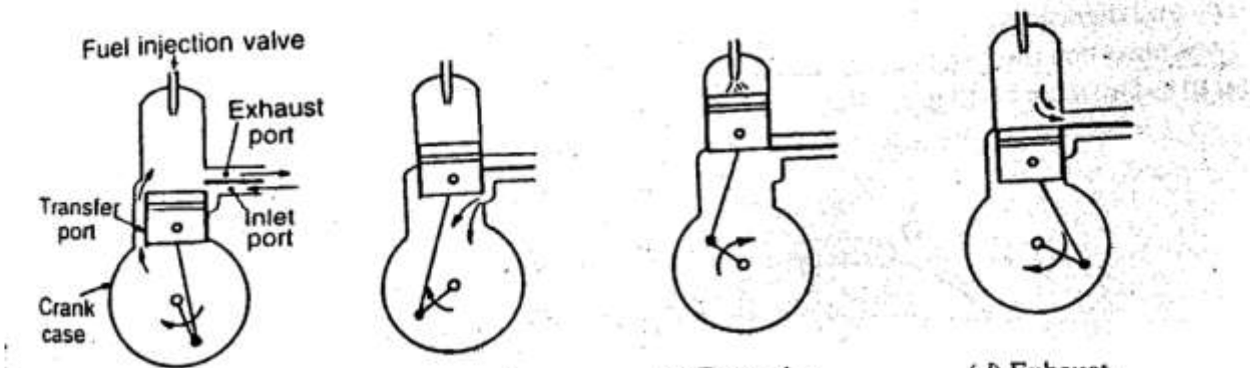
EPC : Exhaust port opens (35° - 50° after *BDC*)

IGN : Ignition (15° - 20° before *TDC*)

Fig. 26.12. Valve timing diagram for a two-stroke cycle petrol engine.

2-stroke Diesel engine/2-stroke CI engine

In CI engine, during suction stroke, air is introduced to the engine chamber instead of air-fuel mixture.



(*a*) Suction. (*b*) Compression. (*c*) Expansion. (*d*) Exhaust.

Fig. 26.13. Two-stroke cycle diesel engine.

Suction stroke: the piston while moving towards BDC, both transfer and exhaust port opens. The fresh air flows into the cylinder through crank case.

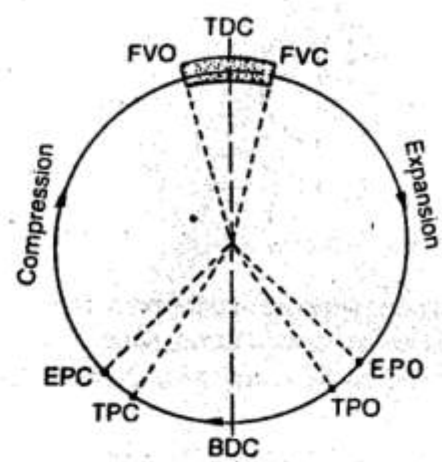
Compression stroke: when the piston starts moving up, it first covers the transfer port and then the exhaust port. The compression of fresh air takes place. In this stage, the fresh air also enters into the crank case as the inlet port opens.

Expansion stroke: before the piston reaches the TDC, the fuel is injected in the form of very fine spray into the cylinder. At this stage the temperature of the compressed air is high enough to starts the ignition of the fuel. The fuel is assumed to be burnt at constant pressure. Due to combustion, the pressure and temperature increases. The increase in pressure at the cylinder pushes the piston towards the BDC and expansion process starts.

Exhaust stroke: the exhaust port opens when the piston starts moving towards BDC. The product of combustion starts escaping from the cylinder through the exhaust port. This completes the cycle.

Valve timing diagram for two stroke Compression ignition Engine

After the ignition, the piston starts moving from TDC toward the BDC due to increase in pressure. The fuel valve closes just a little after the piston starts moving towards BDC. The exhaust port opens just before the piston reaches to the BDC and burnt gases start escaping from the cylinder. After a small fraction of crank rotation, the transfer port opens and the fresh air enters into the cylinder. Now the piston reaches to the BDC and starts moving up. As the crank moves a little beyond the BDC, the transfer port closes and then the exhaust port closes. Fresh air stuck into the cylinder now started to compress with both the port closed. Fuel valve open a little before the piston reaches to the TDC. The fuel is injected in very fine sprays and gets ignited as it is exposed to high temperature compressed air. The fuel valve closes when the piston moves a little beyond the TDC.



TDC : Top dead centre

BDC : Bottom dead centre

FVO : Fuel valve opens (10° - 15° before *TDC*)

FVC : Fuel valve closes (15° - 20° after *TDC*)

EPO : Exhaust port opens (35° - 50° before *BDC*)

TPO : Transfer port opens (30° - 40° before *BDC*)

TPC : Transfer port closes (30° - 40° after *BDC*)

EPC : Exhaust port closes (35° - 50° after *BDC*)

<u>Comparison between 2-stroke AND 4-stroke engine</u>

4-stroke Engine	2-stroke Engine
The cycle is completed in 4-strokes of piston, two revolution of crank shaft. Thus, one power stroke is obtained in two revolution of crank shaft.	The cycle is completed in 2-strokes of piston, one revolution of crank shaft. Thus, one power stroke is obtained in each revolution of crank shaft.
Requires heavier flywheel	Requires lighter flywheel
As one power stroke requires two revolution of crank shaft, power produced is less for same size engine.	As one power stroke is generated for each revolution of crank shaft, power produced is twice for same size engine.
Engine is heavier and bulkier	Lighter and compact engines
Because of the higher weight and complicated valve mechanism, initial cost of engine is high	Because of the light weight and simplicity due to absence of valve mechanism, initial cost of engine is low
High thermal and volumetric efficiency	low thermal and volumetric efficiency
The consumption of lubricating oil is less in four strokes	The consumption of lubricating oil is more in two strokes
The maintenance cost is more.	The maintenance cost is less

Fuel

- A fuel may be defined as a substance which on burning with oxygen in the atmospheric air, produces a large amount of heat. The amount of heat generated is known as calorific value of fuel.

- The characteristic of fuel have effect on the design, efficiency, output, reliability and durability of the engine.

- Classification

1. Solid fuels
2. Liquid fuels
3. Gaseous fuels

1. Solid fuels

- The natural solid fuels are wood, lignite or brown coal, anthracite coal. The prepared solid fuels are wood charcoal, coke, pulverised coal.

- Wood: it consists of mainly carbon and hydrogen. The wood is converted into coal when burnt in the absence of air. It is not used as a commercial fuel except in industries where large amount of waste wood is available. The average calorific value of wood is 19700 KJ/kg

- Peat: it is a spongy humid substance found in boggy land. It may be considered as first stage of formation of coal. It contains water amount more than 75% and therefore it has be dried before use. Its average calorific value is 23000 KJ/Kg

- Lignite: it is considered as the next stage of peat in the coal formation. It contains nearly 40% moisture and 60% carbon. When dried it crumbles and hence does not store well. Its average calorific value is 25000 KJ/Kg

- Bituminous coal: it is considered as next stage of lignite in the coal formation and contains very little moisture (4-6%) and carbon percentage of 75-90%. It is weather resistance and burn with yellow flame. Average calorific value is 33500 KJ/Kg. It is of two types

    - ❖ Caking bituminous coal: it softens and swells on heating. Its pieces adhere together forming a pasty mass which makes firing difficult. It burns with a fairly long flame. It is also known as soft coal. Its average calorific value 35000 KJ/Kg.
    - ❖ Non-caking bituminous coal: it burns with shorter flame than caking coal and gives off a little and no smoke. It is mostly used in steam boilers so known as steam coal. Its calorific value is 33000 KJ/Kg

- Anthracite coal: it represents the final stage in coal formation and contains 90% or more carbon. It is smokeless and has very little flame. Its calorific value is 36000 KJ/Kg. It is mostly used in all type of heat engines.

- Wood charcoal: it is made by heating wood with limited supply of air to a temperature not less than 280 $^\circ$ C. It is a good prepared solid fuel and used for various metallurgical processes.

- Coke: it is produced when coal is strongly heated continuously for 42 to 48 hours in the absence of air in the closed vessel. This is known as carbonisation of coal. It is black in colour, porous and smokeless. It has high carbon content (85-90%) and higher calorific value than coal. When coke is produced by carbonisation at 900 to 1100 $^\circ$ C, is known as hard coke. This is used in blast furnace for extracting pig iron from iron ores. Also used in cupola for producing cast iron. When carbonisation occurs at lower temperature of about 500-700 °C, is known as soft coke. It is used in domestic purposes.

- Pulverised coal: the low grade coal with high ash content is powdered to produce pulverised coal. The coal is first dried and then crushed into fine powders by pulverising machine. It is mostly used in cement industry and metallurgical processes.

- Briquetted coal: it is produced from fined grind coal by moulding under pressure with or without binding material. The binding materials used are pitch, coal tar, crude oil and clay etc.

2. Liquid fuels

- Almost all commercial liquid fuels are derived from natural petroleum (or crude oil). The liquid fuels consist of hydrocarbons.
- The natural petroleum may be separated into petrol or gasoline, paraffin oil or kerosene, fuel oil and lubricating oil by boiling under crude oil at different temperature and subsequent fractional distillation or by cracking process. The soil products like Vaseline and paraffin wax are recovered from residue in the still.
- Distillation carried out in such a way that the liquid with the lowest boiling point is first evaporated and condensed. The liquid with next boiling point is then evaporated and condensed. The process will continue till all the available fluids are separately condensed according to their boiling points.
- Cracking is a process of heating crude oil to a high temperature under very high pressure to increase the yield of lighter distillates particularly petrol. The residue left after cracking is called cracked residue pressure tar and used in road construction.
- **Petrol or gasoline:** it is the lightest and most volatile fuel and used for light petrol engines. It is distilled at a temperature from 65- 220 ° C
- **Kerosene or paraffin oil:** it is heavier and less volatile than petrol. Used as heating and lighting fuel. It is distilled at a temperature from 220 to 345 °C
- **Heavy fuel oils:** the liquid fuels distilled after petrol and kerosene are known as heavy fuel oils. Used in diesel engines and oil fired boilers. It is distilled at a temperature from 345 to 470 ° C

Merits and demerits of liquid fuel over solid fuel

Merits

- Higher calorific value
- Lower storage capacity
- Better economy in handling
- Better control of consumption by using valves
- Free from dust
- No ashes
- Non-deterioration in storage
- Non-corrosive
- Higher efficiency

Demerits

- High cost
- Greater risk of fire
- Costly storage containers are required

3. Gaseous fuels

- Compressed natural gas (CNG): petroleum and natural gases are obtained by the process of drilling wells. Natural gas is a mixture of components consisting of mainly methane with small amount of other hydrocarbons. The natural gas can be compressed and then is called as CNG. It is used to run automobile vehicles.

- Liquid petroleum gas (LPG): propane and butane are obtained from oil and gas wells. For automobile engines two types of LPG are used. One is propane and other is butane. Some times a mixture of propane and butane is used. LPG used as a fuel in place of petrol. They are compressed and cooled to form liquid. The liquid is kept in pressure tanks which are sealed. They are widely used in bus, car, trucks.

- Coal gas: it is known as town gas. It is obtained by carbonisation of coal and consists of mainly hydrogen, carbon monoxide, and various hydrocarbons. The quality of coal gas depends upon the quality of coal used, temperature and carbonisation. It is largely used in towns for streets and domestic lighting and heating. Also used in furnaces for running gas engines. Its calorific value is about 21000 to25000 KJ/m3.

- Producer gas: it is obtained by partial combustion of Coke, coal, anthracite coal or charcoal in a mixed air steam blast. Mostly used in furnaces for glass melting and power generation. Low calorific value of about 5000 to 6000 KJ/m3

- Water gas: it is a mixture of hydrogen and carbon monoxide and is made by passing steam over incandescent coke. Used in furnaces and for welding. As it burns with blue flame, it is also known as blue water gas.

- Mond gas: it is produced by passing air and a large amount steam over waste coal at about 650°C. Calorific value is about 5850 KJ/m3. It is used for power generation and heating. Also suitable for use in gas engines.

- Blast furnace gas: it is a by product in the production of PIG iron in the blast furnace. Used as a fuel in steel work, for power generation in gas engines, for stem rising in boiler etc. Calorific value 3750 KJ/m3.

- Coke oven gas: it is a by product from coke oven and obtained by the carbonisation of bituminous coal. Its calorific value is from 14500 to 18500 KJ/m3. Use for industrial heating and power generation.

Merits and Demerits of gaseous fuel

Merits

- The supply of fuel gas and hence the temperature of furnace is easily and accurately controlled
- The high temperature is obtained at a moderate cost by preheating gas and air with heat of waste gases of combustion
- Directly used in internal combustion engines.
- Free from solid and liquid impurities
- Do not produce ash or smoke
- They undergo complete combustion with minimum air supply

Demerits

- Highly inflammable
- Requires large storage capacity

Octane number and cetane number

The rating of fuel is done by defining two parameters such as octane number and cetane number. Octane number is a value used to rate the fuel’s resistance to knocking. Cetane number is a measurement of the ignition properties of a fuel. The main difference between octane number and cetane number is that octane number gives an idea about the performance of a fuel whereas cetane number gives an idea about the ignition of a fuel.

Knocking occurs when fuel burns unevenly in engine's cylinders. When cylinders have the correct balance of air and fuel, fuel will burn in small, regulated pockets instead of all at once. After each pocket burns, it creates a little shock, igniting the next pocket and continuing the cycle. Engine knocking happens when fuel burns unevenly and those shocks go off at the wrong time. This results an annoying noise and potential damage to the engine's cylinder walls and pistons.

Octane number

Octane number is a measure of the performance of a fuel. It is also called the antiknock rate of fuel. When fuel is used in an engine, the engine will generate a knocking effect. In other words, the fuel can cause the engine to undergo knocking when burnt.

The octane number is given for a certain fuel based on the relative knocking. This knocking effect is rated based on the knocking of the fuel iso-octane. Isooctane has a minimal knocking effect. Therefore, the octane number of isooctane is considered as 100. In contrast, the octane number of heptane is considered as 0. This is because heptane causes the maximum knocking when used in an engine.

The octane number is equal to the percentage of the volume of isooctane present in the fuel. For example, octane 92 is the fuel that is composed of 92% of isooctane along with 8% of heptane. Therefore, if the octane number is high, it is a good fuel to be used in an engine.

Octane number is given for gasoline/ SI engine fuels.

Cetane Number

Cetane number is the measure of the delay of the ignition of a fuel. It is measured for diesel. A higher cetane number indicates a shorter ignition delay time, which means, it ignites quickly. A lower cetane number indicates a longer ignition delay time; this means, it ignites slowly. This delay time is the time taken by the diesel for its combustion. Cetane is a colorless liquid. It is a hydrocarbon. It ignites easily under the compression. Therefore, it is given the cetane number 100.

Cetane number is given for diesel/ CI engine fuels.

Problem on air cycle

Q1 The cylinder dimensions of an engine working on Diesel cycle are 300 mm x 200mm. Clearance volume is 800000mm³. Find supply cut off at 5% of the stroke. Determine the air standard efficiency of the cycle.

Ans: $L = 300\,mm = 0.3\,m$

$D = 200\,mm = 0.2\,m$

$V_c = 800000\,mm^3 = 0.8 \times 10^{-3}\,m^3$

Cut off = 5% of stroke

$= 0.05 \times V_s$ → stroke volume

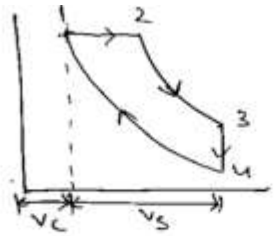
Swept volume / stroke volume $= V_S = \frac{\pi}{4} D^2 L$

$= \frac{\pi}{4} \times (0.2)^2 \times 0.3$

$= 9.42 \times 10^{-3}\,m^3$

1 → 2

Compression ratio,



$$r = \frac{V_4}{V_1}$$

$$= \frac{V_s + V_c}{V_c}$$

$$= \frac{9.42 \times 10^{-3} + 0.8 \times 10^{-3}}{0.8 \times 10^{-3}}$$

$$= 12.77$$

Cut off ratio $= \rho = \frac{V_2}{V_1}$

volume at cut off point, $V_2 = V_1 + 0.05 V_s$

$$= V_c + 0.05 V_s$$

$$V_2 = 0.8 \times 10^{-3} + 0.05 (9.42 \times 10^{-3})$$

$$= 1.271 \times 10^{-3} \ m^3$$

$$\rho = \frac{V_2}{V_1}$$

$$= \frac{1.271 \times 10^{-3}}{0.8 \times 10^{-3}} = 1.59$$

Efficiency of diesel cycle

$$\eta = 1 - \frac{1}{\gamma (r)^{\gamma-1}} \left[\frac{\rho^{\gamma} - 1}{\rho - 1} \right] \qquad [\because \gamma = 1.4]$$

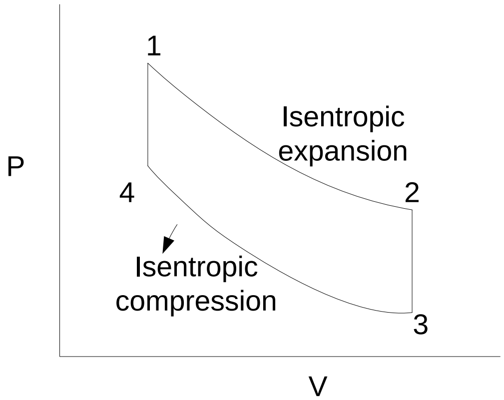
$$= 1 - \frac{1}{1.4 (12.77)^{1.4-1}} \left[\frac{(1.59)^{1.4} - 1}{1.59 - 1} \right]$$

$$= 0.6$$

$$= 60\%$$

Q2. In an Otto cycle, the temperatures at the beginning and end of the isentropic compression are 316K and 596K respectively. Determine the air standard efficiency and the compression ratio. Take γ=1.4

Given T3 =316K and T4 =596 K



r= compression ratio =V3/V4

$$\frac{T3}{T4} = \left(\frac{V4}{V3}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{1.4-1}$$

$r^{0.4} = \frac{T4}{T3} = \frac{596}{316}$ =1.88

$r = (1.88)^{\frac{1}{0.4}} = 4.885$ (ans)

Air standard efficiency

$\eta = 1 - \frac{1}{r^{\gamma-1}}$ for Otto cycle

= $1 - \frac{1}{4.885^{1.4-1}}$

=1- 0.53

=0.47

=47% (ans)