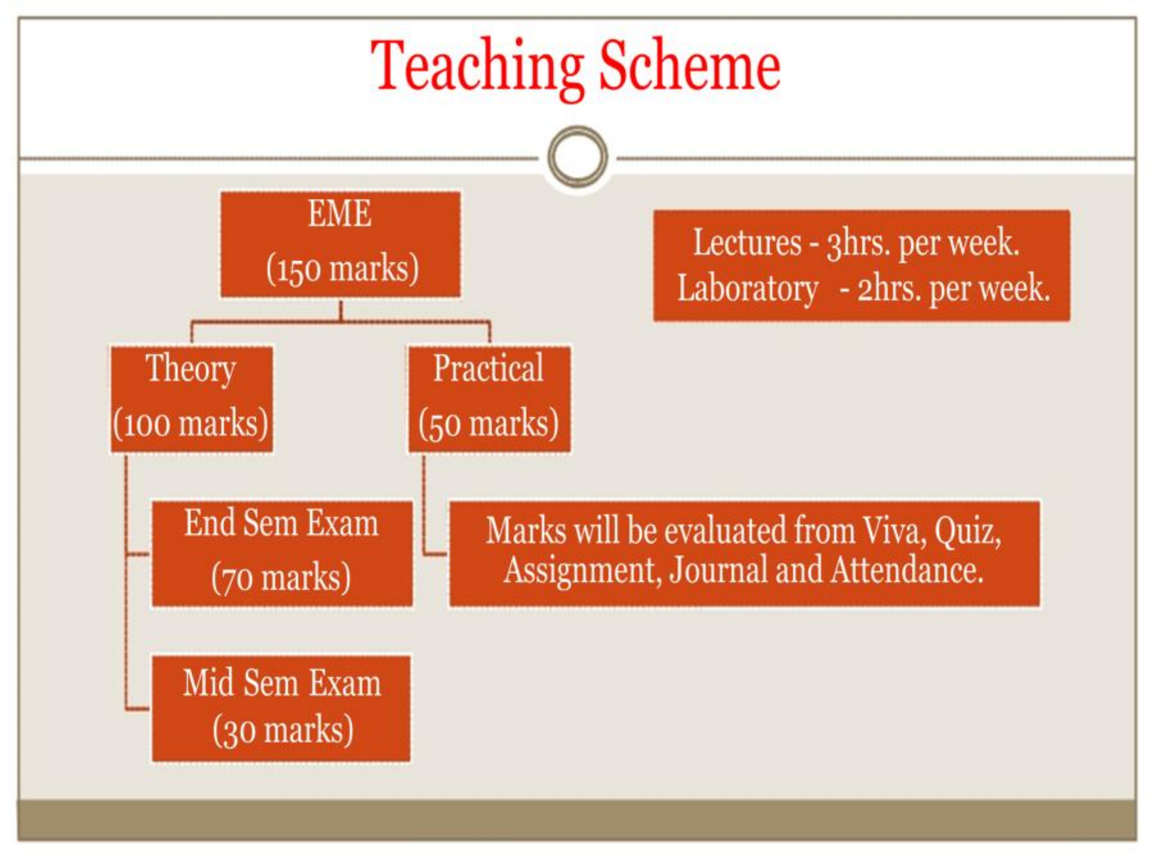

Teaching Scheme
EME
(150 marks)
Lectures - 3hrs. per week.
Laboratory - 2hrs. per week.
Theory
(100 marks)
Practical
(50 marks)
End Sem Exam
(70 marks)
Marks will be evaluated from Viva, Quiz, Assignment, Journal and Attendance.
Mid Sem Exam
(30 marks)

Chapter 1 Introduction

1.1Prime movers

"Prime mover is a device which uses natural sources to convert their energy into mechanical energy or useful work (shaft power)".

1.2 Sources of energy

Prime movers are using various natural sources of energy like fuel, flow of river water, atom, biomass, wind etc.

(i) Fuel: When fuel is burnt, heat energy is liberated. Amount of heat liberated by burning of fuel depends upon calorific value of that fuel. By using heat engine, the heat energy is converted into mechanical energy (shaft power). Fuel is the most widely used source of energy.

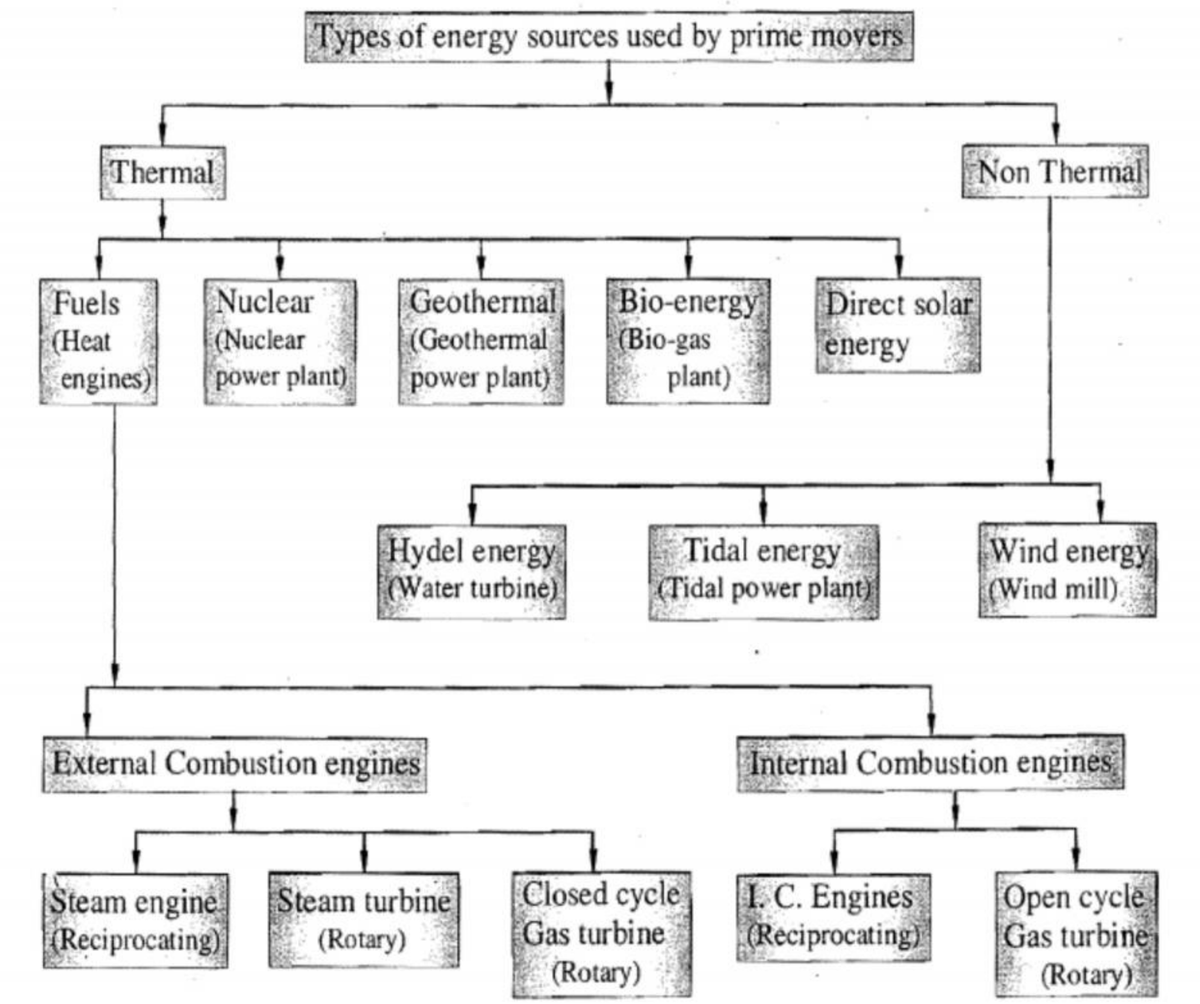
(ii) Flow of river water: This is another useful source of energy. Water stored at high elevation contains potential energy. When water starts flowing, potential energy gets converted to kinetic energy. Hydraulic turbine is a prime mover which converts kinetic energy of flowing water into mechanical energy.

(iii) Atoms (Nuclear Energy): Nuclear energy or atomic energy is recent development. Heat energy produced by the fission or fusion of atoms may be used to produce shaft power by heat engines.

(iv)Nonconventional Energy Sources: these energy resources replenish themselves naturally in a relatively short time and therefore will always be available. The examples of these resources are solar energy, wind energy, tidal energy, bio energy, solid wastes etc. Almost all nonconventional energy resources offer pollution free environment and also help in maintaining the ecological balance.

1.3 Types of prime movers

The prime mover can be classified according to the sources of energy utilized.



1.4 Force and mass

(i) Force: Force is the product of mass and acceleration of the body upon which it is applied.

As per Newton's second law of motion

Force α acceleration

$$F = m \times a \qquad \text{... (1.1)}$$

where, m is (constant) mass of body in kg.

In SI unit (International system), unit of mass is kg and unit of acceleration is m/s^2.

• **Weight:** Weight is force exerted by gravity

Weight = Mass x Gravitational acceleration

$$w = m \times g$$

Weight of body is dependent upon gravitational force, so it is not constant.

(ii) Mass: Mass is the quantity of matter and it is constant. It does not depend upon gravitational force.The fundamental unit of mass is the Kilogram (kg). It is the mass of the platinum iridium lump kept at severs, France.

1.5 Pressure

Pressure is the property of fluid and it is defined as force per unit area.

Pressure = Force/Area or P = F/a N/m^2

•The unit of pressure is N/m^2, N/m^2 is known as Pascal (Pa)

1 Pa = 1 N/m^2 ... (1.2)

• Pressure gauges, Manometers etc are used to measure gauge pressure and Barometer is used to measure atmospheric pressure. Atmospheric pressure is the pressure exerted by atmosphere. It varies with location on earth. Standard atmospheric pressure is a pressure of atmospheric air at mean sea level. It is defined as the pressure developed by a mercury column of 760 mm. If we take density of mercury equal to 13595.09 kg/m3 and gravitational acceleration equals to 9.80665 mls2

• Standard atmospheric pressure will be

$P = pxgxh$ = 13595.09x9.80665xO.760 N/m^2

= 1.01325 $x10^5$ N/m^2. Or Pa

• Absolute pressure is measured with reference to absolute zero pressure. It is the pressure related to perfect vacuum.

Mathematically, Absolute pressure = Atmospheric pressure + Gauge pressure

• Vacuum is defined as the pressure below atmospheric pressure. A perfect vacuum is obtained when absolute pressure is zero; at this instant molecular momentum is zero.

The relation between different pressures is given in Fig. 1.1.

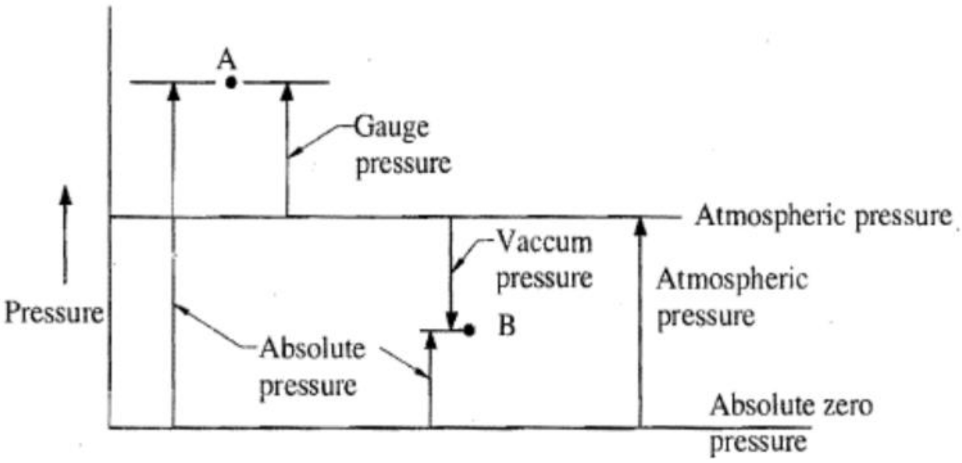


Fig. 1.1. *Relation between different pressures*

1.6 Work

Work is said to be done when a force moves through a distance. If a part of the boundary of a system undergoes a displacement under the action of a pressure, the work done W is the product of the force (Pressure x area) and the distance it moves in the direction of the force. Hence, Work = Force x Distance moved into direction of force.

• If the work is done by the system on surrounding, e.g. when a fluid expands pushing a piston outwards, the work is said to be positive.

Work output of the system = + W

• If the work is done on the system by surrounding e.g. when a force is applied to a piston to compress a fluid, the work is said to be negative.

Work output of the system =- W

• Unit of work (W) = Unit of force x Unit of displacement

= $\mathrm{N} \times \mathrm{m}$ or joule

1.7 Power

Power is defined as the rate of doing work OR the power is work done per unit time,

Mathematically

Power = Work done/ Time and Joule/second ... (1.3)

In SI unit Joule/second is called Watt (W)

Watt is very small unit, so recommended larger units are

(MW), etc.Kilowatt (kW), Megawatt

• *The power available at the engine shaft is called Brake power* (B.P.) and *the power developed by the engine is called Indicated power* (LP.).

1.8 Energy

"Energy", a word derived from the Greek word "Energia", means capacity for doing work.

• The unit of energy is the unit of work i.e. Joule.

Another important unit of energy is Kilowatt hour (kWh) which is derived from the unit of power kilowatt.

• Forms of energy:-

The different forms of energy are;

(1) Mechanical energy (2) Thermal or heat energy

(3) Chemical energy (4) Electrical energy

(5) Nuclear energy

It is possible to convert one form of energy into another form of energy. Heat engine is a device which converts heat energy into mechanical energy.

Energy can neither be created nor be destroyed but the total amount of energy remains constant before and after the transformation. This is called the *law of conservation of energy.*

. • High and Low Grade energy

The second law of thermodynamics prohibits the complete conversion of heat into work. Sources of energy may be divided into two groups viz.

(a) High grade energy: Energy that can be completely converted (neglecting loss) into the work.

Examples: Mechanical work, Electrical energy, Water power, Wind and tidal power, Kinetic energy of jet.

(b) Low Grade energy: Only a certain portion of energy that can be converted into mechanical work (shaft power), that energy is called low grade energy.

Examples: Thermal or heat energy, Heat derived from combustion of fuels, Heat of nuclear fission.

Types of energy:

Energy may be classified as

(1) Stored energy

(2) Energy in transition

The stored energy of a substance may be in the form of mechanical energy, internal energy, nuclear energy etc.

Energy in transition is the energy transferred as a result of potential difference.

This energy may be in the forms of heat energy, work energetic.

• Types of Mechanical Energy:

There are two types of mechanical energy

(a) Potential energy (b) Kinetic energy

(a) Potential energy: The energy which a body possesses by virtue of its elevation or position is known as its potential energy.

Example: Water stored at higher level in a dam

Potential energy, $\mathrm{P.E.} = \mathrm{w} \, . \, \mathrm{h}$

$$\mathrm{P.E.} = \mathrm{m} \times \mathrm{g} \times \mathrm{h} \qquad \text{... (1.4)}$$

Where w=weight of body in N, h=Height in meter, m=mass of body in kg, g=Gravitational acceleration = 9.81 m/s2.

(b) Kinetic Energy: The energy which a body possesses by virtue of its motion is known as its kinetic energy.

Example: Jet of water coming out from nozzle.1

Kinetic Energy $\mathrm{K.E} = \frac{1}{2}\,\mathrm{mv}^2$ N.m

Where m = mass of body in kg, v = velocity of body in m/s.

1.9 Heat

When two bodies at different temperatures are brought into contact there are observable changes in some of their properties and changes continue till the two don't attain the same temperature if contact is maintained. Thus, there is some kind of energy interaction at the boundary which causes change in temperatures. This form of energy interaction is called heat.

• Definition of Heat:

Heat may be defined as the energy interaction at the system boundary which occurs due to temperature difference only. '

When heat is removed from a body or supplied to it, there are some changes found to happen such as (a) change of temperature, (b) change of volume, (c) change of state (solid to liquid, liquid to gas, etc.), (d) change of physical properties, etc.

• **Positive and negative heat**

In general, the heat transferred to the system is considered as *positive heat* while the heat transferred from the system is considered as *negative heat.*

Mass of the substance, specific heat, and temperature difference are the factors on which the heat transfer rate depends.

• **Comparison of work and Heat**

Similarities:

(a) Both are path functions

(b) Both are boundary phenomenon

(c) Both are associated with a process, not a state

(d) Systems possess energy, but not work or heat

Dissimilarities:

(a) In heat transfer, temperature difference is required.

(b) In a stable system there cannot be work transfer, however, there is no restriction for the transfer of heat.

(c) Heat is low grade energy while work is high grade energy.

1.10 Temperature

One is well familiar with the qualitative statement of the state of a system such as cold, hot, too cold, too hot etc. based on the day to day experience. The degree of hotness or coldness is relative to the state of observer. The temperature of a body is proportional to the stored molecular energy i.e. the average molecular kinetic energy of the molecules in a system.

• Definition: Qualitative indication of the relative hotness can be exactly defined by using thermodynamic property known as temperature.

• Unit of temperature

In the International system (SI) of unit, the unit of thermodynamic temperature is

Kelvin. It is denoted by the symbol K. However, for practical purposes the Celsius scale is used for measuring temperature. It is denoted by degree Celsius (OC)

• Absolute zero temperature:

It has been found that a gas will not occupy any volume at a certain temperature. This temperature is known as absolute zero temperature. This is the lowest temperature that can be measured by a gas thermometer.

• Temperature Scale:

A look at the history shows that for quantitative estimation of temperature a German instrument maker Mr. Gabriel Daniel Fahrenheit (1686-1736) came up with idea of instrument like thermometer and developed mercury in glass thermometer. In the year 1742, a Swedish astronomer Mr. Anders Celsius described a scale for temperature measurement. This scale Later on became very popular and is known as Centigrade Scale or Celsius scale. Some standard reference points used for international practical Temperature Scale are given in Table 1.1.

Table 1.1

Sr No.	State	Temperature °C	K
1	Ice Point	0	273.15
2	Steam Point	100	373.15
3	Triple point of water	0.010	273.16
4	Absolute zero	–273.15	0

1.11 Units of Heat

Heat is a form of energy. In SI system, unit of heat is taken as joule. Kilojoules (kJ) and Mega joule (MJ) are recommended larger units of heat.

Calorie (cal.) is also unit of heat. Generally Kilocalorie (kcal) is quantity of heat required to raise temperature of unit mass of water through one degree Celsius or Kelvin.

1 kcal = 4186.8 joules = 4.1868 kilojoules

1.12 Specific heat capacity

Specific heat capacity is also known as specific heat. The specific heat capacity of a substance may be defined as the quantity of heat required to raise the temperature of unit mass of the substance by one degree.

The unit of specific heat is J/kg °c. This unit is small, so kJ/kg-K or kJ/kg °c is recommended larger units.

Mathematically, the heat transfer rate Q is written as

$$Q = m \times c \times \Delta T$$

Where, C = specific heat in kJ/kg.K, m = mass of substance in kg,

ΔT Temperature difference in K.

The product of mass and specific heat is called the heat capacity of the substance.

• Specific heat is function of temperature; hence it is not constant but varies with temperature. Generally it is assumed that it is constant.

• Specific heats in thermodynamics:

The solids and liquids have only one value of specific heat but a gas is considered to have two distinct values of specific heat capacity.

(i) A value when the gas is heated at constant volume, Cv

(ii) A value when the gas is heated at constant pressure Cp

The specific heat at constant volume Cv may be defined as the heat required to increase the temperature of the unit mass of a substance by one degree as the volume is maintained constant.

Same way one can define the specific heat at constant pressure (Cp), here pressure is p maintained constant.

1.16 Internal Energy

In non flow processes, fluid does not flow and has no kinetic energy. There is very small amount of change in potential energy because change in centre of gravity is negligible. From the first law of thermodynamics, we can say that the amount of heat transferred to a body is not fully converted t_p work. When heat (Q) is supplied to a body, some amount of heat is converted into external work (W) due to expansion of fluid volume and remaining amount of heat causes either to increase its temperature or to change its state. Internal Energy is one type of energy which is neither heat nor work; hence it is stored form of energy. It is denoted by U.

Mathematically,

$Q = W + U$ ... (1.6)

Where Q is amount of heat, W is work and *U* is internal energy.

The internal energy per unit mass is called specific internal energy. The eq. (1.6) is referred as non flow energy equation. In other words, for non flow process

$$\begin{Bmatrix}\text{Heat transferred through} \\ \text{system boundary}\end{Bmatrix} = \begin{Bmatrix}\text{Work transferred through} \\ \text{the system boundary}\end{Bmatrix} + \begin{Bmatrix}\text{Change in} \\ \text{Internal energy}\end{Bmatrix}$$

1.17 Enthalpy

Enthalpy is a thermodynamic property of fluid, denoted by H. *It can be defined as the summation of internal energy and flow energy.* Enthalpy of a substance at any point is qualification of energy content in it.

Mathematically, it is given as

$$H = \underbrace{U}_{\text{Internal energy}} + \underbrace{pV}_{\text{Flow energy}}$$

On unit mass basis, the specific enthalpy could be given as

$h = u + pv$ ... (1.7)

A look at expression of enthalpy shows that as we cannot have absolute value of internal energy, the absolute value of enthalpy cannot be obtained. Therefore only change in enthalpy of substance is considered.

1.19 Efficiency

It is observed that amount of energy supplied to engine or machine is not completely converted into work because some amount of energy is lost due to friction and several other reasons. So a fraction of the energy supplied to engine is converted into useful work. This fraction is called efficiency of the engine.

Hence,

$$\text{Efficiency} = \frac{\text{Energy output from engine}}{\text{Energy input to engine}}$$

(a) Brake Power of an engine (B.P.): Brake power of an engine is the power available at engine output shaft. It is measured by dynamometer.

(b) Indicated Power (I.P.): Indicated power is power developed inside engine cylinder by burning of fuel.

(c) Friction Power (RP.): Friction power is given by

F.P. = LP. - B.P.

• Mechanical efficiency *(n_m):*

Mechanical efficiency is indicator of frictional losses.

$$\eta_m = \frac{B.P}{I.P}$$

The range of n_m is 80 to 85% for I.e. engine

. Thermal efficiency *(η_{th}):*

Thermal efficiency is ratio of output of engine to energy supplied by fuel.

$$\eta_{th} = \frac{Output\ of\ engine}{Heat\ inputfrom\ the\ fuel}$$

1.20 Zeroth Law of Thermodynamics

Zeroth law of thermodynamics states that "the *bodies A and B are in thermal equilibrium with a third body* C *separately then the two bodies A and B shall also be in thermal equilibrium with each other".*

This is the principle of temperature measurement. Block diagram shown in Fig. 1.6 shows the zeroth law of thermodynamics.

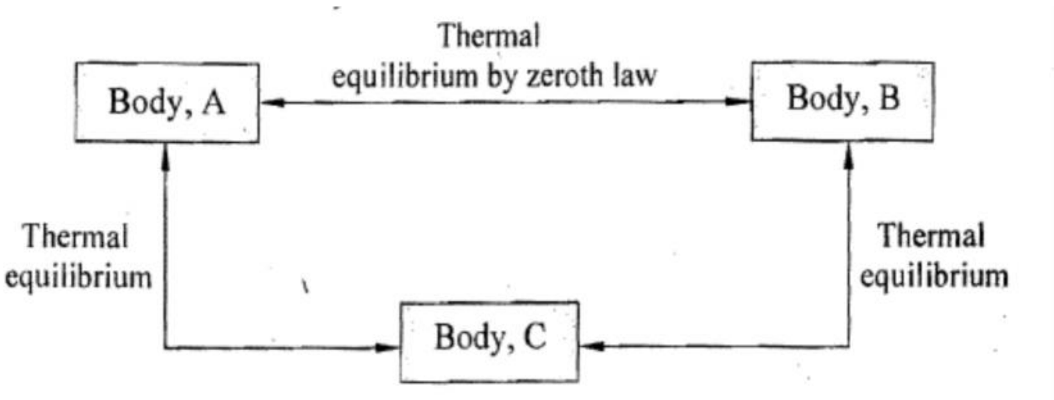


Fig. 1.6 *Zeroth law of thermodynamics.*

1.21 First law of thermodynamics

Let us take water in a container and heat it from the bottom. What will happen? Container and the water inside will get heated up. This heating can be sensed by either touching it or by measuring its initial and final temperatures. What has caused it to happen so?

Answer for the above question lies in the energy interactions.

First law of thermodynamics provides for studying the relationships between the various forms of energy and energy interactions.

This law states that energy can neither be created nor destroyed; it can be converted from one form to another form.

First law may be expressed as,

$$\text{changein total energy} = \text{net energy transfered as heat and work}$$

$$\Delta E = Q - W \quad \text{... (1.13)}$$

Where ΔE is summation of various energies like Internal energy (ΔU), Kinetic energy (ΔKE), Potential energy (ΔPE) etc.

$$\Delta E = Q - W = \Delta U + \Delta KE + \Delta PE \ldots.$$

In closed system, mass is fixed and there is no elevation difference and movement. Hence ΔKE = 0 and ΔPE = 0 $\quad \Delta U = Q - W$

For cyclic process ΔE = 0

Hence first law for a cyclic process is $Q - W = 0$

1.23 Thermodynamic systems

A Thermodynamic system is defined as a quantity of matter or region in space under consideration for analysis.

Examples: piston cylinder assembly, turbine etc.

The system is identified by a boundary around the system. The boundary may be real or imaginary. Everything outside the system boundary is called surroundings. A system and its surroundings together are called the universe.

Universe = system + surroundings

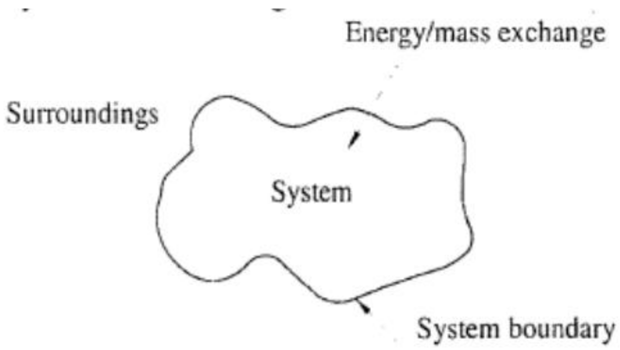


Fig. 1.7 Thermodynamic system

• Types of system: The systems may be classified as

1. Open system 2. Closed system 3. Isolated system

1. Open system: Open system in which energy and mass transfers take place at the system boundary. Examples: Turbine, I.C. engines etc.

In Fig. 1.8 an open system is shown consisting of a turbine.

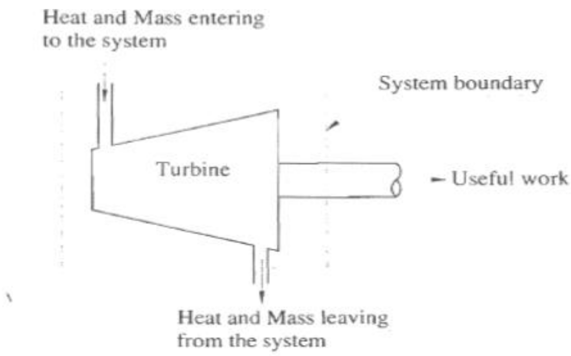


Fig. 1.8 Open system

2 close system

Closed System: A system in which no mass is permitted to cross the system boundary but heat and work is permitted to enter or leave, is called the closed system.

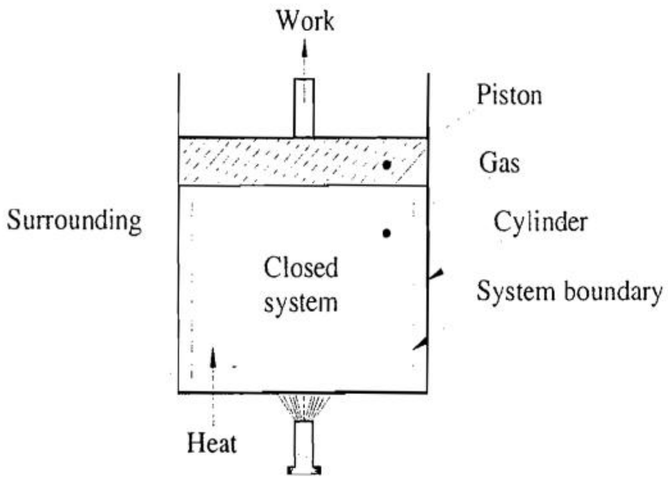


Fig. 1.9 closed system

3 Isolated Systems:

A system, which is not influenced by the surrounding means there is no interaction between system and surrounding, is called isolated system.

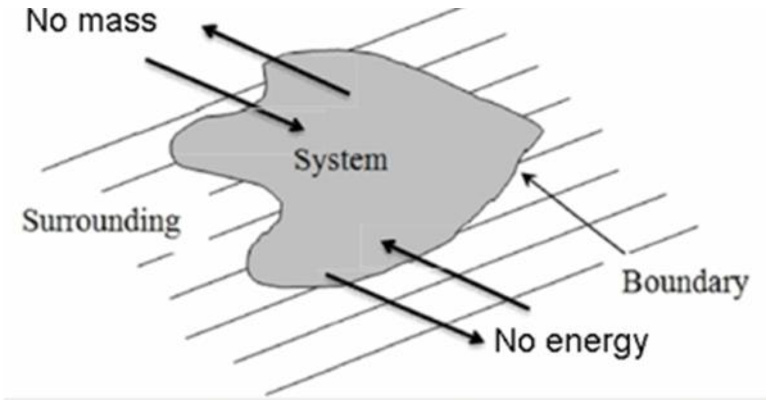


Fig. 1.10 Isolated systems

1.24 Thermodynamic properties

- Properties are any measurable characteristics of a system. eg. Pressure, temperature, volume, mass and density.
- **Extensive properties** are the mass-dependent properties of a system. i.e. the properties that will vary proportionally with mass of the system. E.g. volume
- **Intensive properties** are the properties that are not dependent on mass. Eg. Temperature, density. If any Extensive Property is divided by the mass we would also obtain an intensive property.

- **Properties**:-systems have certain characteristics by which its physical condition can be described such as pressure, temperature, etc. these are called properties.
- all system properties having definite values, the system is said to be in definite state. any operation in which one or more properties change is called change of state.
- **Path**:-succession of states passed through change of state is called path
- **Process**:-if path is completely specified it is called process
- **Cycle**:-a series of change of state such that final state is same as initial state it is called cycle

2. ENERGY

2.1 Sources of energy

The sources and forms of energy can be classified as Non-Renewable Energy and Renewable Energy. Non-renewable energy is obtained from conventional fossil fuels (coal, oil, gas etc.). These have been in use for several decades. The sources of non-renewable energy are reducing at a fast rate and may not be sufficient to meet the increasing energy demand in future. Therefore, these sources are also called exhaustible source of energy.

Renewable energy is obtained from sources that are not exhaustible. These energy resources which replenish themselves naturally in a relatively short time and thus will always be freely available in nature. They can be continuously used. These energy sources are also called non-conventional energy sources because the mankind has started the use recently. Renewable resources include solar power, wind power, geothermal energy, tidal power, hydraulic energy, and ocean thermal energy, energy from biomass, fuel cells, and hydrogen energy. Almost all non-conventional energy resources offer pollution free environment and also help in maintaining the ecological balance.

The various sources of energy can be listed as follows:

(1) Fossil Fuels

(2) Nuclear Fuels (Nuclear Energy)

(3) Stored or flowing water (Hydel Energy)

(4) Sun (Solar Energy)

(5) Wind (Wind Energy)

(6) Rise and fall of tides (Tidal Energy)

(7) Geothermal Energy

(8) Biomass and bio-fuels

2.2 Energy from fossil fuel

Fuel is defined as "a substance composed mainly of carbon and hydrogen which produces a large amount of heat while burning with oxygen. “The main combustible elements of each fuel are carbon, hydrogen, compounds of hydrocarbons and small amount of other substances, such as sulphur, oxygen, nitrogen etc. The combustion of fuel is one of the most important sources of energy utilized for driving prime movers. The combustion of fuel is the process of chemical combination of carbon, hydrogen and sulphur with oxygen which comes from air. When the fuel is burnt in presence of O_2 (air), it produces heat and flue gases. This heat is utilized for heating purpose or for produce mechanical energy with help of prime movers (steam turbine, gas turbine, internal combustion engine etc.).

Classification of fuel

Fuel can be classified as under

(1) According to nature of their existence

(i) Solid

(a) Natural (primary fuel): Wood, Peat, Lignite coal, Bituminous cool, Anthracite coal

(b) Artificial (secondary fuel) : Coke, Charcoal, Briquettes coal, Pulverized coal.

(ii)Liquid

(a) Natural: Petroleum

(b)Artificial: Gasoline (petrol), Diesel, Light Diesel oil, Kerosene, Heavy fuel oil, Alcohol, Tar, Benzoyl, Shale oil

(iii)Gaseous

(a) Natural: Natural gas, Liquefied Natural Gas (LNG)

(b) Artificial : Petroleum gas, Producer gas, Coal gas, Coke-over gas, Blast furnace gas, LPG, CNG, Sewer gas, Water gas

(2) According to nature of their origin

(i) Natural fuels: They occur in nature. They are also known as primary fuels.

(ii)Artificial fuels: They are prepared by further processing of primary fuels. They are

also known as secondary fuels.

2.2.1 Solid fuels

(A) Natural (primary) solid fuels

(1) Wood: It is natural fuel and most commonly used as a domestic fuel. In some cases it is used as industrial fuel for boiler furnace. The disadvantages of using wood as a fuel are its large moisture content and lower gross calorific value (about 16000 kJ/kg). It is ignited easily and so it is mostly used for igniting other fuels.

(2) Peat: It is first stage in the formation of coal from wood. It is a naturally occurring solid fuel consisting of a partly decomposed plant material below ground. It contains huge amount of moisture (90% water) and therefore it is required to make it dry which takes about 1 to 2 months before it is used. All other varieties of coal are derived from peat. The gross calorific value of peat is about 16000 kJ/kg.

(3) Coal: Coal is a fossil fuel laid down from moist vegetable matter and compacted under pressure and temperature within the surface of earth. Coal passes through different stages during its formation from vegetation.

(a) Lignite: These are intermediate stages between peat and good quality coal. They have brown color, high moisture content, low calorific value, bad weathering properties. Lignite can be used in generation of electricity in thermal power station. There are large deposits of lignite in India. It burns with large smoky flame. The gross calorific value of lignite coal is about 25000 kJ/kg.

(b) Bituminous coal: It is next stage in coal development. It is shining black in appearance. It is easier to ignite. It burns with long yellow and smoky flame. The calorific value of bituminous coal is about 33,000 kJ/kg. In India, this coal reserves are located in Bihar, Bengal, M.P. and Orissa. It has good heating qualities. It is a main fuel for industrial furnaces, boilers, and thermal power plants. It is also useful to produce artificial solid fuels like coke, liquid fuels like coal-tar or gaseous fuels like producer gas, coal gas etc.

(c) Anthracite coal: It is very hard coal and has shining black luster. It has higher calorific value, lower volatile matter, and higher carbon content. It is very suitable fuel for thermal power plant. The calorific value of anthracite coal is 36,000 kJ/kg. But it ignites slowly. In India, reserves of this coal are found in Kashmir and Eastern Himalayas.

(B) Artificial or Prepared solid fuels:

(l) Wood Charcoal: It is produced from wood by Carbonization process. Charcoal can be produced from the incomplete burning of wood with insufficient air. Wood charcoal is a source of pure carbon. It easily ignites and burns at low rates. It is extensively used as a fuel in blacksmiths, metal work, and for cottage industries.

(2) Coke: Coke is produced by reducing volatile matter of bituminous coal. It is hard, brittle and porous. It consists of carbon, mineral matter with 2% sulphur and small quantities of hydrogen, nitrogen and phosphorus. It is smokeless and clear fuel. Normally it is not used as a fuel, but it is used to produce coal gas, producer gas, blast furnace gas by different processes.

(3) Briquetted coal: It is produced from finely ground coal mixed with suitable binder and pressed together to form blocks or briquettes. The briquettes can be of any shape. By this method, it is possible to increase heating value of low quality coal.

(4) Pulverized coal: When coal is crushed and produced in powder form it is called pulverized coal. Fine powder coal gets mixed with air rapidly so combustion rate increases. Hence combustion efficiency of boiler with pulverized coal is very high.

2.2.2 Liquid Fuels

The liquid fuels are hydrocarbons and can be classified as

(1)Natural fuel - Petroleum (crude oil)

(2) Artificial prepared fuel - Petrol, Diesel, Kerosene, Light Diesel oil, Heavy fuel oil' Tar 'Alcohols, Shale oil.

Liquid fuel commonly used in internal combustion engines and oil fired boilers'

Petroleum (crude oil): Petroleum fuels are commonly found under the earth's surface by drilling wells in the earth's crust. The crude oil or petroleum as it comes from the wells cannot use in its raw state. It is required to remove dirt, water and other impurities associated with it. After cleaning, it is distilled for separation into its broad and basic groups of components. The following fuels in oil form of different grade are products of fractional distillation of petroleum.

(i)Petrol (ii) Kerosene (iii) Diesel oil

(i) Petrol: It is the lightest and most volatile fuel. It is mainly used for light petrol engine. Petrol comes outat650to 72OoCby distillation of crude oil. It is also known as gasoline. The Calorific value of petrol is about 4480A-46900 kJ/kg.

(ii) Kerosene: Kerosene distills at220o to 3450 C. It is heavier and less volatile than petrol. The calorific value of kerosene is about 47000 kJ/kg. It is used for heating and lighting purposes. It is also known as paraffin oil.

(iii) Diesel oil: It is distilled after petrol and kerosene. Suitable diesel oil may be obtained by straight distillation, by cracking or by blending of several oils. The calorific value of diesel is about 46000 kJ/kg. These fuel are used in diesel engines. They are distilled at temperature from 3450 to4700 C. But modern high speed engine requires more special and light fuel oil. It is known as Light Diesel Oil (LDO).

Tar: It is an important by product obtained during manufacturing of coal gas. When it is redistilled, important fuel like benzene is produced.

Alcohol: It is formed by fermentation of vegetable matter. It is an artificial liquid fuel The cost of alcohol is higher than petrol. The energy content of alcohol is lower than petrol.

The advantages and disadvantages of liquid fuels compared to solid fuel :

Advantages:

(1) It is easy to store and requires less space for storage.

(2) Higher calorific value.

(3) Easy to control the combustion.

(4) Easy handling and transportation.

(5) Cleanliness.

(6) No ash problem.

(7) Ease of ignition and stopping off the operation.

(8) Changes in load in a power plant can be met easily.

Disadvantages:

(1) Cost of fuel is higher than other fuels.

(2) Greater risk of fire.

(3) Special container required for storage and transport.

2.2.3 Gaseous fuel

There are mainly two types of gaseous fuel (i) Natural gas and (ii) Prepared gases (like coal gas, coke oven gas, producer gas water gas, sewer gas, Blast furnace gas, bio-gas, LPG, CNG.

(1) Natural gas: It consists of mainly methane and with small quantities of ethane, propane and hydrocarbons. It is found in upper part of petroleum field, under the earth's surface. It is used for domestic and. industrial heating. The calorific value of the natural gas is 37000 to 46000 kJ/m^3 at standard condition.

(2) Coal gas: It mainly consists of hydrogen, carbon monoxide and hydro carbons. It is produced by carbonization of coal. It is used in boilers and sometimes used for commercial purposes. The gross calorific value of coal gas is about 18,000-20,000 kJ/m^3.

(3) Coke-oven gas: It is produced during production of coke by heating the bituminous coal at 6000 C to 10000 C. The characteristic and composition of coke oven gas is similar to coal gas. It is used for industrial heating and power generation purpose. The gross calorific value of coke oven gas is about 20,000 kJ/m^3.

(4) Producer gas: This gas is produced by partial combustion of solid fuels(gasification), by in complete combustion of coal in presence of limited amount of air supplied. This gas is mainly mixture of carbon monoxide, hydrogen and little amount of other elements It is used in steel industry for firing open hearth furnace. The gross calorific value of producer gas is about 6,000 kJ/m^3.

(5) Water gas: This is produced by blowing the steam on white hot coke or coal. It is mainly mixture of carbon monoxide and hydrogen. Steam (water vapour) is required for its manufacture, so this gas is known as water gas it burns with a blue flame. Therefore it is also known as blue gas. The gross calorific value of water gas blue is about l1,000 kJ/m^3

(6) Blast furnace gas: It is by-product of smelting operation in which air is forced through layers of iron ore, limestone and coke in a blast furnace. It is mixture of carbon dioxide, carbon monoxide, hydrogen, nitrogen etc. it is used in gas engines. The heating value of the gas is very low

(7) Sewer gas: It is produced from sewage disposal waste in which fermentation and decay occurs. It consists of CH_4 collected at large disposal plants. It is used as fuel for gas engine which is turn drives the plants pumps and agitators.

Advantages and disadvantages of gaseous fuels:

Gaseous fuel is becoming popular because of following advantages:

(1) Excess air require is very less for complete combustion'

(2) Good fuel economy and more efficiency of furnace operation'

(3) Combustion control is better.

(4) No problem of storage if the supply is available from public supply line.

(5) Easy to distribute with the help of pipe lines.

(6) Gaseous fuels produces higher temperatures and economical to produce same amount of heat.

Disadvantages

(1) They are very highly inflammable.

(2) Gas is more difficult to transport by pipe line compared to liquid fuel.

(3) Liquefied gases require high pressure/ low temperature insulated expensive tanks

2.2.4 LPG (Liquefied Petroleum Gas):

LPG is a colorless petroleum gas. It is natural derivative of both natural gas and crude oil. The main component gases of LPG are propane and butane or a combination of these two constituents. The gas is liquefied by moderate compression at normal temperature and is stored in tanks and cylinders. The liquefaction is necessary to provide a reduction in volume and produce acceptable energy densities. The calorific value of LPG is about 45,360 kJ/kg. The use of LPG is widespread. LPG is a fuel used for coo king. Also, LPG is a fuel which can run engines of cars, buses and lorries.LPG is best suited for light vehicles such as cars and small vans which normally run on petrol. LPG can be used in vehicles after conversion of vehicle for LPG or modification in engine. It seems that conversion is practically applicable to petrol vehicles only, not diesel vehicles because diesel engines need significant modification. Normally modified engine can be run on either LPG or petrol at the flick of a switch, even while motoring.

The main difference between LPG and petrol or diesel for cars and vans, is the cost of fuel. As a rough data, the cost of LPG is 50 7o less compared to petrol, because the government has reduced the duty on LPG. Pollution produced by LPG vehicles is l57o lower than that produced by petrol vehicles. It produces lower amount of carbon monoxide and hydrocarbons compared to petrol vehicles, but it produces more amount of nitrogen oxides. It deposits less sulphur in the engine.

2.2.5 CNG (Compressed Natural Gas): CNG is made by compressing methane which is extracted from natural gas and is stored at high pressure (about 200 bar). The main component gas of CNG is methane. In addition to methane, it also contains small percentage of ethane, propane, butane and pentane. The calorific value of CNG is about 40,700-41,200 kJ/m3. Due to higher octane number, CNG is an excellent fuel for petrol engine. CNG is burnt at higher temperature resulting into reduced engine knock. Older cars are not difficult to convert from petrol to CNG. However, engine system modification becomes more complicated. Aesop it needs special care during refueling operations against leakage..Pollution produced by CNG vehicles is less than petrol vehicles. Use of CNG results into longer service life and lower maintenance costs.

The big disadvantage of CNG is, storage tank in vehicle has to be robust and heavy because of the high pressure requirement. The major problems with CNG are that it is expensive the cost of converting cars to CNG mode is high and the short range between refueling inconvenient. At present CNG buses are more expensive than diesel buses, however this differential can be expected to reduce with time, its price has been relatively steady.

fuel utilization

Coal + Air+ Heat -+ Water+ Steam -+ Steam Turbine+ Mechanical Energy

Gaseous fuel + Air -+ Combustion product -+ Gas Turbine -+ Mechanical Energy

Oil (petrol/diesel) + Air -+'Combustion product -+ I C Engine -+ Mechanical Energy

CNG/LPG + Air -+ Combustion product -+ I C Engine -+ Mechanical Energy

2.3Nuclear Fuel and utilization

Nuclear energy or atomic energy is recent development. Nuclear energy is the world's source of emission free energy. Heat energy produced by the fission or fusion of atoms may be used to produce shaft power by heat engines. In fission, the nuclei of uranium or plutonium atoms are split with the release of energy. In fusion, energy is released when small nuclei combine or fuse.

The fission process is used in all nuclear power plants, because fusion cannot be controlled. The tremendous amount of heat energy is liberated by fission of nuclear disintegration of nuclear fuel (uranium and other similar fissionable materials). It is estimated that I kg of nuclear fuel is equivalent to about 2.5x106 kg of coal. The heat energy so liberated in atomic reactors is extracted by pumping fluid or molten metal like liquid sodium or gas through the pipe. The heated metal or gas is then allowed to exchange its heat to the heat exchanger by circulation. In the heat exchanger the gas is heated or steam is generated which is utilized to drive gas or steam turbines coupled to alternators thereby generating electrical energy.

The future of nuclear power is very bright as the reserves fossil fuel is fast depleting and hydro power has also a fixed limit up to which can be exploited. However main disadvantage of nuclear power plant are high investment and the fission byproducts are generally radioactive which may cause a dangerous amount of radioactive pollution.

2.4 Hydraulic or Water Energy

This is another useful source of energy. Water stored at high elevation or artificial high level water reservoir contains potential energy. When water starts flowing, potential energy gets converted to kinetic energy. Water at a pressure (water head) or flowing with a high velocity or both can be used to run hydraulic turbines or water wheels coupled to generators and therefore generation of electric power. The water head is created by constructing a dam a river or lake. This method of generation of electric power is becoming more and more popular as it is reliable, requires very less maintenance and operating costs, and it is very neat and clean plant because no smoke or ash is produced. However it requires Large investment cost for dam and reservoir.

2.5 Solar Energy

Sun is the primary source of energy. this energy results from the nuclear reactions which are taking place within the mass of sun. The energy radiated by the sun is in form of electro-magnetic waves which include the heat, light and lot of ultraviolet radiations- Solar energy reaching the earth in tropical zones is about 1 kWm2 per day. In countries within 3200 km of equator, use of such energy can be economically significant. Solar energy is available in abundance in the Indian subcontinent. For ten months of the year, six to eight hours a day, much of India receives high intensity fairly uniform sunshine.

The radiated heat energy by the sun can be utilized for both domestic and commercial purposes such as water heating, water distillation, refrigeration, drying, power generation etc. Solar energy is collected in a device called solar energy collectors. The solar radiation is then transferred to a fluid passing in contact with it.

2.6 Wind Energy

Wind energy is another potential source of energy. Wind is the motion of air caused pressure difference of air due to uneven heating of earth surface by sun and rotation of the earth. Wind energy can be utilized in wind turbines which produce mechanical energy and coupled with electrical generator. It is also utilized to run water pump at remote place where electricity is not available. The main advantage of this source of energy is that it is plentiful inexhaustible, non-polluting and it does not require any operator. It also does not require maintenance and repairs for long intervals. However, this source of energy is unreliable since the production of electrical energy.depencis largely upon the velocity of the wind.

Wind resources in India are tremendous and generation of electrical energy will economical at a number of places. They are mainly located near the sea coasts. Today, total number of wind turbine generators in operation in India is more than 7500 with an installed capacity of about 2300 MW The major wind energy system sites are Lamba (Porbander, Gujarat), Okha (Gujarat), Deogarth (Maharashtra), Tuticorin (Tamil Nadu) Kayothar (Tamil Nadu) and coastal area of Bhavnagar (Gujarat).

2.8 Bio-fuel

Bio fuel is a gaseous or liquid combustible substance made form biomass. Biomass is a material derived from recently living organisms. It includes plants, animals and their by-products. For example drop residues, manure, wood grass, domestic refuse, agricultural and forest crops, animal and human waste and garden waste are all sources of biomass. It is a renewable energy source based on the carbon cycle, unlike other natural resources such as petroleum, coal and nuclear fuels.

The bio-mass is converted into useful fuels by following bio-conversion routes:

(1) The bio-chemical conversion by anaerobic digestion and fermentation to produce biogas.

(2) Thermo-chemical conversion by gasification and liquefaction to produce ethanol or methanol. Direct combustion such as wood waste and bagasse. The agricultural products specifically grown for bio-fuel production include:

- Corn and soybeans in U.S.
- Rapeseed, wheat, sugar beet in Europe.
- Sugarcane in Brazil.
- Palm oil in South East Asia
- Jatropha in India

Considering pollution and increasing prices, bio-fuels offer a reliable and sustainable alternative to supply future energy demand.

Advantages of using bio-fuel in vehicles:

- Reduced pollution.
- Reduces the use of fossil fuel (petroleum).
- Increases opportunities for rural peoples.

- Increases national energy security.

Limitations of bio-fuels :

- Bio-fuel production process is very slow. It must be redesigned and replaced rapidly.
- To reduce the price of bio-fuel, bio-fuel production is to be motivated by government.

Some of the bio-fuels are described below:

Bio-diesel: It is made from vegetable oil. A fat or oil is reacted with an alcohol, like methanol, together with a catalyst to produce glycerin and methyl esters (the chemical name of bio-diesel). The process results in bio-diesel and by product glycerin. Bio-diesel can be mixed with diesel with any proportion. For example,20 7o of fuel is bio-diesel and 80olo is regular diesel, commercially it is known as 820 bio-diesel. Diesel engine can run on pure biodiesel (B100) with little modification. Bio-diesel produces lower pollution compared to pure diesel.

Bio-ethanol: Bio-ethanol is produced from crops such as sugar beet. sugar cane, corn etc. Ethanol can be produced from biomass by hydrolysis and sugar fermentation processes.

Bio-ethanol can be mixed with petrol at any proportion. The 85% Bio-ethanol mixed with 5% petrol, commercially it is known as EB85 bio-ethanol. Petrol engines can run on 5% bioethanol with petrol (EB5) without any modification. Above L}To bio-ethanol, engine is to be modified.

Vegetable oil: it can be used either food or fuel. It can be used in many older diesel engines, but only in warm climates. For example, jatropha, coconut etc. In most cases, vegetable oil is used to manufacture bio diesel

Bio-gas : it is produced by the process of anaerobic digestion of organic materials like animal waste, agriculture waste and municipal waste. The solid by product can be used as solid bio-fuels or fertilizers. The calorific value of bio gas is about 34,000 kJ/m^3.

syngas : it is produced by the combined process of pyrolysis, combustion and gasification.

2.9 Hydrogen (H_2) Gas

Hydrogen is the simplest, order less and colorless gas. An atom of hydrogen consists of only one proton and one electron. It’s also the most plentiful element in the universe. But hydrogen does not exist freely in nature It always combined with other element for example water is combination of hydrogen and oxygen. Hydrogen is not an energy source, but, it is only produced from other sources of energy, so it is often referred to as an energy carrier that is an efficient way to store and transport energy. Hydrogen can be produced (1)by means of thermo-chemical process (2) by water splitting is possible through thermolysis ore bio photolysis (3)by electrolysis (4)from sunflower oil or from coal gasification.

Hydrogen can be mixed with natural gas to create an alternative fuel for vehicle that uses certain types of internal combustion engine is called hydrogen ICE vehicle. Hydrogen internal combustion engine is simple a modified version of traditional gasoline powered internal combustion engine. Hydrogen is also used in fuel cell a vehicle that run on electricity produced by the petrochemical reaction that occurs when hydrogen and oxygen are combined in the fuel stack is known as hydrogen fuel cell vehicle

The major problem of using H2 as fuel is due to its high explosive nature during combustion. Also speed of flame development is very high, H2 can be used as fuel for power generation in fuel cells. The recent develop[mint is going on to use H2 as fuel for automobiles.

2.10 Global warming

Global warming is the rise in the average temperature of earth's atmosphere and oceans since the late 19^{th} century and its projected continuation. Since the early 20^{th} century, earth's mean surface temperature has increased by about 0.8 C, which is greater than that of the increasing since 1980

Cause of global warming

The most of scientists believe that global warming is primarily caused by increasing concentration of greenhouse gasses produced by human activities such as the burning of fossil fuels like coal, oil, natural gas etc. and another factor is deforestation when forests are cut down or burned, they can no longer store carbon, and the carbon is released to the atmosphere. The gas especially CO_2 in the atmosphere are higher than at any time during the last $6.5*10^5$ years. Earth has warmed at a rate higher than that of previous time over the last hundred years and particularly over the last two decades.

Indicators of global warming:

There are ten indicators which represents the global warming as:(i)Sea ice decrease, (ii) Snow cover decrease, (iii) Glaciers decrease, (iv) Sea surface temperature increase' (v) Temperature over ocean increase, (vi) Humidity increase, (vii) Troposphere temperature increase, (viii) Temperature over land increase, (ix) Sea surface increase, and (x) Ocean heat content increase.

Impacts of global warming:

- Human societies have to bear the effects of extreme weather events rather than Gradual climate change.
- Pests and disease is increased. There are sensible effects on human health on populations in high-latitude areas'
- In small islands and mega-deltas, heavy flood as a result of sea level rise is expected to harm vital infrastructure and human settlements. This could lead to issues of homelessness in countdes2+h low lying areas such as Bangladesh, as well as statelessness for populatioris in countries such as the Maldives and Tuvalu.
- Ocean acidification is increased; also, various ecosystems are disturbed.
- Agricultural output is reduced and increases area of deserts. Under present trends, by 2030, maize production in Southern Africa could decrease by up to 30% while rice, millet and maize in South Asia could decrease by up to 10% By 2080, yields in developing countries could decrease by l0%o to25%o on average while India Could see a drop of 307o to 407o.
- Over the 21stcentury, climate change is likely to adversely affect hundreds of millions of people through increased coastal flooding, reductions in water supplies, increased mal-nutrition and increased health impacts, reduction in food production.

Mitigation of global warming:

In order to limit global warming to within the lower range it will be necessary to adopt special policies that will limit greenhouse gas emissions. This will become more and more

difficult with each year of increasing volumes of emissions and even more drastic measures will be required in later years to stabilize a desired atmospheric concentration of greenhouse gases' Most countries are Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The ultimate objective of the Convention is to prevent dangerous human interference of the climate system.

2.11 Ozone Depletion

The atmosphere of the Earth is divided into 5 layers. From closest to farthest layers troposphere, stratosphere, mesosphere, thermosphere and exosphere. The majority of atmosphere’s ozone remains in the stratosphere, which extends from 10 kms above the surface to 50 kms. The earth's stratospheric ozone layer plays a critical role in absorbing ultra violet radiation emitted by our sun and protects the Earth from the harmful effect of ultra violet rays; otherwise it causes skin cancer of human and can lead to genetic damage hence, the ozone layer is essential to life on earth, as it absorbs harmful ultraviolet-B radiation from the sun. In recent years the thickness of this layer has been decreasing, leading to create holes in the layer is called ozone depletion in the last thirty years, it has been discovered that stratospheric ozone is depleting as a result of chlorine and bromine based pollutant. Every atom can destroy up to 10, 0 000 ozone molecules.

Ozone depletion occurs when the natural balance between the production and destruction of stratospheric ozone is stopped. The main ozone depleting substances are:

(i) Chlorofluorocarbons - it is used as coolants in refrigerators, freezers and air in buildings and cars.

(ii) Halons - it is used in some fire extinguishers, in cases where materials and would be destroyed by water or other fire extinguisher chemicals.

(iii) Methyl Chloroform - it is used mainly in industry for reducing vapor, some aerosols, cold cleaning, adhesives and chemical processing.

(iv) Carbon Tetrachloride - it is used in solvents and some fire extinguishers. Chlorofluorocarbons (CFCs) are main substance causing ozone depletion, accounting 80% of total stratospheric ozone depletion. CFCs are not destroyed in reactions with chemicals or washed back to Earth by rain. They simply do not break down in the lower and they can remain in the atmosphere from 20to l2 years or more. Finally, they into the stratosphere where they broke down by ultra violet (UV) rays from, releasing free chlorine. The chlorine becomes actively involved in the process of destruction of ozone. The net result is that two molecules of ozone are replaced by three of molecular oxygen, leaving the chlorine free to repeat the process. Ozone is converted to oxygen, leaving the chlorine atom free to repeat the process up to 100,000 times, resulting in reduced level of ozone.

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O \rightarrow Cl + O_2$$

There are a number of things that we as individuals can do to protect the ozone layer. These include proper disposal of old refrigerators, the use of halon-free fire extinguishers and

the recycling of foam and other non-disposable packaging. Also, if emissions of ozone depleting are now being controlled, the ozone layer is not likely to fully repair itself for several decades. Consequently, we should take precautions when exposing ourselves to the Sun.

2.12 Introduction of Energy Conservation Act 2001

Considering the vast potential of energy savings and benefits of energy efficiency, the Government of India made the law of the Energy Conservation (EC) Act, 2001. The act provides for the legal framework, institutional arrangement and a regulatory mechanism at central and State level to embark upon energy efficiency drive in the country.

The EC Act 2001 provides for the efficient use of energy and its conservation. Act provides for the formation of a bureau of Energy Efficiency (BEE), New Delhi, the agency for developing policy and strategies in energy conservation, and also empowers Central Government to facilitate the enforcement and efficient use of energy and its conversation Five major provisions of EC Act relate to Designated Consumers, Standard Labeling of Appliances ,Energy conservation Building codes (ECBC), creation of institutional Set up (BEE) and Establishment of Energy Conservation Fund.

The EC Act became effective from 1st March, 2002 and Bureau of Energy Efficiency

(BEE) operationalized from last March, 2002.Energy efficiency institutional practices programs in India are now mainly being guided through various voluntary and mandatory provisions of the EC Act.

Features of the Act:

- Empower the central government to specify energy consumption standards.
- Prohibit the manufacture and sale of appliances that do not conform to energy consumption standards.
- Identify energy intensive industries and commercial establishments as designated consumers.
- Prescribe energy consumption norms and standards for these consumers.
- Prescribeenergyconservationbuildingcodesforefficientuseofenergy,andenergy conservation in new commercial buildings with a contract load of -500 kW and above.
- Direct consumers to prepare and implement schemes for efficient use of energy.

The EC Act was amended in 2010 and the main amendments of the Act are given below:

1. The central government may issue the energy savings certificate to the designated consumer whose energy consumption is less than the prescribed norms and standards in accordance with the procedure as may be prescribed.

2. The designated consumer whose energy consumption is more than the prescribe norms and standards shall be entitled to purchase the energy savings certificate comply with the prescribed norms and standards.
3. The central government may, in consultation with the Bureau, prescribe the value of per metric ton of oil equivalent of energy consumed.
4. Commercial buildings which are having a connected load of 100 kW or contract demand of 120 kVA and above come under the purview of ECBC under: EC Act

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2.13 Electricity Act 2003

The Electricity Act, 2003 is legislation in India that aims to improve and regulate the power sector in India. The act covers major issues involving generation, distribution, transmission, and trading in power. As per the act, L\Vo of the power supplied by suppliers and distributors to the consumers have to be generated using renewable and non-conventional sources of energy so the energy is reliable. The Act de-licenses distribution in rural areas and brings in a licensing for distribution in urban areas.

The main/features of the act are as follows:

1. Generation has been licensed and captive generation freely permitted.
2. No person shall transmit electricity; or distribute electricity; or undertake trading in electricity unless he is authorized to do so by a license issued, exceptions informed by authorized commissions through notifications.
3. Central Government may make region wise modification and limits from time to time for the efficient, economical and integrated transmission and supply of electricity, and
4. in particular to facilitate voluntary inter-connections and co-ordination of facilities for the inter-State, regional and inter-regional generation and transmission of electricity' Open access in transmission with provision for surcharge for taking care of current level of cross subsidy, with the surcharge being gradually phased out.
5. Setting up state electricity regulatory commission made mandatory.
6. metering of electricity supplied made mandatory' Provisions related to thefts of electricity made more stringent.
7. Trading as, a distinct activity recognized with the safeguard of Regulatory commissions being authorized to fix ceiling on trading margins
8. For rural and remote areas standalone system for generation and distribution permitted'
9. Thrusttocompleteruralelectrificationandprovideformanagementofruraldisttibution by panchayat, cooperative societies, NGOs, franchises etc.
10. Central government to prepare national electricity policy and tariff policy.
11. Central electricity authority to prepare National electricity plan.

Chapter: 3 Properties of Gases

❖ Vapour:

It can be defined as that state of the substance in which the evaporation from its liquid state is not complete.

- A Vapour consists of a mixture of the pure gaseous form and liquid particles in suspension. Example: Steam contains water particles.
- With the changes in temperature and pressure, a vapour can undergo condensation or evaporation.
- Vapour may be in three conditions, wet, dry and superheated. Superheated vapour behaves like a perfect gas. By changing temperature conditions can be changed.

❖ Gas:

It is the state of a substance in which the evaporation from the liquid state is complete.

- Within the limits of temperature and pressure in thermodynamics, the substance like O_2, H_2, air, N_2 are taken as gases.

❖ Perfect Gas:

A gas which strictly obeys all the gas laws under all conditions of temperature and pressure is called a perfect gas.

- There is no gas which is perfect, but many gases like O_2, N_2, H_2, and air tend to behave like perfect gases. They are known as real gases.

❖ Gas laws:

1. Boyle's law:

This law was discovered by Robert Boyle in 1662 A.D. and it can be defined as follows:

"*The volume of a given mass of a perfect gas varies inversely as the absolute pressure when the temperature is constant.*"

$$V \propto \frac{1}{p}$$

$$\therefore pV = C \qquad \text{.... (1)}$$

where p = The absolute pressure of gas in *Pa*,
V = Volume occupied by the gas, at above pressure p in m^3,
C = Constant of proportionality.

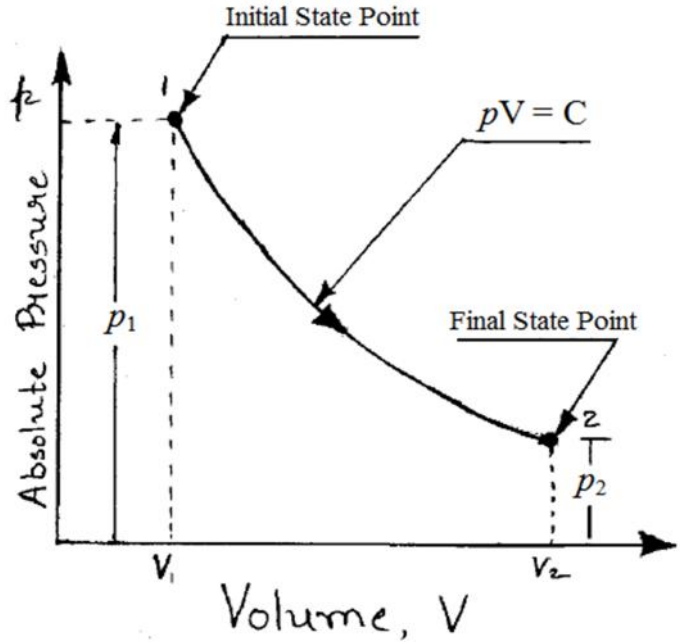


Fig. 1 Boyle's law

In fig.1, let a quantity of gas at pressure P_1 and volume V_1 changes its pressure and volume in a cylinder without change in temperature. Let, P_2 and V_2 be the final pressure and volume respectively.

∴ According to Boyle's law,

$$p_1 V_1 = p_2 V_2 = \text{ Constant} = C$$

$$\therefore p_1 V_1 = p_2 V_2 \qquad \text{.... (2)}$$

Above equation is useful working relation of Boyle's Law.

2. Charles law:

This law was discovered by Charles in 1787 A.D. and it can be defined as follows:

"*If the pressure of the given mass of a gas is kept constant, then the volume of the gas varies directly in proportion to its absolute temperature.*"

$$V \propto T$$

where V = The volume occupied by a given mass of gas in m^3.

T = Absolute temperature of the gas in K.

$$\therefore V = C\,T \quad \text{OR} \quad \frac{V}{T} = C \qquad \text{.... (3)}$$

where C = Constant

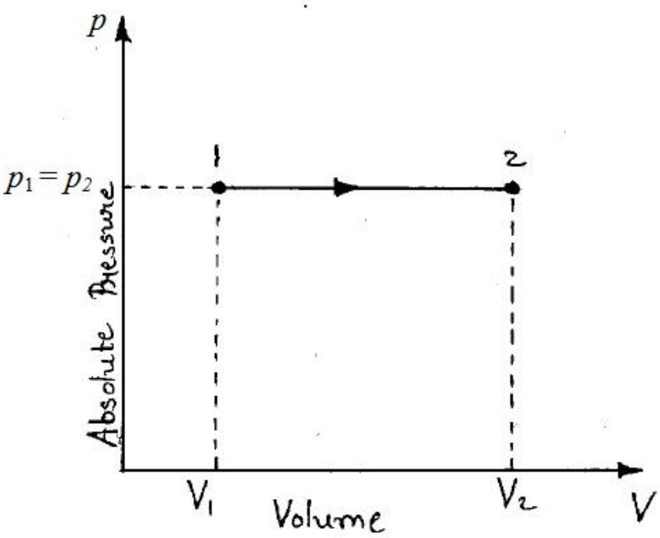


Fig. 2 Charles law

Referring to fig. 2,

If V_1 and T_1 = Initial conditions of volume and absolute temperature at point 1

V_2 and T_2 = Final conditions of volume and absolute temperature at point 2

$\therefore$ By using above equation

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \text{ Constant}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \qquad \text{.... (4)}$$

- Charles Law can also be stated as "**The pressure of a gas varies with the absolute temperature provided the volume occupied by the given mass of the gas is constant".**

$$\therefore p \propto T$$

$$\therefore \frac{p}{T} = \text{ Constant}$$

$$\therefore \frac{p_1}{T_1} = \frac{p_2}{T_2} = \text{ Constant}$$

$$\therefore \frac{p_1}{p_2} = \frac{T_1}{T_2} \qquad (5)$$

3. Combined gas law:

In practice, the pressure, volume and the temperature of a gas changes at the same time. As the pressure changes, Charles law cannot be applied and as the temperature changes, Boyle's law cannot be applied. By combining these two laws the final conditions of the gas can be determined.

Let us consider a *m kg of mass* of a perfect gas to change its state in the following two successive processes (Fig. 3) (i) Process 1-2 at constant pressure, and (ii) Process 2-3 at constant temperature.

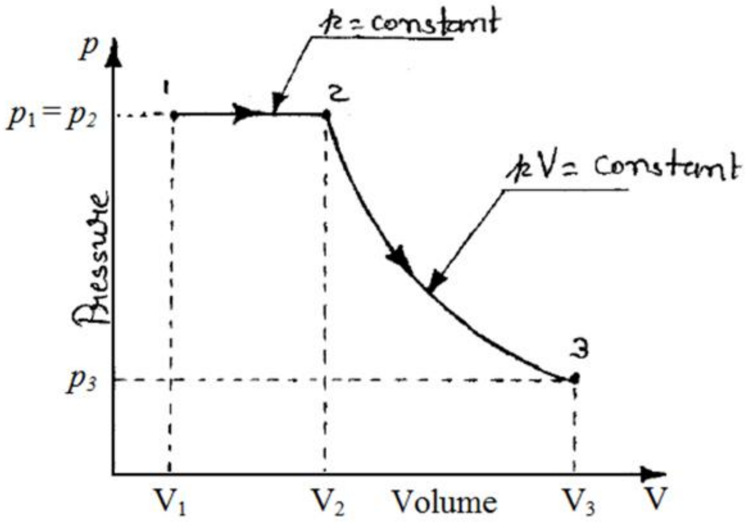


Fig. 3 Combined gas law

Applying Charles law

We have, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (∵ p = constant)

And since $T_2 = T_3$, we may write $\frac{V_1}{T_1} = \frac{V_2}{T_3}$ …. (6)

Applying Boyle's law (Process 2-3)

$$p_2 V_2 = p_3 V_3 \text{ and since, } p_2 = p_1$$

$$\therefore p_1 V_2 = p_3 V_3$$

$$\therefore V_2 = \frac{p_3 V_3}{p_1} \quad \text{…. (7)}$$

Substituting the value of V_2 from eq. (7) in eq. (6), we get

$$\therefore \frac{V_1}{T_1} = \frac{p_3 V_3}{p_1 T_3}$$

$$\therefore \frac{p_1 V_1}{T_1} = \frac{p_3 V_3}{T_3}$$

$$\therefore \frac{p V}{T} = \text{constant} \quad \text{…. (8)}$$

The magnitude of this constant depends upon the particular gas and it is denoted by R, where R is called the characteristics gas constant. For *m* kg of gas,

$$\therefore \frac{pV}{T} = mR$$

$$\therefore pV = mRT \qquad \text{.... (9)}$$

Equation () is called equation of state for a perfect gas.

$$p\frac{V}{m} = RT$$

$$\therefore pv = RT \qquad \text{... (10)}$$

where $v = \frac{V}{m} =$ specific volume, m^3/kg.

Equation () is called the characteristics gas equation of state for a perfect gas.

V = Volume of gas in m^3,
p = Pressure of gas
T = Temperature of gas in K
R = Characteristic gas constant, J/kg K

Non flow processes:

Non flow process is the one in which there is no mass interaction across the system boundaries during the occurrence of the process.

Different types of non flow process of perfect gases is given below,

i. Constant volume process
ii. Constant pressure process
iii. Isothermal process
iv. Polytropic process
v. Adiabatic process

Constant Volume Process

In a constant volume process, the working substance is contained in a rigid vessel. Hence the boundaries of the system are immovable and no work can be done on or by the system. This process is also known as ***Isochoric process.***

Below figure shows the system and states before and after heat addition at constant volume.

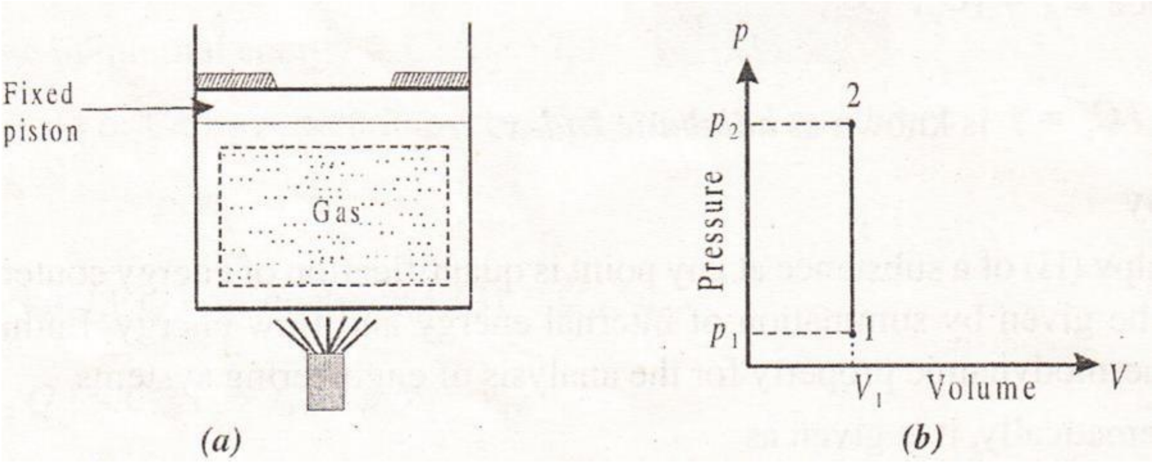


Fig. 3.1 Constant volume process

- **Work done during the process**

  We have,

  Work done = p dV

  Total work done = $\int_{V_1}^{V_2} pdV$

  Since for constant volume process, Change in volume dV = 0.

  Work done, W = 0

- **Relation between *p*, V and T:**

  We know that

  $$\frac{p\,\mathbf{V}}{T} = Const$$

  $$\frac{p_1\,\mathbf{V}_1}{T_1} = \frac{p_2\,\mathbf{V}_2}{T_2}$$

  But $V_1 = V_2$ = Constant

  $$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

- **Change in internal energy:**

  We know that,

  du = C_v (T_2-T_1)

  So, du = m C_v (T_2-T_1) (For m kg of gas)

- **Heat transferred:**

  According to first law of thermodynamics,

  $$\delta Q = \delta W + \delta U$$

For constant volume process,

$dV = 0$, So $\delta W = 0$

$\therefore$ ¢Q $= dU$

So, Heat transfer = Change in internal energy

- **Change in enthalpy:**

  As per definition of enthalpy, $H = U + p\,V$

  Foe state 1 and 2,

  $H_1 = U_1 + p_1\,V_1$

  $H_2 = U_2 + p_2\,V_2$

  Change in enthalpy, $\Delta H = H_2 - H_1$

  $= (U_2 - U_1) + (p_2V_2 - p_1V_1)$

  $= m\,C_v\,(T_2 - T_1) + m\,R\,(T_2 - T_1)$ $\qquad (\because PV = mRT)$

  But $R = C_p - C_v$

  $\therefore \Delta H = m\,C_v\left(T_2 - T_1\right) + m\,(C_p - C_v)\left(T_2 - T_1\right)$

  $\therefore \Delta H = m\,C_p\left(T_2 - T_1\right)$

Constant Pressure Process

In a constant volume process, the process of the gas remains constant.

- **Work done during the process**

  We have,

  Work done = p dV. But p is constant,

  Hence work done, $W = p\int_{V_1}^{V_2} dV = p\,(V_2 - V_1)$

  The work done by the gas during constant pressure process is represented by area below the line 1 - 2 on p – V diagram in below figure.

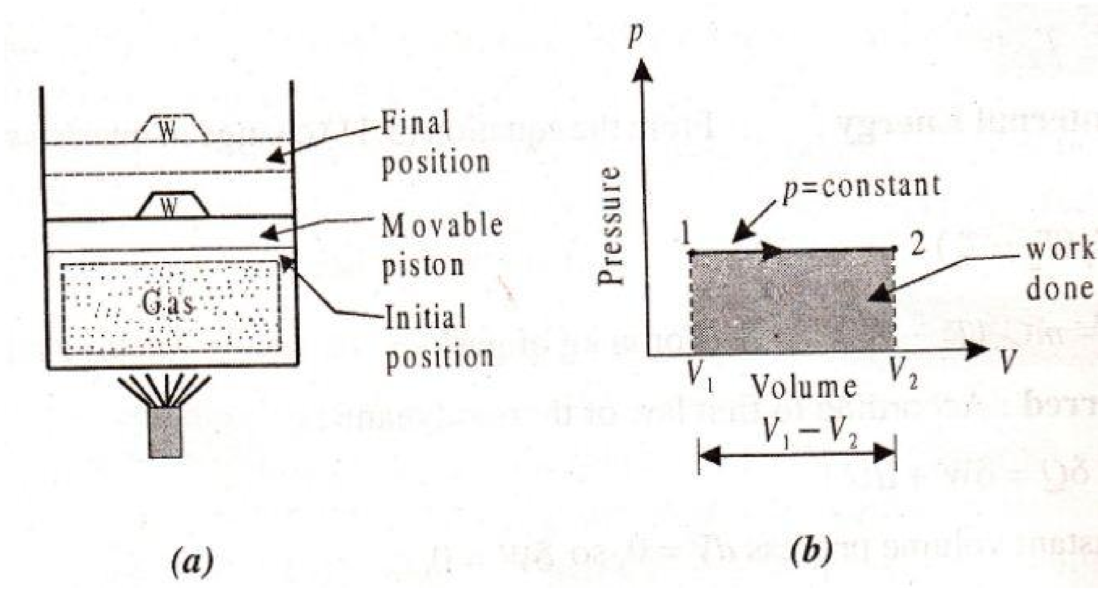


Fig. 3.2 Constant pressure process

- **Relation between *p*, V and T:**

  We know that

  $$\frac{p_1\ \mathbf{V}_1}{T_1} = \frac{p_2\ \mathbf{V}_2}{T_2}$$

  But $p_1 = p_2$ = Constant

  $$\frac{\mathbf{V}_1}{T_1} = \frac{\mathbf{V}_2}{T_2}$$

  This is the equation of Charle's law.

- **Change in internal energy:**

  We know that,

  du = m C_v (T_2-T_1) because internal energy is a function of temperature alone.

- **Heat transferred:**

  According to first law of thermodynamics,

  δQ = δW + δU

  $= p\ (V_2 - V_1) + m\ C_v\ (T_2 - T_1)$

  $= m\ R\ (T_2 - T_1) + m\ C_v\ (T_2 - T_1)$ $\qquad (\because PV = mRT)$

  $= \ m\ (C_p - C_v)\ (T_2 - T_1) + m\ C_v\ (T_2 - T_1)$

- **Change in enthalpy:**

As proved earlier for constant volume process, similarly change in enthalpy,

$$\therefore \Delta H = \text{m}\, C_p \left(T_2 - T_1\right)$$

Isothermal Process

In isothermal process, the temperature remains constant during the process. This process follows Boyle's law. Thus the law of expansion or compression for isothermal process on p – V diagram is hyperbolic as p is inversely varies as V. Thus this process is also known as ***hyperbolic process or Constant Internal energy process.***

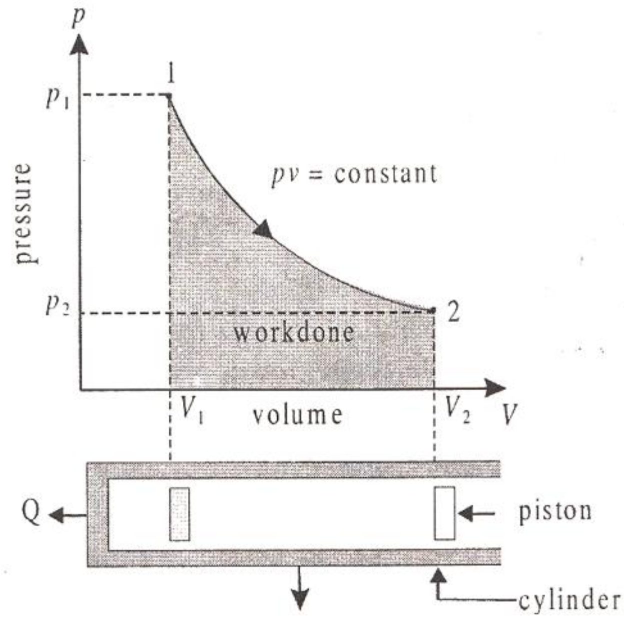


Fig. 3.3 Isothermal process

- **Work done during the process**

  Work done, W = Area below the curve

  $$= \int_{V_1}^{V_2} dV$$

  But p V = p_1 V_1 = C

  Hence, p = C / V

Substituting for p in the integral, we get,

$$W = \int_{V_1}^{V_2} \frac{C}{V} dV = C \int_{V_1}^{V_2} \frac{dV}{V} = C \log_e \frac{V_2}{V_1}$$

Substituting for C, we get

Work done, $W = p_1 V_1 \log_e \frac{V_2}{V_1}$

$$= p_1 v_1 \log_e \text{r r}$$

Where, $\frac{V_2}{V_1}$ = r = ratio of expansion

But p_1 V_1 = m R T_1 and p_2 V_2 = m R T_2

Therefore, Work done = mRT_1 $\log_e$ r = mRT_2 $\log_e$ r

- **Relation between *p*, V and T:**

  We know that

  $$\frac{p_1\ \mathbf{V}_1}{T_1} = \frac{p_2\ \mathbf{V}_2}{T_2}$$

  But T_1 = T_2 = Constant

  $$p_1\ \mathbf{V}_1 = p_2\ \mathbf{V}_2$$

- **Change in internal energy:**

  We know that, du = m C_v (T_2-T_1), but T_1 = T_2

  Therefore, change in internal energy dU = 0.

  So, during the isothermal operation ***change in internal energy is zero*** and hence this process is also known as ***constant internal energy process.***

- **Heat transferred:**

  According to first law of thermodynamics,

  δQ = δW + δU

  But change in internal energy dU = 0.

  So, δQ = δW

  $$\therefore \text{Heat transfer, } ¢Q = p_1 V_1 \log_e \frac{V_2}{V_1} = p_1 V_1 \log_e \frac{p_1}{p_2}$$

  $$= mRT_1 \log_e \frac{p_1}{p_2}$$

- **Change in enthalpy:**

  Change in enthalpy, ΔH = H_2 – H_1 = m C_p (T_2 – T_1)

  But, T_1 = T_2. So ΔH = 0.

Adiabatic Process

An adiabatic process is the thermodynamic process in which there is no heat interaction during the process, i.e. during the process Q = 0. In these processes the work interaction is there at the expense of internal energy. There is no supply of heat takes place during compression process. Frictionless adiabatic process is known as ***isentropic process***.

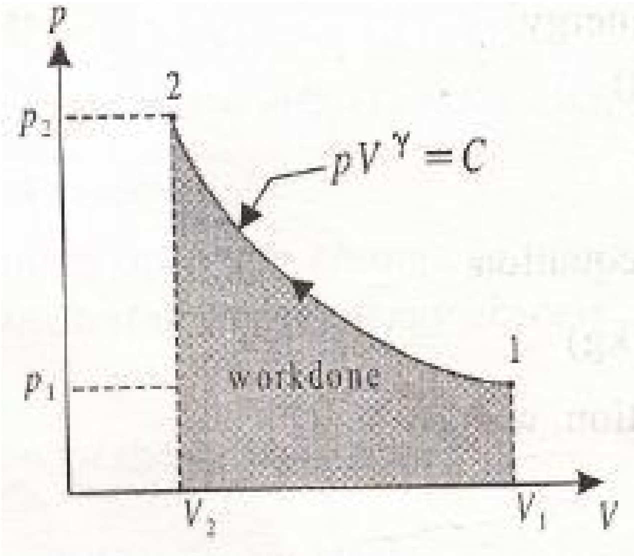


Fig. 3.4 Adiabatic process

- **Derivation of the equation pV^γ = Constant:**

According to first law of thermodynamics,

Heat supplied = Change in internal energy + work done

Let us consider unit mass of gas

We have, $dq = C_v dT + pdv$

For, adiabatic process dq = 0

$$\therefore C_v dT + pdv = 0$$

We have characteristic gas equation

$$p\,v = RT \qquad (\because m = 1kg)$$

By differentiating this equation, we get

$$pdv + vdp = RdT$$

$$\therefore dT = \frac{pdv + vdp}{R}$$

Substituting value of dT in above equation,

$$\therefore \frac{C_v\left(pdv + vdp\right)}{R} + pdv = 0$$

$$\therefore C_v\left(pdv + vdp\right) + R\left(pdv\right) = 0$$

$$\therefore C_v\left(pdv + vdp\right) + (C_p - C_v)\left(pdv\right) = 0$$

$$\therefore C_v vdp + C_p.pdv = 0$$

Dividing above equation by C_v. $p\,v$, we have,

$$\therefore \frac{C_p}{C_v}\left(\frac{dv}{v}\right)+\frac{dp}{p}=0$$

By integrating above equation and putting $C_p / C_v = \gamma$, we get

$$\gamma \log_e v+\log_e p=\log_e c \qquad (\because C=const)$$

$$\log_e v^{\gamma}+\log_e p=\log_e c$$

$$pv^{\gamma}=Const$$

The above equation is known as Poission’s law.

The adiabatic process on *p* – V diagram is represented in above Fig. 3.4.

- **Work done during the process**

Work done, W = $\int_{V_1}^{V_2} pdV$

But $p\,V^{\gamma}$ = Constant = C

Hence, $p = C / V^{\gamma}$

Substituting for *p* in the integral, we get,

$$W=\int_{V_1}^{V_2}\frac{C}{V^{\gamma}}dV=C\int_{V_1}^{V_2}\frac{dV}{V^{\gamma}}=C\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_{v_1}^{v_2}$$

$$=\frac{C}{-\gamma+1}\left(V_2^{-\gamma+1}-V_1^{-\gamma+1}\right)$$

$$C=p_1V_1^{\gamma}=p_2V_2^{\gamma}$$

By substituting for C, we get

Work done, $W=\frac{1}{-\gamma+1}\left[p_2V_2^{\gamma}\times V_2^{-\gamma+1}-p_1V_1^{\gamma}\times V_1^{-\gamma+1}\right]$

$$=\frac{p_2V_2-p_1V_1}{1-\gamma}$$

$$\therefore W=\frac{p_1V_1-p_2V_2}{\gamma-1}$$

We know that $p_1 V_1 = m R T_1$ and $p_2 V_2 = m R T_2$

$$\therefore W=\frac{R\left(T_1-T_2\right)}{\gamma-1}m$$

$$=\frac{\left(C_p-C_v\right)\left(T_1-T_2\right)}{\gamma-1} \qquad \left(\because R=\left(C_p-C_v\right), m=1kg\right)$$

$$=\frac{(C_p - C_v)(T_1 - T_2)\times C_v}{(C_p - C_v)} \qquad \left(\because \gamma - 1 = \frac{C_p - C_v}{C_v}\right)$$

$\therefore W = C_v\left(T_1 - T_2\right)$ = Change in internal energy.

- **Relation between *p*, V and T:**

  We know that $p\,V^{\gamma}$ = Constant and $\frac{p\,\mathbf{V}}{T} = Const$

  Dividing above twp equations, we get, $V^{\gamma-1}\,T$ = Constant

  We can rewrite as, $V_1^{\gamma-1}\,T_1$ = Constant, and $V_2^{\gamma-1}\,T_2$ = Constant

  From above equations, we get, $T_1\,V_1^{\gamma-1} = T_2\,V_2^{\gamma-1}$

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$p_1 V_1^{\gamma} = p_2 V_2^{\gamma}$$

$$\therefore \frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^{\gamma}$$

$$\therefore \frac{V_2}{V_1} = \left(\frac{p_1}{p_2}\right)^{1/\gamma}$$

  From above equations, we get,

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

- **Change in internal energy:**

  According to first law of thermodynamics, δQ = δW + δU

  But for adiabatic process δQ = 0. (No heat transfer)

  Therefore, dU = - δW

  So, change in internal energy = - work done

  For adiabatic process, change in internal energy is numerically equal to work done. When the work is done by the gas, it loses internal energy and gains internal energy when the work is done on the gas.

- **Heat transferred:**

  During adiabatic process, heat transfer is zero.

  So, $\delta Q = 0$.

- **Change in enthalpy:**

  Change in enthalpy, $\Delta H = m\,C_p\,(T_2 - T_1)$

Polytropic Process

Polytropic process is the most commonly used in practice. In this case, the thermodynamic process is said to be governed by the law $p\,V^n$ = Constant, where n is the index which can vary from - ∞ to + ∞. But generally index n lies within the range of 1 to 1.7. Thus the various thermodynamic processes discussed above are special uses of *isentropic process*.

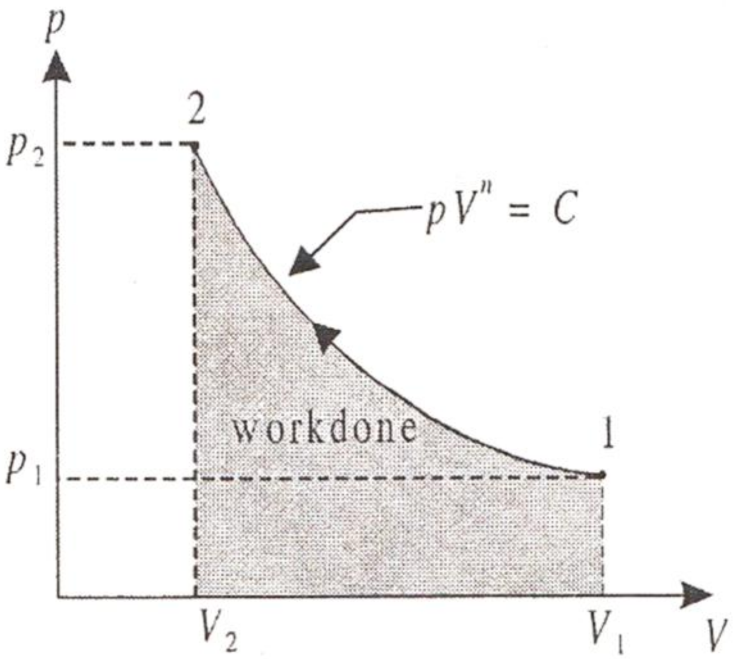


Fig. 3.5 Polytropic process

The main difference in equation of isentropic and polytropic process is that if we replace γ by n in the relation of adiabatic operation, we get relation for polytropic process.

(a)
$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

$$\frac{p_2}{p_1} = \left(\frac{V_2}{V_1}\right)^n$$, where n is an index for process.

(b) When n = 0

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^0 = 1$$

$$\therefore p_1 = p_2$$

So, the process is a *constant pressure process*.

(c) When n = 1,

$$\therefore \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} = \left(\frac{p_2}{p_1}\right)^{\frac{1-1}{1}} = \left(\frac{p_2}{p_1}\right)^0 = 1$$

$$\therefore T_1 = T_2$$

So, the process is a *constant temperature process*.

(d) When n = γ

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^n = \left(\frac{V_1}{V_2}\right)^{¥}$$

So, the process is an *adiabatic process*.

(e) When n = ∞,

$$\therefore \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\infty-1}{\infty}} = \left(\frac{p_2}{p_1}\right)$$

$$\therefore \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)$$

So, the process is a *constant volume process*.

When these values are plotted on p – V diagram as shown in below figure, it can be seen that they form a family of curves.

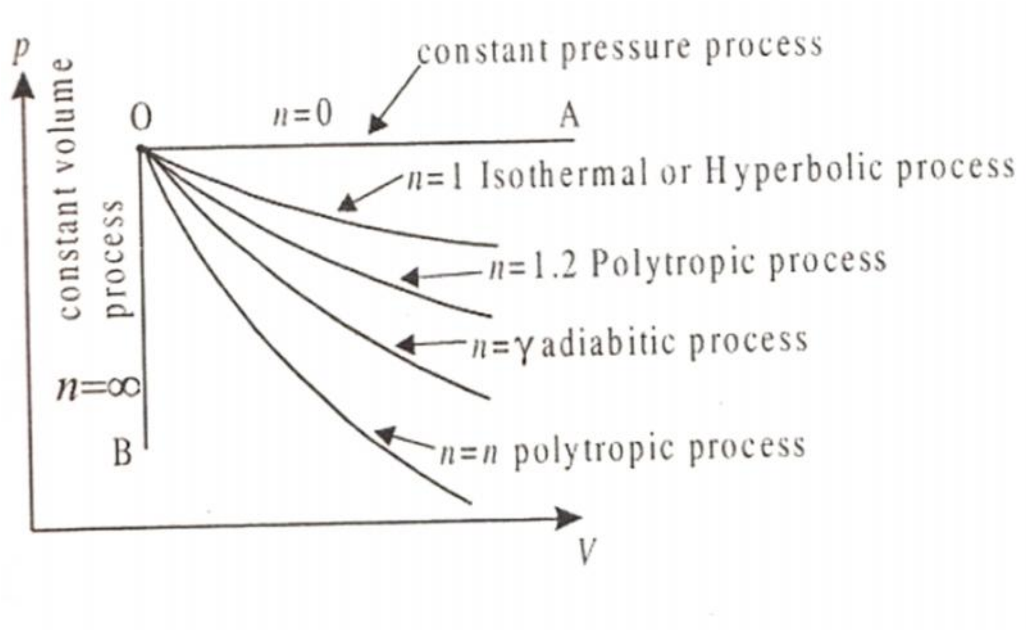


Fig. 3.6 Polytropic processes on *p* – V diagram

- **Work done during the process**

  From adiabatic process, we know that $W = \dfrac{p_1V_1 - p_2V_2}{\gamma - 1}$. So substituting γ = n in equation, we get, $W = \dfrac{p_1V_1 - p_2V_2}{n-1} = \dfrac{mR(T_1 - T_2)}{n-1}$

- **Relation between *p*, V and T:**

  Similarly from the adiabatic process, substituting γ = n, we can

$$\therefore \frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^n$$

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}} = \left(\frac{V_2}{V_1}\right)^{n-1}$$

- **Change in internal energy:**

  We know that, $\Delta U = m\,C_v\,(T_2 - T_1)$

- **Heat transferred:**

  We have, $W = \dfrac{p_1V_1 - p_2V_2}{n-1}$

  Change in internal energy = $m\,C_v\,(T_2 - T_1)$

  But, $C_v = \dfrac{R}{\gamma - 1}$, $p_1 V_1 = m R T_1$ and $p_2 V_2 = m R T_2$

By first law of thermodynamics

Heat supplied = Work done + Change in internal energy

So, heat transferred,

$$\text{¢}Q = \frac{p_1V_1 - p_2V_2}{n-1} + \mathrm{m\ C_v}\left(\mathrm{T_2} - \mathrm{T_1}\right)$$

$$= \frac{p_1V_1 - p_2V_2}{n-1} + \frac{\mathrm{mR}}{\text{¥} - 1}\left(\mathrm{T_2} - \mathrm{T_1}\right)$$

$$= \frac{p_1V_1 - p_2V_2}{n-1} + \frac{\mathrm{mRT_2} - \mathrm{mRT_1}}{\text{¥} - 1}$$

$$= \frac{p_1V_1 - p_2V_2}{n-1} + \frac{p_2V_2 - p_1V_1}{\text{¥} - 1} \qquad (\because pV = mRT)$$

$$= \left(p_1V_1 - p_2V_2\right)\left[\frac{1}{n-1} - \frac{1}{\text{¥} - 1}\right]$$

$$= \frac{\left(p_1V_1 - p_2V_2\right)\left[\text{¥} - 1 - n + 1\right]}{(n-1)(\text{¥} - 1)}$$

$$= \left(\frac{p_1V_1 - p_2V_2}{n-1}\right)\left(\frac{\text{¥} - n}{\text{¥} - 1}\right)$$

But, $\dfrac{p_1V_1 - p_2V_2}{n-1}$ = work done

$$\therefore H\text{eat transferred,}\ \text{¢}Q = \left(\frac{\text{¥} - n}{\text{¥} - 1}\right) \times \text{work done during polytropic process}$$

- **Change in enthalpy:**

  Change in enthalpy, $\Delta H = m\ C_p\ (T_2 - T_1)$

Chapter: 4 Properties of Steam

4.1 Difference between Steam and Gas:

Steam (Vapour)	Gas
1. It is state of substance in which evaporation is not completed from its liquid state.	1. It is state in which there is complete vaporization of liquid. It is gaseous state.
2. It does not obey Boyle' law, Charle's law and characteristics gas law. Hence it is not perfect gas.	2. It obeys all gas laws, hence it is perfect gas.
3. When the steam is cooled it gets condensed.	3. It remains in gaseous state at moderate pressure and temperature.
4. Specific volume of steam is less compared to gases.	4. Specific volume of gases is more compared to steam.

4.2 Steam Formation:

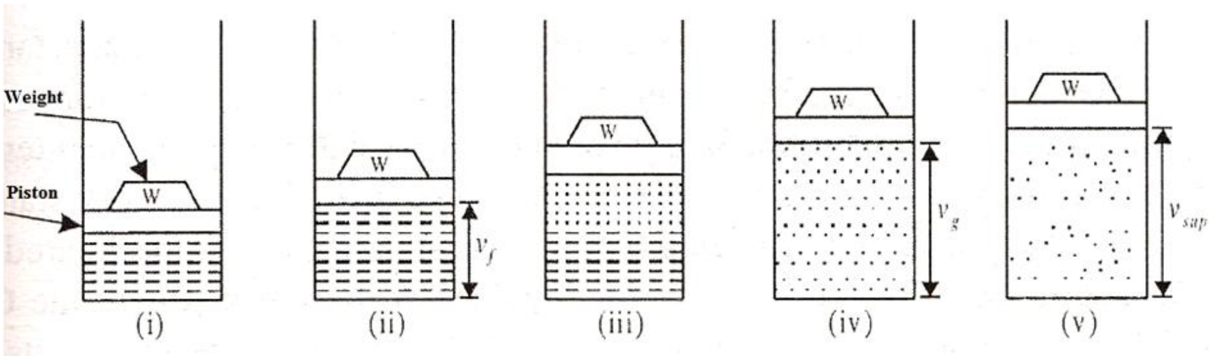


Fig. 4.1 Formation of steam

- Consider a cylinder fitted with a piston which can move freely upwards and downwards in it. Consider 1 kg of water at 0° C under the piston (Fig. 4.1(i)).
- A weight w is placed over the piston so that it exerts constant pressure *p* on the water.
- This condition of water at 0° C is represented by the **point A** on the temperature – enthalpy graph as shown in Fig. 4.2.
- Now if the heat is supplied to water, a rise in temperature will be noticed and this rise will continue till boiling point is reached.
- When the boiling point of water is reached, there will be a slight increase in the water as shown in Fig. 4.1 (ii).

* The **saturation temperature** is defined as the temperature at which the water begins to boil at the stated pressure. This condition of water at temperature T_s is represented by the **point B** on the graph.

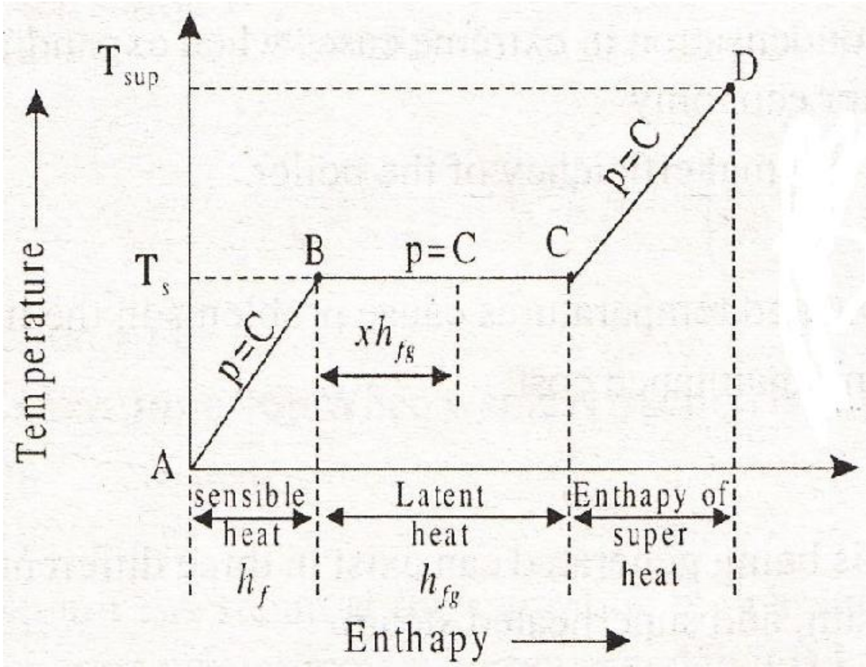


Fig. 4.2 Temperature – Enthalpy diagram

* The amount of heat required to raise the temperature of 1 kg of water from 0° C to the saturation temperature T_s ° C at a given pressure is known as the **sensible heat** and denoted by h_f. This heat is also called **enthalpy of the liquid**.
* Now, if supply of heat to water is continued it will eliminate the evaporation of water while the temperature remains at the saturation temperature T_s because the water will be saturated with heat and any further addition of heat changes only the phase from the liquid phase to the gaseous phase.
* This evaporation will be continued at the same saturation temperature T_s until the whole of the water is completely into steam as shown in Fig. 4.1 (iv). This point is represented by the **point C** on the graph.
* This constant pressure and constant temperature heat addition is represented by the horizontal **line BC** on the graph. The heat being supplied does not show any rise of temperature but changes water into vapor state (steam) and is called **latent heat** or **hidden heat** or **enthalpy of evaporation**. It is denoted by h_{fg}. If the steam is in contact with water, it is called **wet steam** (Fig. 4.1 (iii)).

- Again, if supply of heat to the saturated steam is continued at constant pressure there will be increase in temperature and volume of steam. The temperature of the steam above the saturation temperature at a given pressure is called **superheated temperature**.
- During this process of heating, the dry steam will be heated from its dry state, and the process of heating is called **superheating.** The steam when superheated is called **superheated steam.** This superheating is represented by the inclined **line CD** on the graph.
- The amount of heat required to raise the temperature of dry steam from its saturation temperature to any required higher temperature at the given constant pressure is called **amount of superheat** or **enthalpy of superheat.** The difference between the superheated temperature and the saturation temperature is known as **degree of superheat**.

4.3 Types of Steam:

1) **Wet steam:** A wet steam is a two-phase mixture of entrained water molecules and steam in thermal equilibrium at the saturation temperature corresponding to a given pressure.

   The quality of the wet steam is specified by the dry fraction which indicates the amount of dry steam present in the given quantity of wet steam and is denoted by *x*.

   Dryness fraction of steam: It is the ratio of the actual dry steam present in a known quantity of wet steam to the total mass of the wet steam.

   Let m_s = mass of dry steam present in the given quantity of wet steam.

   m_w = mass of superheated water molecules in the given quantity of wet steam.

$$\text{Dryness fraction x} = \frac{\text{Mass of dry steam present in wet steam}}{\text{Total mass of wet steam}}$$

$$x = \frac{m_s}{m_w + m_s}$$

   The dryness fraction of wet steam is always less than 1 and for dry steam it is equal to 1.

   Wetness fraction of steam: It is the ratio of the mass of water particles present in a in a known quantity of wet steam to the total mass of the wet steam.

$$\text{Wetness fraction} = \frac{m_w}{m_s + m_w}$$

$$= \frac{m_w}{m_s + m_w} + 1 - 1 = 1 - \left(\frac{m_s}{m_w + m_s} \right)$$

$\therefore$ Wetness fraction = $(1 - x)$

Priming: When wetness fraction is expressed in percentage, it is known as priming.

$\therefore$ Priming = $100\,(1 - x)$

2) **Dry saturated steam**: A steam at the saturation temperature corresponding to a given pressure and having no water molecules entrained in it is known as dry saturated steam or dry steam. Its dryness fraction will be unity.

3) **Superheated steam**: When a dry saturated steam is heated further at the given constant pressure, its temperature rises beyond its saturation temperature. The steam in this state is said to be superheated.

4.4 Enthalpy of Steam:

1) **Enthalpy of Liquid:** The amount of heat required to raise the temperature of 1 kg of water from 0° C to the saturation temperature T_s ° C at a given pressure is known as the **sensible heat** or **enthalpy of the liquid** and denoted by h_f.

$$h_f = C_{pw}\,(t_f - 0)$$

Where,

h_f = Enthalpy of liquid in kJ/kg,

C_{pw} = Specific heat of water = 4.1868 kJ/kg K

t_f = Temperature of water in ° C

2) **Enthalpy of Dry Saturated Steam:** It is defined as the total amount of heat required to convert 1 kg of water into 1 kg of dry saturated steam from its freezing point. It is denoted by h_g.

h_g = Heat required to raise the temperature of 1 kg of water to the boiling point + Heat required to convert the same water from its boiling point to dry saturated steam at constant temperature (T_s)

$$h_g = h_f + h_{fg}$$

3) **Enthalpy of Wet Steam:** It is defined as the total amount of heat supplied at a constant pressure to convert 1 kg of water at 0° C to 1 kg of wet steam at the specified dryness fraction. It is denoted by h.

$$h = h_f + x\, h_{fg} \text{ kJ/kg}$$

4) **Enthalpy of Superheated Steam:** It is defined as the total amount of heat required to convert 1 kg of water at 0° C into 1 kg of superheated steam. It is denoted by h_{sup}.

h_{sup} = Heat required to raise the temperature of 1 kg of water to the boiling point + Heat required to convert the same water from its boiling point to dry saturated steam at constant temperature (T_s) + Heat required to convert the same steam into superheated steam(T_{sup})

$$h_{sup} = h_f + h_{fg} + C_{ps}\,(T_{sup} - T_{sat})$$

Where

C_{ps} = Specific heat of superheated steam at constant pressure = 2.0934 kJ/kg K

T_{sup} = Temperature of superheated ° C

T_{sat} = Saturated temperature at given pressure ° C

- **Degree of superheat**: It is defined as the difference between the temperature of superheated steam and dry saturated steam at the given pressure.
  Mathematically, Degree of superheat = $(T_{sup} - T_{sat})$
- **Amount of superheat**: It is defined as the amount of heat added during superheating of steam. It is also known as heat of superheat.
  Mathematically, Amount of superheat = $C_{ps}\,(T_{sup} - T_{sat})$

4.5 Specific Volume of Steam:

It is defined as the volume occupied by the unit mass of a substance. It is expressed in m^3/kg. The volume of water and steam increases with the increase in temperature.

- **Specific Volume of Saturated Water (v_f)**: It is defined as the volume occupied by 1 kg of water at the saturation temperature at a given pressure. See Fig. 4.1 (ii).
- **Specific Volume of Dry Saturated Steam (v_g)**: It is defined as the volume occupied by 1 kg of dry saturated steam at a given pressure. See Fig. 4.1 (iv).

- **Specific Volume of Wet Steam (*v*)**: It is defined as the volume occupied by 1 kg of steam with dryness fraction *x* which contains some dry steam as well as water molecules suspended in it at a given pressure.

  Specific volume of steam = Volume of dry steam at given pressure + Volume of water molecules in suspension

  Consider *x* kg of dry steam and (1 - *x*) kg of water molecules in suspension.

  $$v = x\, v_g + (1 - x)\, v_f$$

  Generally $(1 - x)\, v_f$ is very low and often is neglected.

  Therefore, $v = x\, v_g$ m^3/kg

- **Specific Volume of Superheated Steam (v_{sup})**: It is defined as the volume occupied by 1 kg of superheated steam at a given pressure and superheated temperature. See Fig. 4.1 (v).

  The superheated steam behaves like a perfect gas; therefore its specific volume is determined approximately applying Charle's law.

  $$\frac{v_g}{T_s} = \frac{v_{sup}}{T_{sup}}$$

  $$\therefore v_{sup} = v_g \frac{T_{sup}}{T_s}$$

  Where

  v_g = Specific volume of dry saturated steam at pressure p, m^3/kg

  T_s = Saturation temperature at pressure p, K

  T_{sup} = Superheated temperature, K

  v_{sup} = Specific volume of superheated steam at pressure p, m^3/kg

4.6 Throttling Process:

It is the type of expansion process, in which steam passes through a narrow passage and expands with a full of pressure without doing any external work.

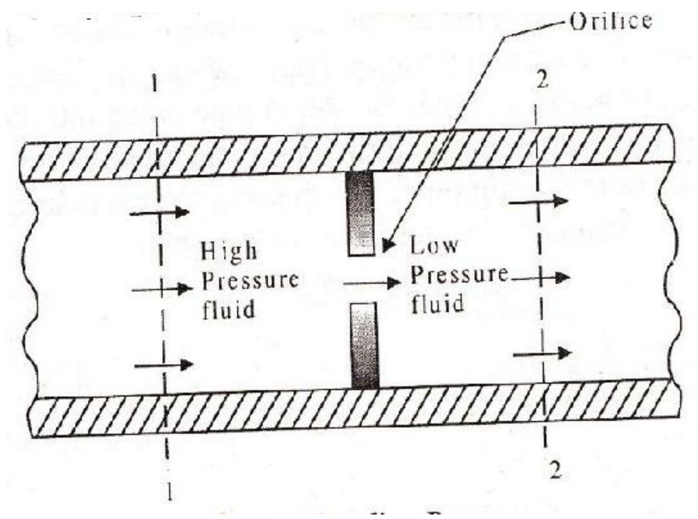


Fig. 4.3 Throttling Process

In this process, there is no interchange of heat and the enthalpy remains constant therefore this process is also called **constant enthalpy process**.

Throttling process is a steady flow process hence steady flow energy equation can be applicable.

$$h_1 + \frac{v_1^2}{2} + gz_1 + q = h_2 + \frac{v_2^2}{2} + gz_2 + W$$

No work is done during throttling process hence W = 0.

No change in elevation hence $z_1 = z_2$

Change in K.E. energy is negligible hence $V_1 = V_2$ (No change in velocity)

Therefore above equation can be rewritten as

$$h_1 = h_2$$

Initial enthalpy = Final Enthalpy

4.7 Measurement of Dryness Fraction:

It is necessary to determine the quality of wet steam in order to ascertain the actual state of the wet steam. The dryness fraction of the steam is measured experimentally. Various types of calorimeters used for measuring dryness fraction of steam are as follows:

- Bucket or Barrel calorimeter
- Separating calorimeter
- Throttling calorimeter
- Separating and Throttling calorimeter

4.7.1 Bucket or Barrel Calorimeter

4.7.1.1 Construction

Bucket calorimeter consists of a calorimeter which is placed on wooden blocks in a vessel. The vessel is large enough to provide an air space around the calorimeter. This air space provides insulation to prevent heat loss. The top cover is made of wood and it closes both the calorimeter and the vessel. This cover has two holes. Through one hole, the steam pipe is led into the calorimeter. The steam is distributed in the calorimeter by the holes in the bottom ring which is connected to the end of the steam pipe. The thermometer is inserted from the second hole to measure the temperature of water in the calorimeter.

4.7.1.2 Working

The calorimeter is placed in the vessel. The top cover is placed in position and the steam pipe is connected to main steam pipe. The steam comes in contact with water in the calorimeter when steam is passed through the water. It condenses and gives out its entire enthalpy of evaporation (latent heat) and part of its sensible heat. Due to heat transfer from steam to water in the calorimeter, the temperature of water increases. Condensation of steam will increase the mass of water. Sufficient quantity of steam should be blown in the calorimeter so that sufficient rise in temperature of water and thereby errors are reduced to minimum. Afterwards the steam cock is closed.

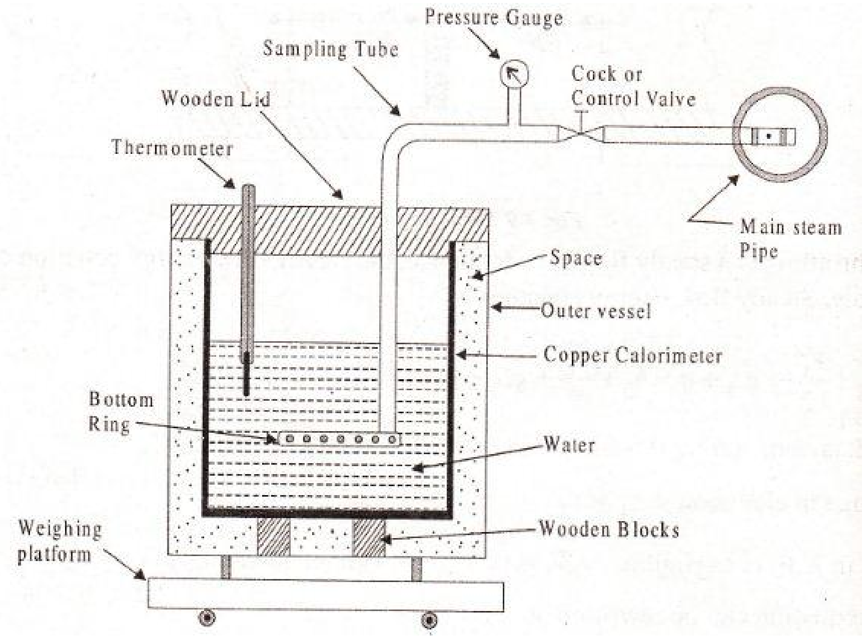


Fig. 4.4 Barrel or Bucket calorimeter

4.7.1.3 Calculation

Let

p = Pressure of steam in a steam pipe, bar

h_{f1} = Enthalpy of liquid at p, kJ/kg K

t_1 = Temperature of water and vessel before experiment, °C

t_2 = Temperature of water and vessel after experiment, °C

h_{f2} = Enthalpy of water after mixing at t_2, kJ/kg K

h_{fg1} = Enthalpy of evaporation of steam, kJ/kg

m_s = Mass of steam condensed, kg

m_w = Mass of water in calorimeter, kg

m_{cal} = Mass of calorimeter, kg

C_{pw} = Specific heat of water, kJ/kg K

C_{pc} = Specific heat of calorimeter, kJ/kg K

x = Dryness fraction of steam

Heat lost by the steam = Heat gained by water and calorimeter

$$\therefore m_s(h_{f1} + xh_{fg1} - h_{f2}) = m_{cal}C_{pc}(t_2 - t_1) + m_wC_{pw}(t_2 - t_1)$$

$$= (m_{cal}C_{pc} + m_wC_{pw})(t_2 - t_1)$$

$$= \left(\frac{m_{cal}C_{pc}}{C_{pw}} + m_w\right)(t_2 - t_1)C_{pw}$$

The term $\frac{m_{cal}C_{pc}}{C_{pw}}$ is called Water Equivalent of Calorimeter. Dryness fraction of steam (x) can be obtained by using above equation.

4.7.3.4 Limitations

1) This method is not accurate.
2) Accuracy decreases as temperature difference (t_2-t_1) increases because of losses are more at higher temperature difference.

4.7.2 Separating Calorimeter

4.7.2.1 Construction

Separating calorimeter consists of two chambers, viz inner chamber and outer chamber. At the top of inner chamber perforated tray is provided where water droplet in the wet steam is separated due to its inertia. Separated droplet is collected in inner chamber while steam is condensed in barrel calorimeter.

4.7.2.2 Working

From main steam pipe certain quantity of steam is taken to the calorimeter through sampling tube. In calorimeter steam against the baffle plates/perforated tray. Due to inertia of droplets and sudden change in direction, water droplets are separated from steam which is collected in inner chamber. Steam is condensed in barrel calorimeter. Quantity of water droplet separated can be read from scale and quantity of steam can be calculated from difference in mass of water of barrel calorimeter.

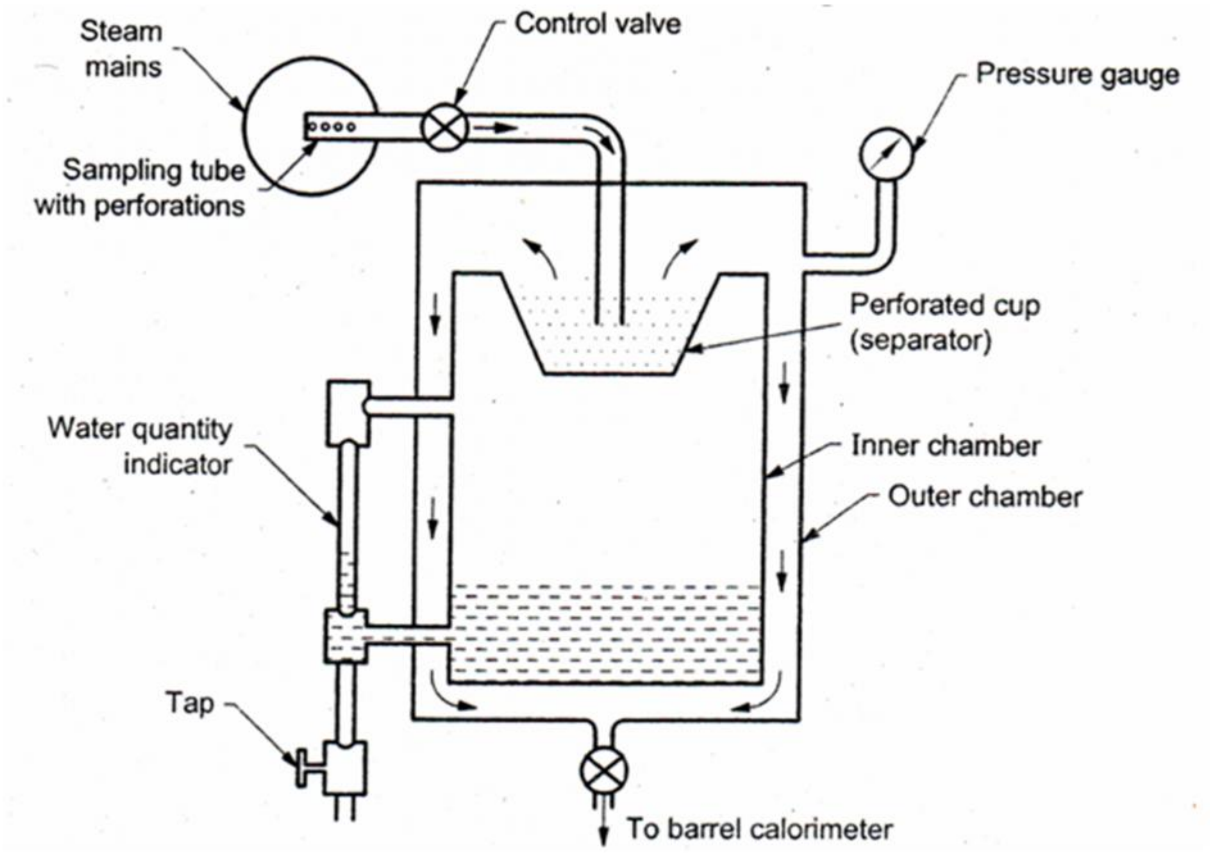


Fig. 4.5 Separating Calorimeter

4.7.2.3 Calculation

Let m_w= mass of water separated

m_s= mass of steam condensed in a bucket calorimeter.

$m_s = m_2 - m_1$

m_1= mass of bucket with water before mixing.

m_2=mass of bucket with water after mixing the steam

The dryness fraction of steam is given by

$$x = \frac{m_s}{m_s + m_w}$$

4.7.2.4 Limitation

100% separating of suspended water particles from wet steam by mechanical mean is not possible.

4.7.3 Throttling Calorimeter

4.7.3.1 Construction

Fig. shows throttling calorimeter which essentially consists of throttle valve, pressure gauge, thermometer and manometer. Through sampling tube steam is taken to throttle valve where steam is throttled from higher pressure to lower pressure. Pressure gauge is used to measure pressure before throttling and manometer is used to measure pressure after throttling. Thermometer is used to measure temperature after throttling.

4.7.3.2 Working

With full open steam stop valve, steam is allowed to throttle until steady pressure and temperature is reached. At steady state condition pressure before throttling (p1) and temperature after throttling is to be measured.

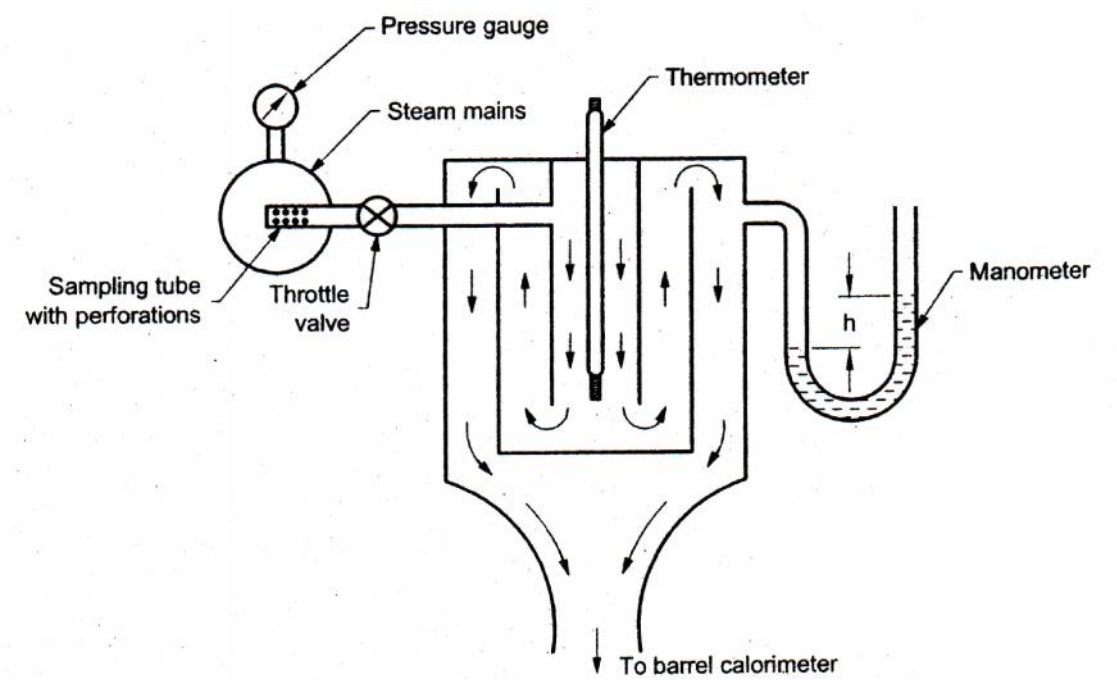


Fig. 4.5 Throttling calorimeter

4.7.3.3 Calculation

As we know that during throttling process enthalpy remains constant. This fact is used to measure dryness fraction of wet steam.

Enthalpy before throttling = Enthalpy after throttling

$$h_{f1} + X_1 h_{fg1} = h_{f2} + h_{fg2} + C_{ps}(T_{\sup 2} - T_{s2})$$

$$= h_{g2} + C_{ps}(T_{\sup} - T_{s2})$$

$$\therefore \quad X_1 = \frac{h_{g2} + C_{ps}(T_{\sup} - T_{s2}) - h_{f1}}{h_{fg1}}$$

Let X_1 = unknown dryness fraction,

h_{f1} = enthalpy of saturated liquid at p1, kJ/kg

h_{fg1} = latent heat of steam at p1, kJ/kg

h_{f2} = sensible heat of steam at p2, kJ/kg

h_{fg2} = latent heat of steam at p2, kJ/kg

C_{ps}= specific heat of superheated steam assumed 2.1 kJ/kg k

T_{sup2}= temperature of steam measured by thermometer after throttling

T_{s2}= saturation temperature of steam at p2

4.7.3.4 Limitation

Condition of steam after throttling must be superheated.

4.7.4 Combined Separating and Throttling Calorimeter.

It is already stated that the dryness fraction of the steam can be found by using throttling calorimeter only if the dryness fraction is greater than 0.95. When the dryness fraction is less than 0.9, then part of water is removed first passing the steam through separating calorimeter and then it is passed through a throttling calorimeter with a combined arrangement of separating and throttling calorimeter as shown in Fig. 5.3. Even load values of dryness fraction of steam can be easily determined.

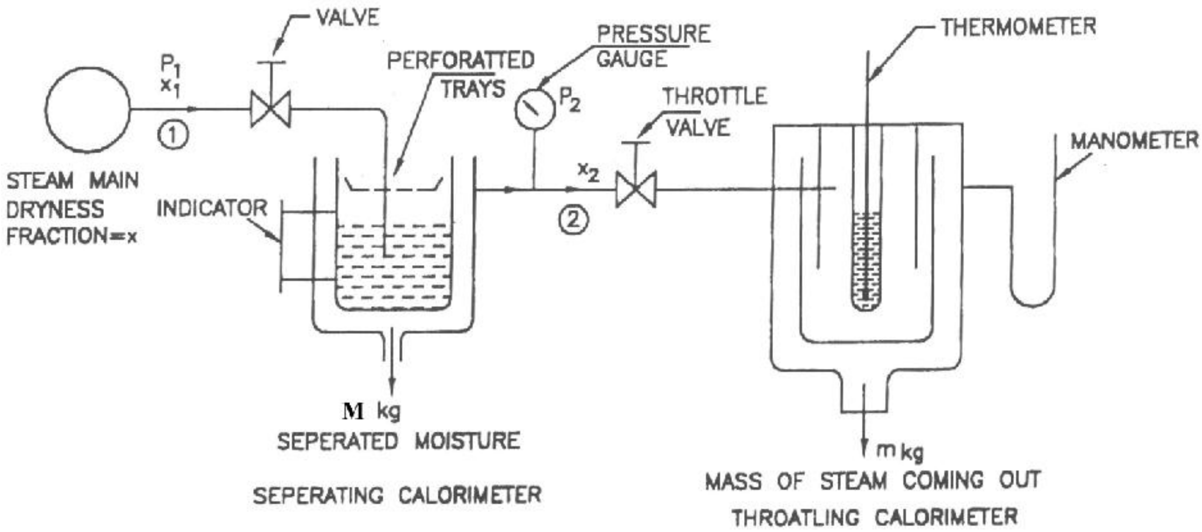


Fig. 4.6 Combined separating and throttling calorimeter

4.7.4.1 Construction

This calorimeter has two calorimeters namely separating calorimeter and throttling calorimeter in series.

4.7.4.2 Working

In a separating and throttling calorimeter, the steam from sampling tube is first passed through the separating calorimeter where it is partly dried up and then it is further passed on to the throttling calorimeter from where it comes out as superheated steam. The steam coming out from throttling calorimeter is condensed in a condenser and the mass of the condensate coming out of the condenser is recorded.

4.7.4.3 Calculation

If X_1 is the dryness fraction of steam measured by separating calorimeter then

$$X_1 = \frac{m}{m + M}$$

Let m = mass of steam condensed and collected from condenser.

M = mass of water collected from separating calorimeter.

If X_2 is the dryness fraction of steam entering throttling calorimeter, then X_2 can be calculated using equation

$$h_{f1} + X_2 h_{fg1} = h_{f2} + h_{fg2} + C_{ps}(T_{\sup} - T_{sat})$$

Where, h_{f1}, h_{fg1}, T_{sup} and T_{sat} has same meaning as in case of throttling calorimeter.

Let X be the initial dryness fraction of steam then the original water droplet in the sample is (1-X) (m+M) kg. Out of this $(1-X_1)$ (m+M) is removed by separating calorimeter and $(1-X_2)$. m kg is passed through throttling calorimeter.

$$(1-X)(M + m) = (1- X_1)(M + m) + (1- X2)\,m$$

$$(1-X) = (1- X_1) + (1- X_2)\,m/(M + m)$$

Substituting the value of m / M+ m

$$(1-X) = (1- X_1) + (1- X_2)\quad X_1$$

$$(1-X) = 1 - X_1 + X_1 - X_1\,X$$

$$X = X_1\,X_2$$

5. HEAT ENGINES

❖ Thermal prime movers:

The thermal prime mover is a prime mover that is made to utilize the heat energy for conversion into mechanical work.

- Thermal prime movers are widely used for performing various functions, for example, to run vehicles, to run household appliances; to run machines etc. this is the most important of all the prime movers.
- Thermal prime movers have played very important role in the field of transportation and communication on land, on sea and in the space.
- Internal combustion engines, steam turbines, gas turbines, rockets etc. are examples of thermal prime movers.

❖ Sources of Energy (Heat):

The industrial progress of any country is based on the per capita consumption of electrical power. This electrical power can be generated by using different forms of energy in prime movers.

The sources of energy can be of two types –

(a). **Renewable** or **Non-conventional energy**

(b). **Non-renewable** or **conventional energy**

The following table lists theses energy sources.

Different sources of energy	
Renewable energy sources	**Non Renewable energy sources**
1. Solar energy 2. Wind Energy 3. Tidal energy 4. Geothermal energy 5. Wave energy 6. Energy stored in water (Potential energy)	1. Coal, coke etc. 2. Petroleum and its derivatives such as Diesel, Petrol, Kerosene etc. 3. Natural Gas 4. Nuclear Power

❖ ENGINE:

An engine is a device which transforms one form of energy into another form.

❖ HEAT ENGINE:

Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine.

- Generally source of heat is combustion chamber or furnace where combustion of fuel takes place. Heat is continuously supplied to the medium from the combustion chamber for conversion into mechanical work.
- In addition to the above three elements, there is one cold body, at a lower temperature than the source is known as ***heat sink.***

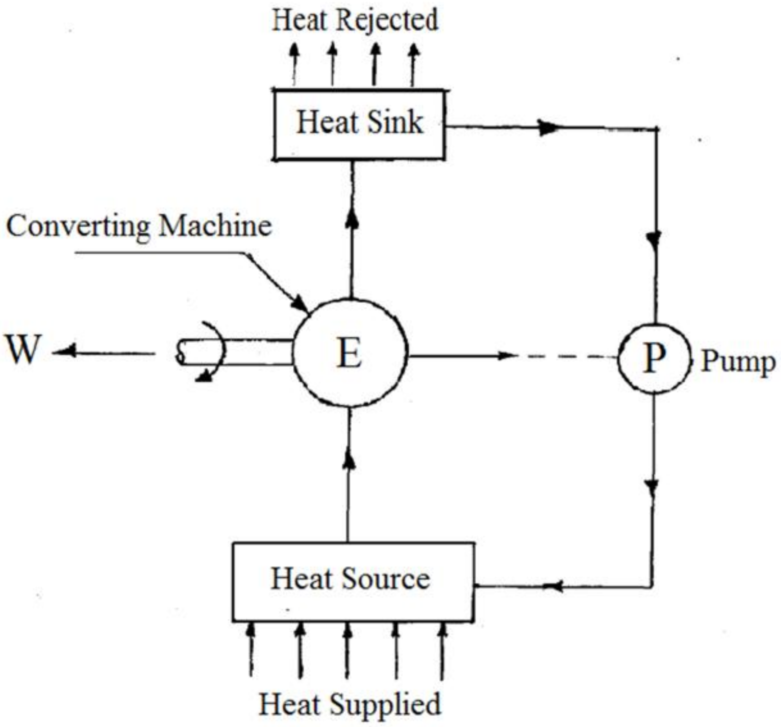


Fig. 1 Elementary Heat Engine.

- Fig. 1 illustrates the basic principle of an elementary heat engine. The working fluid takes heat from heat source and flows to the converting machine E where heat energy converts into mechanical work.
- After this conversion it is discharged into the sink where it is cooled and comes to the original state. From the heat sink working fluid is supplied to heat source by the pump P, where it is heated again and cycle is repeated.

❖ Classification of Heat Engine:

Heat engine are divided into two broad classes:

(i) External combustion engine
(ii) Internal combustion engine

1. External Combustion Engine:

In this case, combustion of fuel takes place outside the cylinder as in case of steam engines where the heat of combustion is employed to generate steam which is used to move a piston in a cylinder. Other examples of external combustion engine are hot air engines, steam turbine and closed cycle gas turbine. These engines are generally used to drive locomotives, ships, generation of electric power etc.

2. Internal Combustion (IC) Engine:

In this case combustion of fuel with oxygen of the air occurs within the cylinder of the engine. The internal combustion engines group includes engines employing mixture of combustible gases and air, known as gas engines, those using lighter liquid fuel or spirit known as petrol engines and those using heavier liquid fuels, known as oil compression ignition or diesel engines.

❖ Advantages of Heat Engines:

The advantages of internal combustion engines are:

1. Grater mechanical efficiency.
2. Lower weight and bulk to output ratio.
3. Lower first cost.
4. Higher overall efficiency.
5. Lesser requirement of water for dissipation of energy through cooling system.

The advantage of external combustion engines are:

1. Use of cheaper fuels.
2. High starting torque.
3. Higher weight and bulk to output ratio.

❖ DEFINITIONS:

- **Working substance:**

  When a gas or mixture of gases or a vapour is used in engine for transferring heat, it is known as working fluid or working substance.

  Working fluids are able to absorb heat, store within them and give up heat when required. During the process of absorbing and giving up heat, its pressure, volume, and temperature changes accordingly. Working fluid is never destroyed or reduced in quantity during the process.

- **Converting machines:**

  Any machine, which converts heat energy of the working fluid into mechanical work is called converting machine.

- **Reciprocating machine:**

  It is the machine consisting of a hollow cylinder into which a piston reciprocates by the action of a working fluid.

- **Rotary machine:**

  It is the machine consisting of a wheel, fixed on a shaft, fitted with blades or vanes rotating due to the action of the working fluid upon the blades.

- **Jet machine:**

  It is the machine in which the fluid is discharged from the machine in the form of a jet and producing an impact which causes the motion.

- **Cycle:**

It is defined as a series of processes performed in a definite order or sequence so that, after different and definite number of processes, all the concerned substances are returned to their original state and condition.

- **Direct cycle:**

  A heat engine, operating on a cycle produces or develops **Mechanical energy** or **work** is said to be working on a direct cycle.

- **Reversed cycle:**

  If the sequence of operation or processes in direct cycle are reversed it is said to be operating on reversed cycle.

❖ HEAT ENGINE CYCLES:

Following are the various heat engine cycles which will be discussed in detail in this chapter.

(1) Carnot cycle (2) Rankine cycle (3) Otto cycle (4)Diesel cycle

❖ CARNOT CYCLE:

- Sadi Carnot in 1824 first proposed the concept of heat engine working on reversible cycle called Carnot cycle.
- According to **Carnot theorem "No cycle can be more efficient than a reversible cycle operating between the same temperature limits."**
- Carnot cycle is useful to compare the efficiency of any cycle under consideration with the efficiency of any cycle operating between the same two temperatures.

- **Assumptions made in the working of the Carnot cycle**
  (1) Working fluid is a perfect gas.
  (2) Piston cylinder arrangement is weightless and does not produce friction during motion.
  (3) The walls of cylinder and piston are considered as perfectly insulated.
  (4) Compression and expansion are reversible.
  (5) The transfer of heat does not change the temperature of sources or sink.

- **Carnot cycle Processes:**

  This cycle consists of four processes in the following order.

  (1) Isothermal expansion,
  (2) Adiabatic expansion,
  (3) Isothermal compression,
  (4) Adiabatic compression.

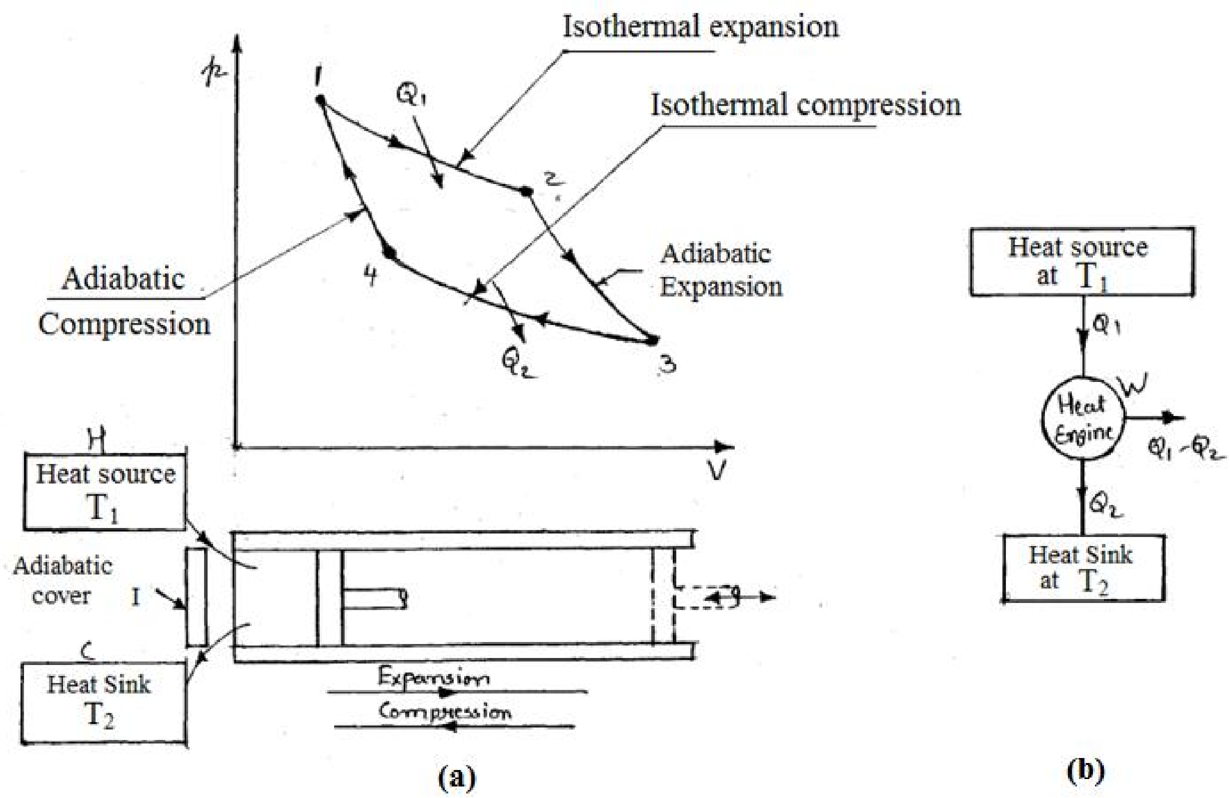


Fig. 2 Carnot cycle.

(1) Isothermal expansion (1-2) :-

The source of heat is applied to the end of the cylinder and isothermal reversible expansion occurs at T_1. During this process Q_1 heat is supplied to the system

(2) Adiabatic expansion (2-3) :-

The cylinder becomes perfect insulator because of non-conducting walls and end. Adiabatic cover is brought in contact with the cylinder head. Hence no heat transfer takes place. The fluid expands adiabatically and reversibly. The temperature falls from T_1 to T_2.

(3) Isothermal compression (3-4) :-

Adiabatic cover is removed and sink C is applied to the end of the cylinder. The heat, Q_2 is transferred reversibly and isothermally at temperature T_2 from the system to the sink C.

(4) Adiabatic compression (4-1) :-

Adiabatic cover is brought in contact with cylinder head. This completes the cycle and system is returned to its original state at 1. During the process, the temperature of system is raised from T_2 to T_1.

- Carnot cycle is represented on p-V diagram in Fig.2 (a) and schematically in Fig.2 (b) which shows the energy transfer.

➢ Efficiency of Carnot cycle :

Consider 1 kg of working substance

- Heat supplied during isothermal process (1-2)

$$Q_1 = p_1V_1 \log_e \frac{V_2}{V_1}$$

$$= RT_1 \log_e \frac{V_2}{V_1} \quad \ldots.(1)$$

- Heat rejected during isothermal compression (3-4);

$$Q_2 = p_3V_3 \log_e \frac{V_4}{V_3}$$

$$= RT_2 \log_e \frac{V_4}{V_3} \quad \ldots.(2)$$

- During ***adiabatic expansion (2-3)*** and ***adiabatic compression (4-1),*** the heat transfer from or to the system is ***zero***.
- Let r = ratio of expansion for process (1-2) $= \frac{V_2}{V_1}$

  = ratio of compression for process (3-4) $= \frac{V_4}{V_3}$

by substituting the value of *r* in eq.(1) & (2) we have

$$Q_1 = RT_1 \log_e r \text{ and } Q_2 = RT_2 \log_e r$$

$\therefore$ Work done = Heat supplied (Q_1) – Heat rejected (Q_2)

$$= RT_1 \log_e r - RT_2 \log_e r$$

$\therefore (Q_1 - Q_2) = \text{work done} = R \log_e r\,(T_1 - T_2)$

$\therefore$ Thermal efficiency η = $\dfrac{Work\ done}{Heat\ supplied} = \dfrac{Q_1 - Q_2}{Q_1}$

$$\therefore \eta = \frac{R \log_e r (T_1 - T_2)}{R T_1 \log_e r}$$

$$\therefore \eta = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}$$

where T_1 = Maximum temperature of cycle (K)

T_2 = Minimum temperature of cycle (K)

- **Assumptions made in the working of the Carnot Engine:**
  - ✓ The piston moving in a cylinder does not develop any friction during motion.
  - ✓ The walls of piston and cylinder are considered as perfect insulators of heat.
  - ✓ The cylinder head is so arranged that it can be a perfect heat conductor or perfect heat insulator.
  - ✓ The transfer of heat does not change the temperature of source or sink.
  - ✓ The working medium is a perfect gas with constant specific heats.
  - ✓ Compression and expansions are reversible.

- **Limitations of Carnot cycle:**
  - ✓ The Carnot cycle is hypothetical.
  - ✓ The thermal efficiency of Carnot cycle depends upon absolute temperature of heat source T1 and heat sink T2 only, and independent of the working substance.
  - ✓ Practically it is not possible to neglect friction between piston and cylinder. It can be minimized but cannot be eliminated.
  - ✓ It is impossible to construct cylinder walls which are perfect insulator. Some amount of heat will always be transferred. Hence perfect adiabatic process cannot be achieved.
  - ✓ The isothermal and adiabatic processes take place during the same stroke. Therefore the piston has to move very slowly for isothermal process and it has to move very fast during remaining stoke for adiabatic process which is practically not possible.
  - ✓ The output obtained per cycle is very small. This work may not be able to overcome the friction of the reciprocating parts.

❖ CARNOT VAPOUR CYCLE:

In the Carnot Vapour Cycle, steam or any other vapour is used as working substance in place of a perfect gas.

Components and arrangement of Carnot vapour cycle is shown in fig.(3) and same is represented on p-V diagram in fig.(4)

- **Process (1-2):** This is an isothermal heat addition in the boiler, isothermal process having $T_1 = T_2$ = constant. This is also constant pressure process. The saturated water at point 1 is isothermally converted into dry saturated steam in a boiler.

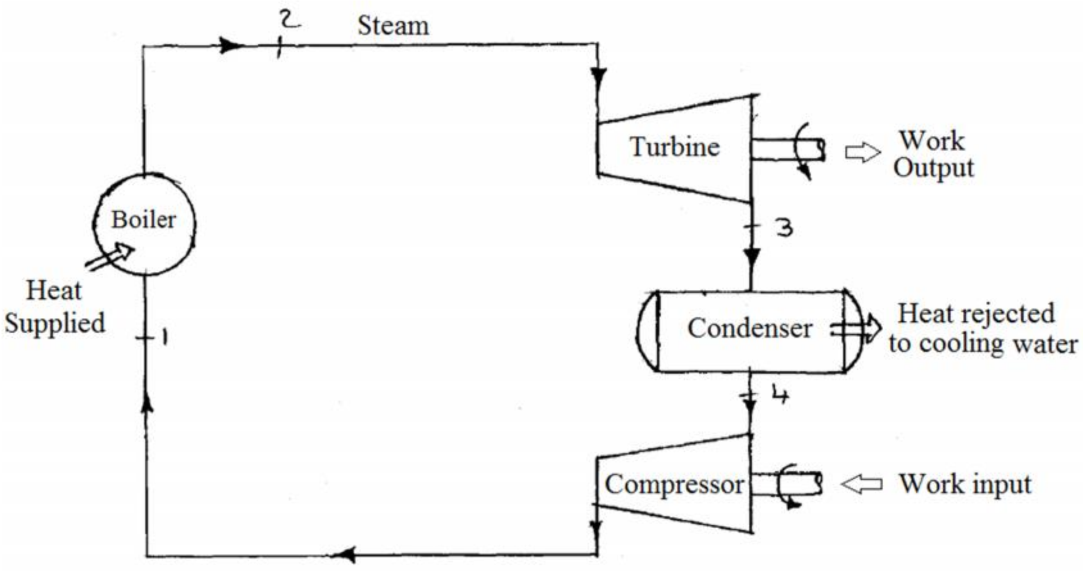


Fig. 3 Arrangement of Carnot vapour cycle

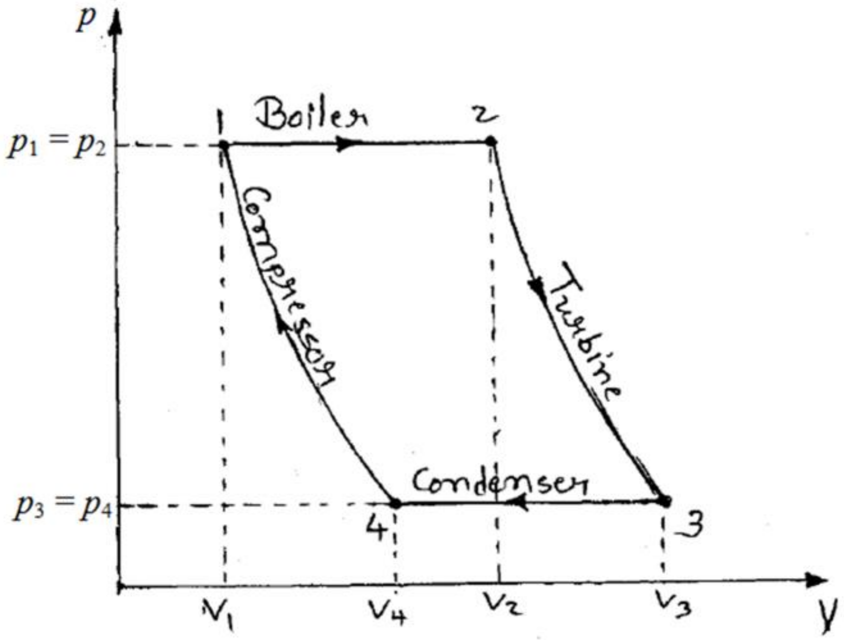


Fig. 4 p-V diagram of Carnot vapour cycle

- **Process (2-3):** The steam produced from the boiler enters steam turbine at condition (2). The steam expands in the turbine. This is reversible adiabatic/isentropic expansion. This expansion will reduce the pressure of the steam from P_1 to P_2 and the condition at exit will be 3 after this expansion. Turbine develops work W_T.

- **Process (3-4):** This is the heat rejection process in the condenser. The expanded steam enters the condenser at condition (3) changing condition from (3) to (4). The process 3-4 is at constant pressure and temperature as shown in p-V diagram.
- **Process (4-1):** At (4) steam and water enter the compressor in which reversible adiabatic/isentropic compression will take place. The pressure will increase from P_2 to P_1 by compression. Compressor consumes power W_C. This completes the cycle.

➢ **Efficiency of Carnot vapour cycle:**

Consider 1 kg of working substance.

Work developed by turbine, $W_T = (h_2 - h_1)$

Work input during compression, $W_C = (h_1 - h_4)$

$\therefore$ Net work developed, $W_{net} = W_T - W_C$

$$= (h_2 - h_1) - (h_1 - h_4)$$

Heat supplied = $h_2 - h_1$

$$\therefore \eta = \frac{\text{Net work developed}}{\text{Heat supplied}}$$

$$= \frac{(h_2 - h_3) - (h_1 - h_4)}{(h_2 - h_1)}$$

$$= \frac{(h_2 - h_1) - (h_3 - h_4)}{(h_2 - h_1)}$$

$$= 1 - \frac{(h_3 - h_4)}{(h_2 - h_1)}$$

But $(h_3 - h_4) = Q_R$, heat rejected by condenser, and

$(h_2 - h_1) = Q_S$, heat supplied by boiler.

$$\therefore \eta = 1 - \frac{Q_R}{Q_S}$$

Entropy is defined as $ds = \int \frac{dQ_{rev}}{T}$

So, we can write

$$Q_R = T_2(S_3 - S_4) \text{ and } Q_S = T_1(S_2 - S_1)$$

$$\therefore \eta = 1 - \frac{T_2(S_3 - S_4)}{T_1(S_2 - S_1)}$$

But process (2-3) and (4-1) are isentropic, $S_2 = S_3$ and $S_1 = S_4$.

$$\therefore \eta = 1 - \frac{T_2}{T_1}$$

where T_1 = Maximum temperature of cycle (K)

T_2 = Minimum temperature of cycle (K)

- **Limitations:**
  - ✓ Process (4-1) is adiabatic/isentropic compression of wet vapour, it is very difficult to achieve because the liquid tends to separate out from the vapour.
  - ✓ Practically, compression and expansion process are having irreversibility. This will reduce the actual efficiency than theoretical cycle.
  - ✓ To achieve superheating of steam at constant temperature, pressure has to be reduced. It means expansion and heat addition is to be done simultaneously which is practically very difficult.

❖ RANKINE CYCLE:

It is very difficult to pump mixture of vapour and liquid as in case of Carnot vapour cycle. This difficulty is eliminated in Rankine cycle by complete condensation of vapour in condenser and then pumping the water isentropically to the boiler at boiler pressure.

- The heat energy of the fuel is converted into mechanical work or power in steam turbine power plants. The flow diagram and (p-V) diagram of Rankine cycle are shown in fig.

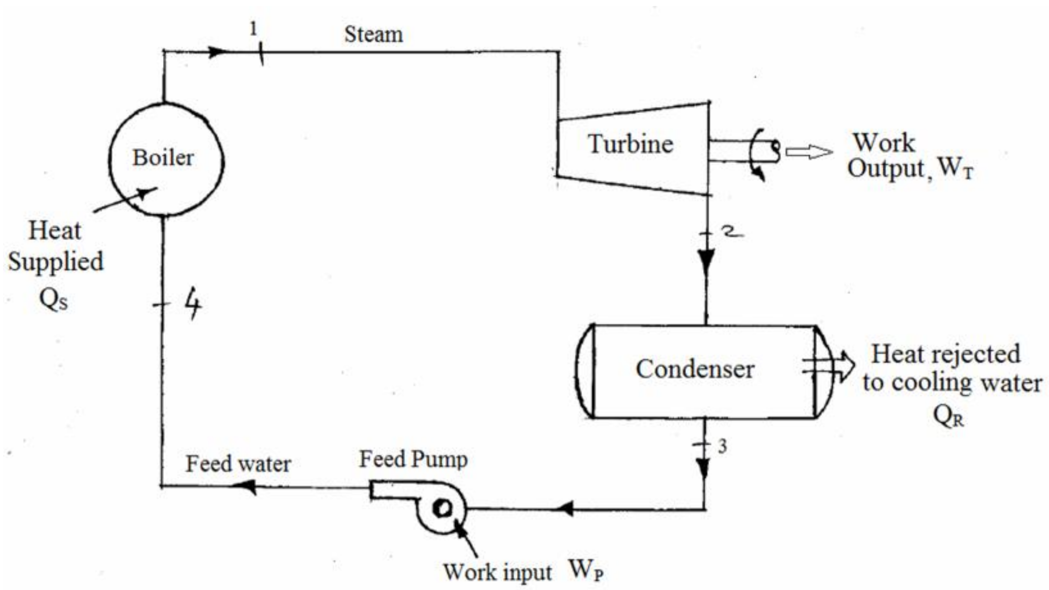


Fig. 5 Flow diagram of Rankine cycle

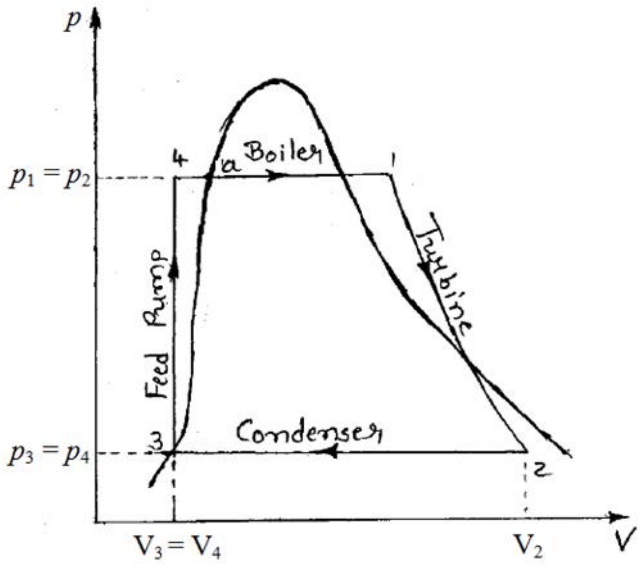


Fig. 6 p-V diagram of Rankine cycle.

- The four main components of cycle are:
  (1) Boiler, (2) Turbine, (3) Condenser, (4) Feed pump.
- **Process (1-2):** High pressure and high temperature superheated, dry saturated or wet steam generated in the boiler at p_1 and T_1 is supplied to the steam turbine. This steam expands isentropically into steam turbine up to the condenser pressure. Steam turbine develops mechanical work, W_T due to expansion of steam.
- **Process (2-3):** The exhaust steam from turbine enters into condenser, where it is condensed at constant pressure by circulating cooling water in the tubes. The heat rejected by exhaust steam is Q_R.
- **Process (3-4):** The condensed water coming from condenser is pumped to boiler at boiler pressure with the help of feed pump. To do so work, W_P is supplied to feed pump.
- **Process (4-1):** The water is heated at constant pressure p_1 in the boiler until the saturation temperature is reached (process (4-a)), Saturated water is converted into saturated steam at constant pressure (process (a-b)). During process (b-1) steam is superheated in superheater.

➢ Efficiency of Rankine cycle:

Heat supplied in boiler, Q_S

$$\therefore Q_S = h_1 - h_4$$

Work developed by turbine, W_T

$$\therefore W_T = h_1 - h_2$$

Heat rejected to cooling water in condenser, Q_R

$$\therefore Q_R = h_2 - h_3$$

Work supplied to feed pump, W_P

$$\therefore W_P = h_4 - h_3$$

Net work output, W_{net}

$$\therefore W_{net} = W_T - W_P$$

$$\therefore W_{net} = (h_1 - h_2) - (h_4 - h_3)$$

$$\therefore \text{Rankine cycle efficiency} = \frac{\text{Net work output}}{\text{Heat supplied in boiler}}$$

$$\therefore \eta_R = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}$$

$$\therefore \eta_R = \frac{(h_1 - h_4) - (h_2 - h_3)}{(h_1 - h_4)}$$

$$\therefore \eta_R = 1 - \frac{h_2 - h_3}{h_1 - h_4}$$

Usually pump work is very small, hence it is neglected

$$\therefore \eta_R = \frac{h_1 - h_2}{h_1 - h_4}$$

- **Difference between Rankine cycle and Carnot cycle:**
  (1) The exhaust steam from the turbine is not completely condensed in condenser in case of Carnot cycle; while in case of Rankine cycle it is completely condensed.
  (2) The compressor is used in Carnot cycle to handle mixture of water and steam. In Rankine cycle pump is used in place of compressor, it has to handle only liquid.
  (3) Superheating of steam is very difficult to achieve in Carnot cycle but there is a possibility of superheating of steam in Rankine cycle.

❖ OTTO CYCLE:

Nicholas-A-Otto, a German engineer developed the first successful engine working on this cycle in 1876. This cycle is also known as Constant volume cycle because heat is supplied and rejected at constant volume. Mainly this cycle is used in petrol and gas engines.

- **Air standard efficiency:**

  The efficiency of engine in which air is used as working substance is known as ***air standard efficiency.***
  - The air standard efficiency is always greater than the actual efficiency of cycle. Otto cycle is also one of the air standard cycle.
- **Assumptions made for analysis of Air standard cycle:**
  (1) The working fluid is air.
  (2) In the cycle, all the processes are reversible.
  (3) The air behaves as an ideal gas and its specific heat is constant at all temperatures.

$C_P = 1.005\, kJ / kg\ K,\ C_V = 0.718\, kJ / kg\ K,\ \ ¥ = 1.4$

(4) Mass of working fluid remains constant through entire cycle.

(5) Heat is supplied from constant high temperature heat reservoir. Some heat is rejected from fluid to a heat sink.

- **Processes of Otto cycle:**

Otto cycle consists of two constant volume and two adiabatic processes as shown in fig. 7.

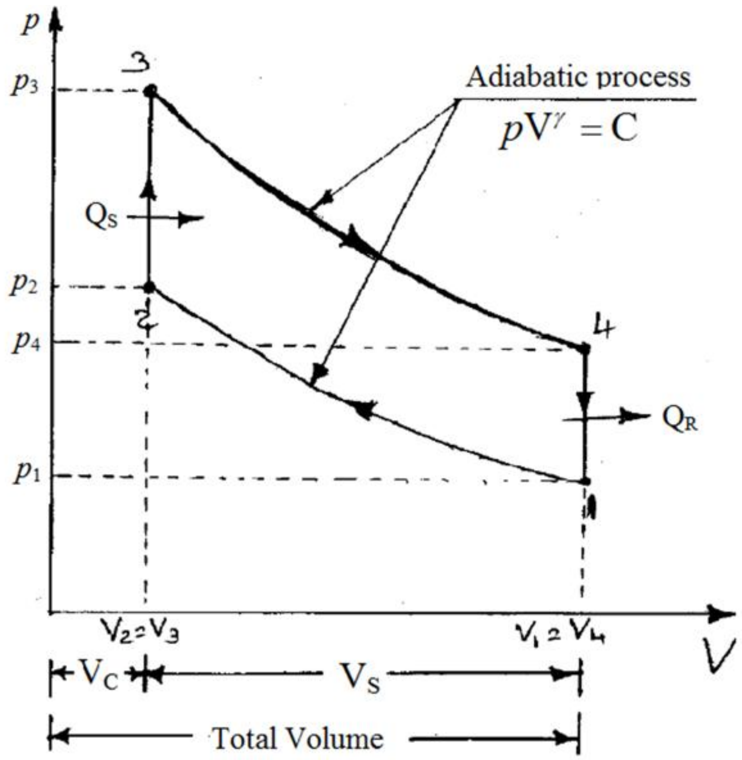


Fig. 7 p-V diagram for Otto cycle.

Consider 'm' kg of air in the cylinder.

- **Process (1-2):** Reversible adiabatic or isentropic compression of air. During this process air is compressed from state-1 to state-2, pressure and temperature of air increases.
- **Process (2-3):** During this process heat is added to air at constant volume. Due to heat addition, pressure and temperature increases.

$\therefore$ Heat supplied, $Q_S = mC_v(T_3 - T_2)$ **….** (1)

- **Process (3-4):** Reversible adiabatic or isentropic expansion of air from state-3 to state-4. Work is developed during this process. Pressure and temperature of air decreases.
- **Process (4-1):** Constant volume heat rejection is carried out during this process. Hence pressure and temperature of air decreases to initial value. This way, a cycle is completed.

$\therefore$ Heat rejected, $Q_R = mC_v(T_4 - T_1)$ …. (2)

- **Efficiency of Otto cycle:**

Net work done, $W_{net} = \text{Heat supplied} - \text{ Heat rejected}$

$$= mC_v(T_3 - T_2) - mC_v(T_4 - T_1)$$

Air standard efficiency, $¦ = \dfrac{\text{Net work done}}{\text{Heat supplied}}$

$$= \frac{mC_v(T_3 - T_2) - mC_v(T_4 - T_1)}{mC_v(T_3 - T_2)}$$

$$= 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} \qquad \text{….}$$

(3)

Compression ratio is defined as $r = \dfrac{V_C + V_S}{V_C}$

But $V_C + V_S = V_1$ (From fig. 7)

$V_C = V_2$

$\therefore r = \dfrac{V_1}{V_2}$

Expansion Ratio, $r = \dfrac{V_4}{V_3}$

For process (1-2):

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{¥-1} = r^{¥-1} \qquad (\because r = \frac{V_1}{V_2}) \qquad \text{….}$$

(4)

For process (3-4):

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{¥-1} = r^{¥-1} \qquad \text{….}$$

(5)

From the equation (4) and (5), we get

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = r^{(¥-1)} \qquad \text{….}$$

(6)

By substituting eq. (6) into eq. (3)

$$\eta = 1 - \left[\frac{\left(\frac{T_3}{r^{\gamma-1}} - \frac{T_2}{r^{\gamma-1}} \right)}{T_3 - T_2} \right]$$

$$\therefore \eta = 1 - \frac{1}{r^{\gamma-1}} \qquad \text{.... (7)}$$

- It is clear from above equation that the efficiency of Otto cycle depends upon compression ratio (r) only. Generally a compression ratio of 6 to 10 is used in petrol engine.

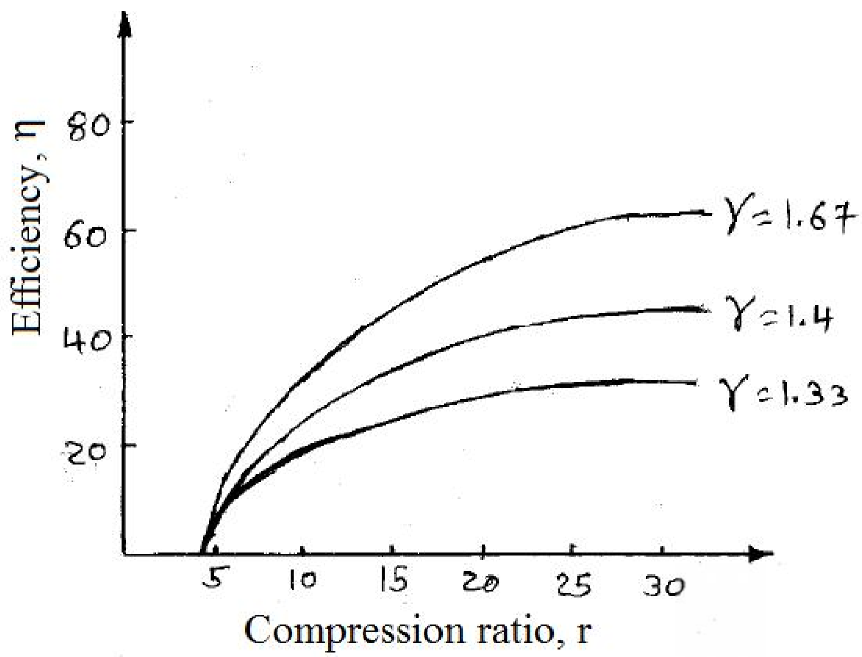


Fig. 8 Effect of compression ratio on η

- The effect of compression ration air standard efficiency of Otto cycle is illustrated in fig. 8. Theoretically, efficiency can be increased by increasing the compression ratio.

❖ DIESEL CYCLE:

This cycle was discovered by a German engineer Dr. Rudolph Diesel. Diesel cycle is also known as ***constant pressure heat addition cycle.***

- The diesel cycle consists of two reversible adiabatic process, a constant pressure process and constant volume process. (p-V) diagram of this cycle is shown in fig. 9.
- **Process (1-2):** Reversible adiabatic or isentropic compression of air from state-1 to state-2. Pressure and temperature of air increases.

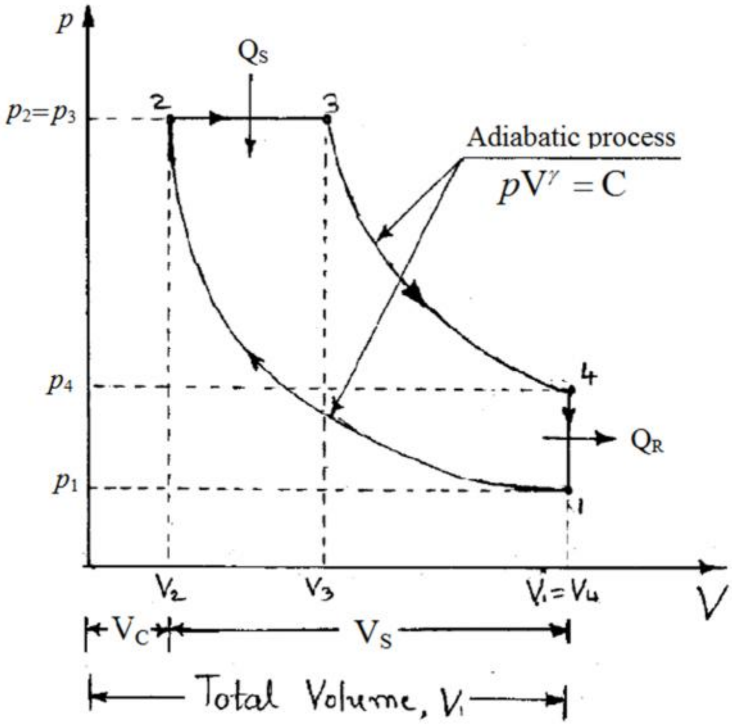


Fig. 9 p-V diagram for diesel cycle

- **Process (2-3):** During this process heat is added to air at constant pressure. Due to heat addition volume and temperature of air increases. Volume ratio $\frac{V_3}{V_2}$ is known as cut-off ratio.

$$\therefore \text{ Heat supplied, } Q_S = mC_p(T_3 - T_2) \qquad \text{…. (10)}$$

- **Process (3-4):** Reversible adiabatic or isentropic expansion of air from state-3 to state-4. Work is developed during this process.
- **Process (4-1):** Constant volume heat rejection is carried out during this process. Hence pressure and temperature of air decreases to initial value. This way cycle is complete.

$$\therefore \text{ Heat rejected, } Q_R = mC_v(T_4 - T_1) \qquad \text{…. (11)}$$

➢ Efficiency of Diesel cycle:

Net work done, $W_{net} = \text{Heat supplied} - \text{ Heat rejected}$

$$= mC_p(T_3 - T_2) - mC_v(T_4 - T_1)$$

$$\text{Air standard efficiency, } \eta = \frac{\text{Net work done}}{\text{Heat supplied}}$$

$$= \frac{mC_p(T_3 - T_2) - mC_v(T_4 - T_1)}{mC_p(T_3 - T_2)}$$

$$= 1 - \frac{(T_4 - T_1)}{\gamma (T_3 - T_2)} \quad \text{....} \quad (12)$$

Let, compression ratio, $r = \frac{V_1}{V_2}$

Cut-off ratio, $\rho = \frac{V_3}{V_2}$

$$\text{Expansion Ratio } = \frac{V_4}{V_3} = \frac{V_4 / V_2}{V_3 / V_2} = \frac{r}{\rho} \quad (\because V_1 = V_4)$$

For process (1-2):

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma - 1} = r^{\gamma - 1}$$

$$\therefore T_2 = T_1 \cdot r^{\gamma - 1} \quad \text{...} \quad (13)$$

For process (2-3)

$$\frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3}$$

Since $p_2 = p_3$ (from fig. 9)

$$\therefore T_3 = T_2 \cdot \frac{V_3}{V_2}$$

By substituting the value of T_2 from eq. (13)

$$\therefore T_3 = \left[T_1 \cdot r^{\gamma - 1}\right] \cdot \rho \quad \text{...} \quad (14)$$

For process (3-4):

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma - 1} \quad \text{But } \frac{V_4}{V_3} = \frac{r}{\rho}$$

$$= \left(\frac{\rho}{r}\right)^{\gamma - 1}$$

$$\therefore T_4 = T_3 \cdot \frac{\rho^{\gamma-1}}{r^{\gamma-1}}$$

By substituting the value of T_3 from eq. (14), we get

$$T_4 = (T_1 r^{\gamma-1} \cdot \rho)\left(\frac{\rho^{\gamma-1}}{r^{\gamma-1}}\right)$$

$$\therefore T_4 = \rho^{\gamma} \cdot T_1 \qquad \ldots (15)$$

By substituting the values of T_2, T_3 and T_4 in eq. (12)

we get,

$$\therefore \eta = 1 - \frac{1}{\gamma}\left[\frac{T_1 \cdot \rho^{\gamma} - T_1}{T_1 \cdot \rho \cdot r^{\gamma-1} - T_1 \cdot r^{\gamma-1}}\right]$$

$$\therefore \eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\gamma\left(\rho - 1\right)}\right] \qquad \ldots (16)$$

- It is clear from the above equation that the efficiency of diesel cycle depends upon compression ratio (r), ratio of specific heat (γ), and cut-off ratio ρ.
- Cut-off ratio ρ is always greater than 1 and γ = 1.4 for air, the quantity in bracket is always greater than one.
- The efficiency of Diesel cycle is always less than Otto cycle for same compression ratio due to above reason.
- Heat is added at constant volume in Otto cycle while heat is added at constant pressure in Diesel cycle.
- From the eq. (16) it is clear that the efficiency of Diesel cycle increases with the increase of compression ratio and with the decreases of cut-off ratio.

6. STEAM BOILERS

6.1. Introduction

- Steam boiler may be defined as “ A closed pressure vessel in which steam is generated with capacity exceeding 25 litres,gauge pressure greater than or equal to 1 kg/cm2 , and water Is heated at 100®C or above. The steam produced may be supplied:
    1) For generating power in steam Engine or steam turbines.
    2) At low pressures for industrial process work in cotton mills, sugar factories, etc., and
    3) For producing hot water for supply of hot water and for heating the buildings in cold whether

6.2. Classification of Steam Boilers

6.2.1 According to relative position of water and hot gases.

- Fire Tube boiler - hot gases pass through fire tubes which are surrounded by water
- Water tube - water flows inside the tubes and the hot flue gases flow out side the tubes.

6.2.2 According to the axis of the shell

- Vertical boiler – the axis of the shell is vertical.
- Horizontal boiler – the axis of the shell is horizontal
- Inclined boiler – the axis of the boilers is inclined.

6.2.3 According to the method of firing

- Externally fired boilers – furnace is located outside the shell.
- Internally fired boilers – furnace is located inside the shell, means combustion takes place inside the boiler shell.

6.2.4 According to the Method of Water circulation

- Forced Circulation boilers - water is circulated by pumps which is driven by motor and
- Natural Circulation boilers - water is circulated by natural convection currents which are set up due to the temperature difference produced by the application of heat.

6.2.5 According to the Pressure of steam

- High pressure – boilers working pressure is less than 10 bars. Example: Babcock and Wilcox boiler
- Medium pressure boilers – working pressure is 10 to 70 bars. Example: Lancashire and locomotive boiler
- Low pressure boilers – working pressure is above 70 bars. Example: Cochran and Cornish boiler.

6.2.6 According to the mobility of boiler

- Stationary boilers – it is used for stationary plants.
- Mobile boilers – it can move from one place to another.

6.2.7According to the number of tubes in the boiler

- Single tube boilers – they have only one fire or water tube.
- Multi tube boilers – they have more than one fire or water tubes.

❖ Comparison between fire-tube and water tube boilers

Sr.No	Particulars	Fire tube boiler	Water tube boiler
1	Position of water and hot gases	Hot gases inside the tube water outside the tube	water inside the tube and hot gases outside the tube
2	Operating pressure	Operating pressure limited to 25 bar	Can work under as high pressure as more than 125 bar
3	Rate of steam generation	Lower	Higher
4	Suitability	Not suitable for larger power plant	Suitable for larger power plant
5	Chance of explosion	Less due to low pressure	More due to high pressure
6	Floor space requirement	More	Less
7	Cost	Less	More
8	Requirement of skill	Required less skill for efficient and economic working	Required more skill and careful attention for efficient and economic working
9	Use	For producing process steam	For producing steam for power generation as well as process heating
10	Scale deposition & over heating	There is no water tubes, no problem of scale deposition and less problem of overheating	Small deposition of scale will cause overheating and bursting of the tubes.

6.3. General terms used in Steam Boiler

6.3.1 Cylindrical shell

- It is made up of steel plates bent into cylindrical form and rewetted and welded together. The ends of shell are closed by means of plates in different shapes. It should have sufficient capacity to contain water and steam.

6.3.2 Combustion chamber

- It is the space, generally below the boiler shell, meant for burning fuel in order to produce steam from the water contained in the shell.

6.3.3 Grate

- It is a platform, in the combustion chamber, upon which fuel is burnt. The grate consists of cast iron bars which are spaced apart so that air can pass through them.

6.3.4 Furnace

- It is a chamber formed by the space above grate and bellows the boiler shell in which combustion take place. It is also called a Fire box.

6.3.5 Fire Hole

- It is the hole through which coal is added to the furnace.

6.3.6 Ash Pit (ash pan)

- It is the area in which the ash of burnt coal is collected.

6.3.7 Smoke chamber (smoke box)

- The waste gases are collected here and then releases to the chimney and then to atmosphere.

6.3.8 Man Hole

- It is a hole provided on to the boiler shell so that a workman can go inside the boiler for inspection.

6.3.9 Hand Holes

- It is a hole provided on the shell to give to give east access for thr purpose of cleaning the water tubes or some other internal parts of boiler.

6.3.10 Mud box

- It collects all impurities present in the water. It is at the bottom of the barrel or shell. These impurities are removed time to time by help of blow off cock.

6.3.11 Steam collecting pipe

- When the steam leaving the boiler, it contains certain amount of water.Antipriming pipe is used to separate water particles from the steam and to collect dry steam from boiler.

6.3.12 Mountings

- These are the safety devices for the safe working of steam boiler and they are mounted on the steam boiler like Water indicator valve, pressure gauge, fusible plug, etc.

6.3.13 Accessories

- These devices are used for increasing the efficiency of boilers. They are integral parts of the boiler and are not mounted on the boiler. They include Super heater, Economiser, etc.

6.4. Cochran Boiler (Vertical multi-tubes boiler)

6.4.1 Characteristics of boiler:

A vertical, multi tubes, fire tube, internally fired, natural circulated boiler.

6.4.2 Construction:

It is a fire tube boiler in which the flue gases from the furnace are passed through a number of small tubes surrounded by water as shown in fig. 6.1. It consists of an external cylindrical shell (CS), crown and fire box (F), all being of hemispherical shapes. The bottom most portion is ash-pit (A) and above this is grate (G) on which the coal is burnt in presence of air. The combustion chamber (CC) is lined up with fire bricks (B) to reduce the heat losses. A door (D) is provided in the smoke box for cleaning and maintenance of the boiler. A mud hole (H) is provided at the bottom most point for draining out the water from the boiler.

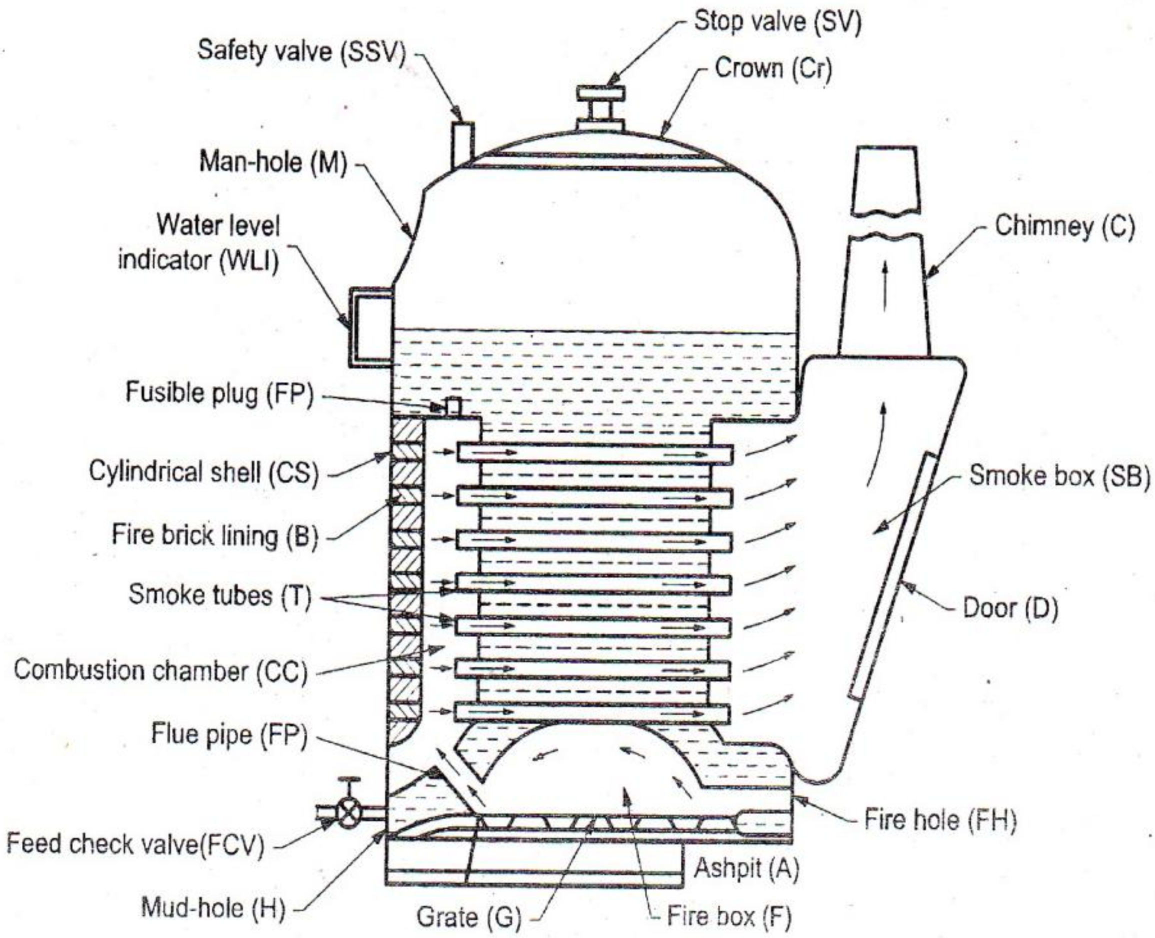


Fig. 6.1 Cochran Boiler

6.4.3 Working

- The fuel is burnt on the grate and ash is collected and disposed out of from ash pit. The gases of combustion produced by burning of fuel enter the combustion chamber through the flue tube and strike against firebrick lining which direct them to pass through number of horizontal tubes, being surrounded by water. After which the gases escape to the atmosphere through smoke box and chimney.

6.4.4 Advantages

1) It is compact and portable boiler therefore minimum floor area is required.
2) Initial cost of boiler is less
3) It can be moved and set up readily in different locations.
4) Quick and easy installation.
5) Any type of fuel can be used. (Coal or Oil)

6.4.5 Disadvantages

1) Steam raising capacity is less due to vertical design.
2) Water along with steam may enter the steam pipe under heavy loads sue to small steam space.
3) Efficiency is poor in smaller sizes.

6.5 Babcock and Wilcox water tube Boiler

6.5.1 Characteristics of boiler :

- Horizontal, multi-water tube, externally fired, natural circulation of water, forced circulation of air and hot gases, solid as well as liquid fuel fired.

6.5.2 Construction

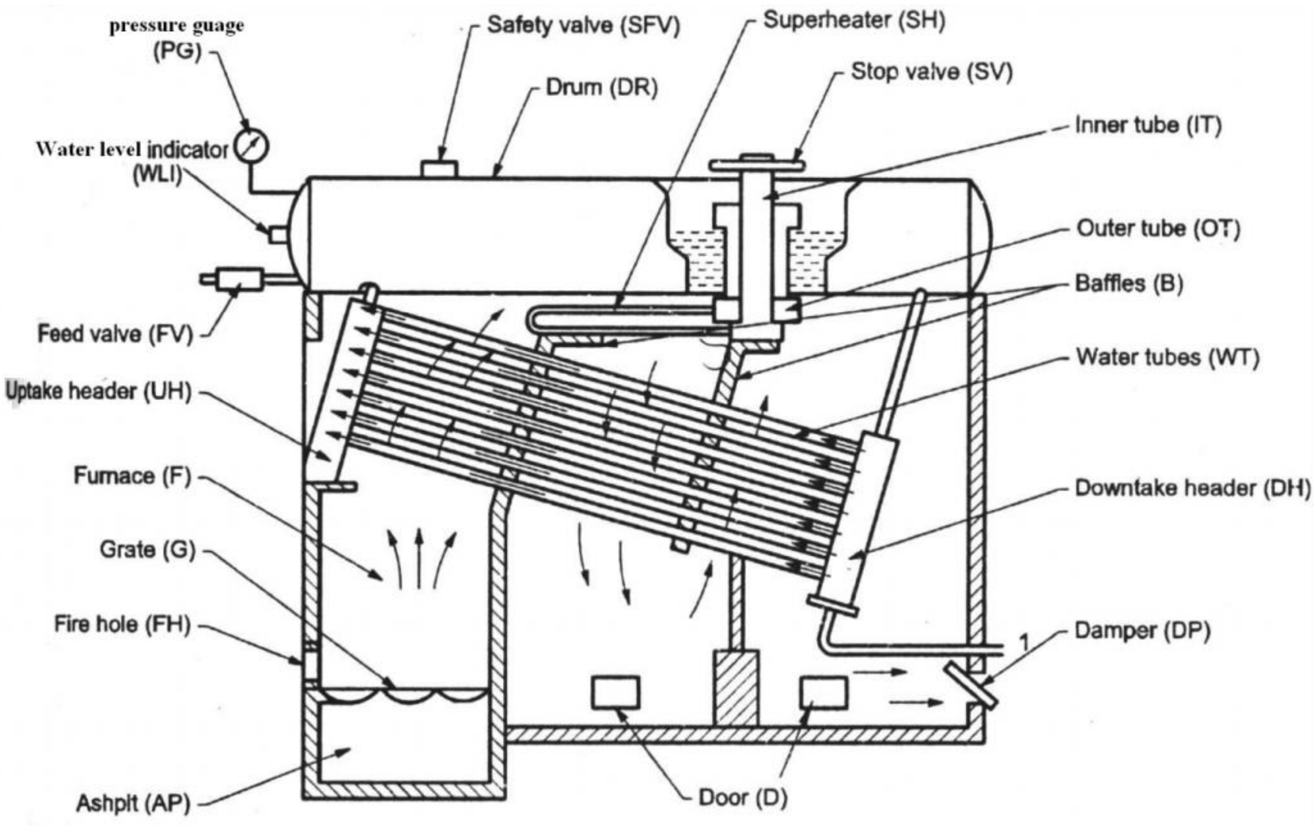


Fig. 6.2 Babcock Wilcox Boiler

- Fig.6.2 shows a Babcock and Wilcox boiler having longitudinal drum. It consists of number of inclined water tubes (WT) connected between the uptake header (UH) and downtake header (DH). Headers are provided with hand holes in the front tubes and are covered with caps (C). Whole combustion chamber is divided into number of parts with the help of baffles (B) so that the hot gases first move from the furnace (F) upwards between the tubes and then move downward and upwards between the baffles over the tubes and finally these are exhausted to the chimney through the damper (DP). The dampers regulate the amount of flue gases and thus the supply of air to the grate. Doors (D) are provided for a man to enter in the boiler for cleaning and repairing purposes.

6.5.3 Working

- The feed water enters the front of the drum (DR) and travels to the back part of the drum and then descends through the vertical tube to the down take header. From here the water enters into the water tubes to the uptake header and then again to the drum. The water tubes near the uptake header are in contact with the hotter flue gases compared to the portion near the down take header due to which the water in the uptake header rises due to decreased density and enters the drum which is replaced by colder water from the down take header. Water continues to circulate like this till it is evaporated.

- The superheating of steam is done in the superheater (SH). It consists of large number of steel tubes. Wet steam from the boiler drum enters in the outer tube (OT), then passes into the superheated tubes and during its passage it gets further heated up. Superheated steam now enters into the inner tubes (IT) and from here it is withdrawn through a stop valve (SV).

6.5.4 Advantages

1) The steam generation capacity of the boiler is very high, about 2000 to 40000 kg/hr
2) Replacement of defective tubes is easy.
3) The draught losses as compared to other boilers are minimum.
4) It is used in power station for generating large quantity of steam.
5) Boiler is required less space area compared to fire tube boilers, and offers greater operational safety.

6.6 Boiler Mountings & Accessories

6.6.0 List of Boiler Mountings & Accessories

- According to IBR the following **mountings** should be fitted to the boilers'
  1) Two Safety valves
  2) Two water level indicators
  3) A pressure gauge
  4) A Steam stop valve
  5) A feed check valve
  6) A blow off cock
  7) An attachment of inspector's test gauge
  8) A man hole
  9) Mud holes or sight holes
- Commonly used boiler **accessories** are as
  1) Feed pumps
  2) Injector
  3) Economiser

4) Air preheater
5) Superheater
6) Steam separator
7) Steam trap

6.6.1 Water level indicator

6.6.1.1 Function

- It is an important fitting, which indicates the water level inside the boiler to an observer. It is a safety device, upon which correct working of boiler depends. This fitting may be seen in front of boiler, and are generally two in number.

6.6.1.2. Construction

- It consists of three cocks and a glass tube. Stem Cock 1 keeps the glass tube in connection with the steam space. Water cock 2 puts the glass tube in connection with the water in the boiler. Drain cock 3 is used at frequent intervals to ascertain that the steam and water cocks are clear.

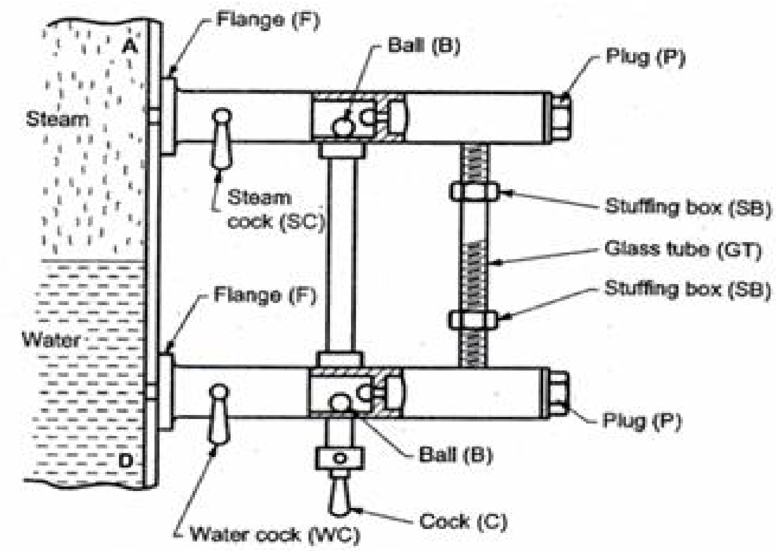


Fig. 6.3 Water Level Indicator

6.6.1.3 Working

- In the working of a steam boiler and for the proper functioning of the water level indicator, the steam and water cocks are opened and the drain cock is closed. In this case handles are placed in a vertical position. The rectangular passage at the ends of the glass tube contains two balls. In case the glass tube is broken, the two balls are carried along its passages to the ends of the glass tube. It is thus obvious, that water and steam will not escape out. The glass tube can be easily replaced by closing the steam and water cocks and opening the drain cock.

6.6.2 Pressure Gauge

6.6.2.1 Function

- It is used to measure the pressure of the steam inside the steam boiler. The pressure gauges generally used are of Bourdon tube type.

6.6.2.2 Construction

- It consists of an elliptical elastic tube XYZ bent into an arc of a circle, as shown in Fig. 6.4. This bent up tube is called Bourdon's tube. One end of the gauge is fixed and connected to the steam space in boiler .The other end is attached by links and pins to a toothed quadrant. This quadrant meshes with a small pinion on the central spindle.

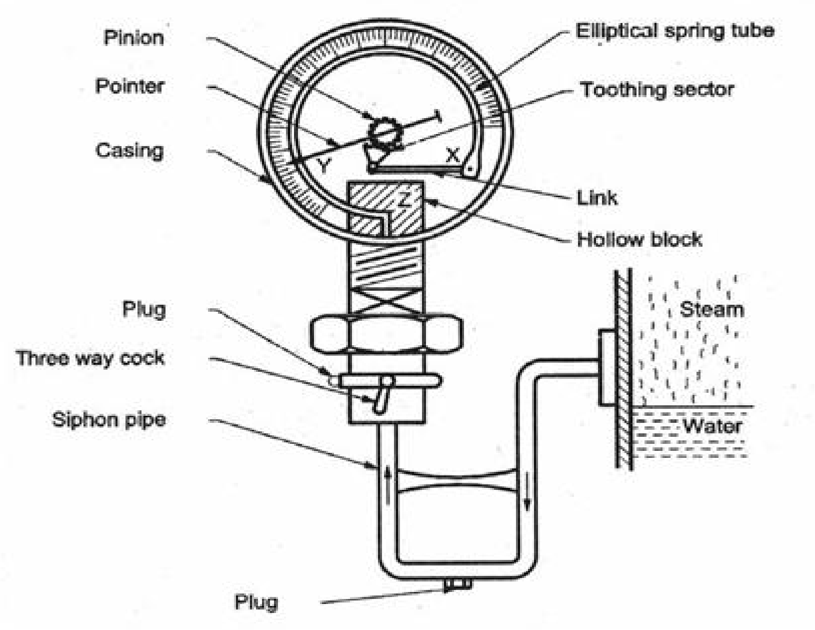


Fig 6.4 pressure gauge

6.6.2.3 Working

- The steam under pressure flows into tube. As a result of this increased pressure, tube tends to straighten itself. Since the tube is encased in a circular curve, therefore it tends to become circular instead of straight. With the help of simple pinion and sector arrangement, the elastic deformation of the Bourdon's tube rotates the pointer. This pointer moves over a calibrated scale, which directly gives the gauge pressure.

6.6.3 Safety Valves

- These are the devices attached to the steam chest for preventing explosions due to excessive internal pressure of steam. A steam boiler is usually, provided with two safety valves. These are directly placed on the boiler. Following are the four types of safety valves are used.

6.6.3.1 Lever Safety Valve

- A lever safety valve used on steam boilers is shown in fig. 6.5. A lever safety valve consists of a valve body with a flange fixed to the steam boiler. The bronze valve seat is screwed to the body, and the valve is also made of bronze. The thrust on the valve is transmitted by the strut. The guide keeps the lever in a vertical plane.

- When the pressure of steam exceeds the safe limit, the upward thrust of steam raises the valve from its seat. This allows the steam to escape till the pressure falls back to its normal value. The valve then returns back to its original position.

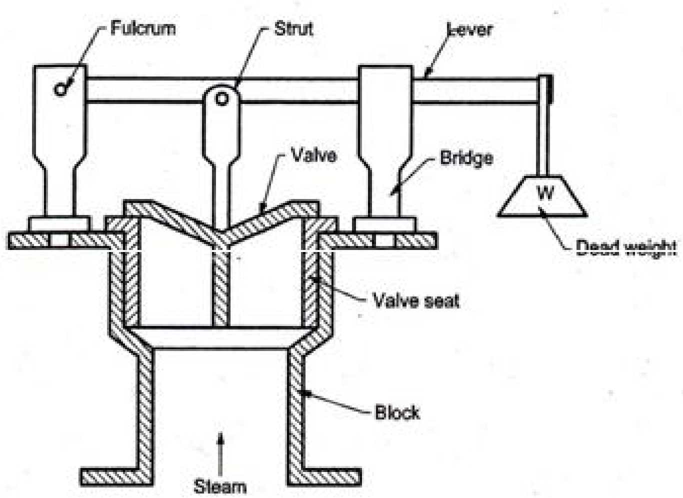


Fig 6.5 lever safety valve

6.6.3.2 Dead weight safety valve

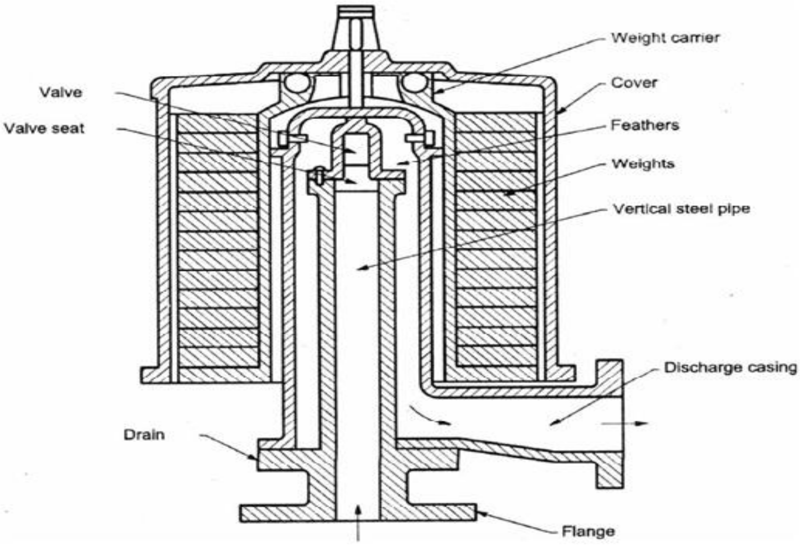


Fig 6.6 Dead weight safety valve

- When the steam pressure exceeds the normal limits, this high pressure steam creates upward force on valve, thus valve V lift with its weights and the excess steam escapes through the pipe to the outside.

6.6.3.3 High steam low water safety valve

- It allows the steam to escape out of boiler when steam pressure exceeds normal value or water lever in the boiler falls below the normal level.

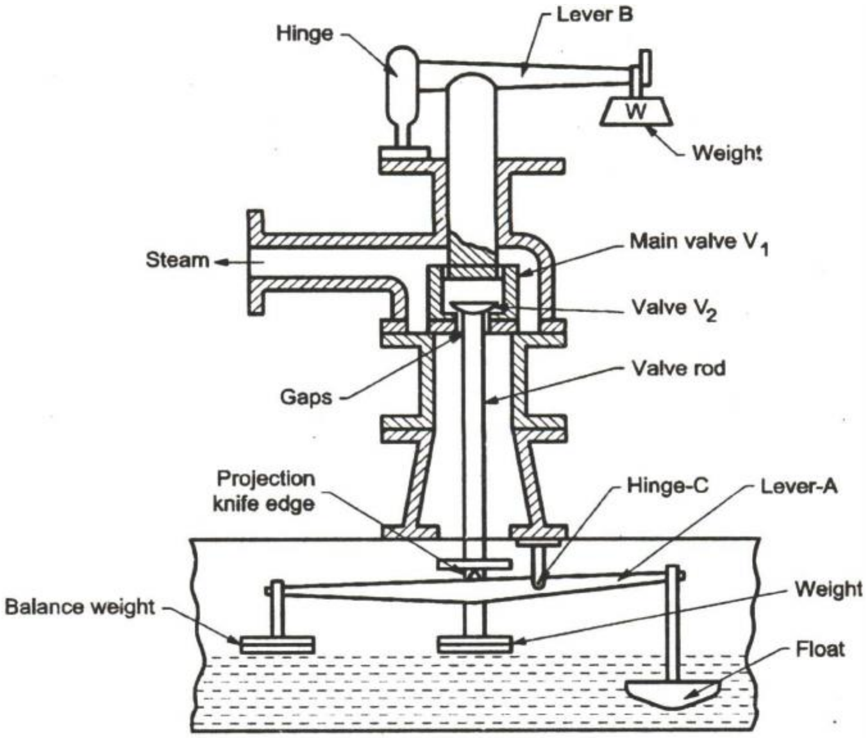


Fig. 6.7 high stem low water safety valve

- It consists of lever A which is hung inside the boiler shell and it is hinged at point C. One end of the lever carries a balance weight and the other end carries an earthen float immersed in water. The balance weights are kept in such a way that the knife edge of the lever just touches the projection when the float just dips into water. It also consists of two valves. One is main valve V1 which rests on its seat. The edge of the central opening in the valve V1 forms the seat for the hemispherical valve V2 and the end of valve rod carries a weight.
- When the water level falls and float is sufficiently uncovered from water, the weight of the float increases and no longer it is balanced by the balance weights. Consequently, the float end of the lever will descend and causes a swing in the lever A. When the lever swings, the valve rod is pushed up. It also pushes up the hemispherical valve V2 and the steam leaks through the gaps provided with a loud noise. This acts as a warning to the boiler attendant. When the hemispherical valve is closed, the main valve V1 acts as an ordinary lever safety valve and it guards against the high pressure in the boiler. The valve V1 is held in position partly by the weight on the rod of valve V2 and partly by the loaded lever above the valve casing. When the steam pressure exceeds the limiting working pressure, the main valve V1 along with valve V2 lifts up and the steam leaks out through the discharge duct.

6.6.3.4. Spring Loaded safety valve

- A Ramsbottom spring loaded safety valve is shown in Fig. 6.8. It is usually, fitted to locomotives. This valve consists of a cast iron body having two branch pipes. Two valves sit on corresponding valve seats at the end of the pipes. The lever is placed over the valves by means of two pivots. The lever is held tight at its position by means of a compression spring. One end of this spring is connected with the lever while the other ends with the body of the valve.

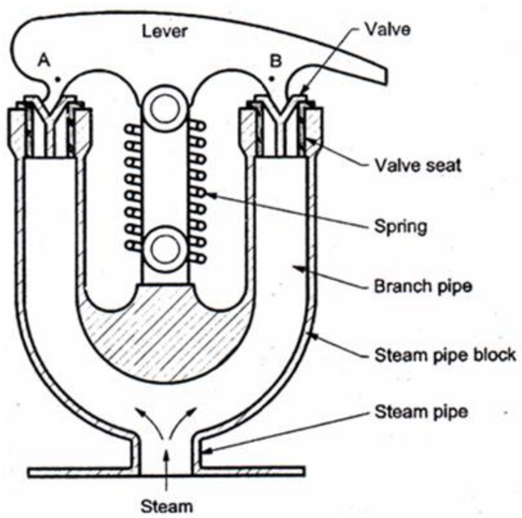


Fig. 6.8 Spring Loaded Safety valve

- Under the normal conditions, the spring pulls the lever down. This applies downward force on valves which is greater than the upward force applied by steam. When steam pressure exceeds normal value, upward force become, larger than the downward force on the valve due to spring. Thus the valves are lifted from their seats, opening the passage for steam to release out. The valve closes due to spring force when the pressure in the boiler becomes normal.

6.6.4 Steam stop valve

- The principal functions of a stop valve are:
    - To control the flow of steam from the boiler to the main steam pipe.
    - To shut off the steam completely when required.
- The body of the stop valve is made of cast iron or cast steel. The valve, valve seat and the nut through which the valve spindle works, are made of brass or gun metal. The spindle passes through a gland and stuffing box. The spindle is rotated by means of a hand wheel. The rotation of the spindle causes the valve to move up and down. When the valve sits over the valve seat, the passage of steam is completely closed. The passage may be partially or fully opened for the flow of steam by moving the valve up, rotating the hand wheel.

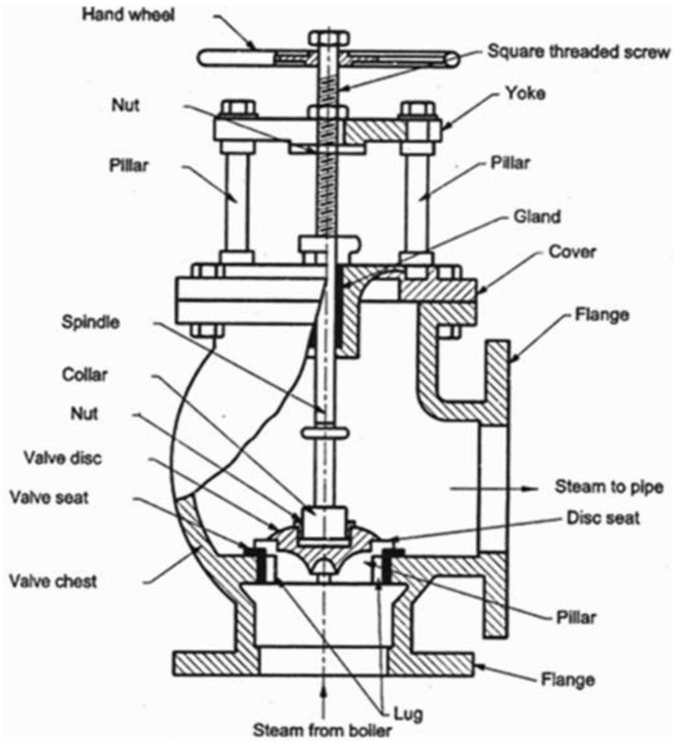


Fig. 6.9 Steam Stop Valve

6.6.5 Feed Check Valve

- It is a non return valve, fitted to a screwed spindle to regulate the lift. Its function is to regulate the supply of water, which is pumped into the boiler, by the feed pump. This valve must have its spindle lifted before the pump is started.
- Pump pressure acts from below the non-return valve and boiler pressure acts from above it. Under normal working conditions, the pump delivery pressure is higher than the boiler pressure. So the valve is lifted from it seat and allows the water to flow to boiler. The lift of the valve is controlled by moving the spindle up and down with the help of the hand wheel. Thus, the flow of water can be controlled.
- If the boiler pressure is higher than pump pressure or the pump is stopped, the upward force on non-return valve is higher. So it sits on its seat and closes the passage. Thus water from boiler is not allowed to flow backward.

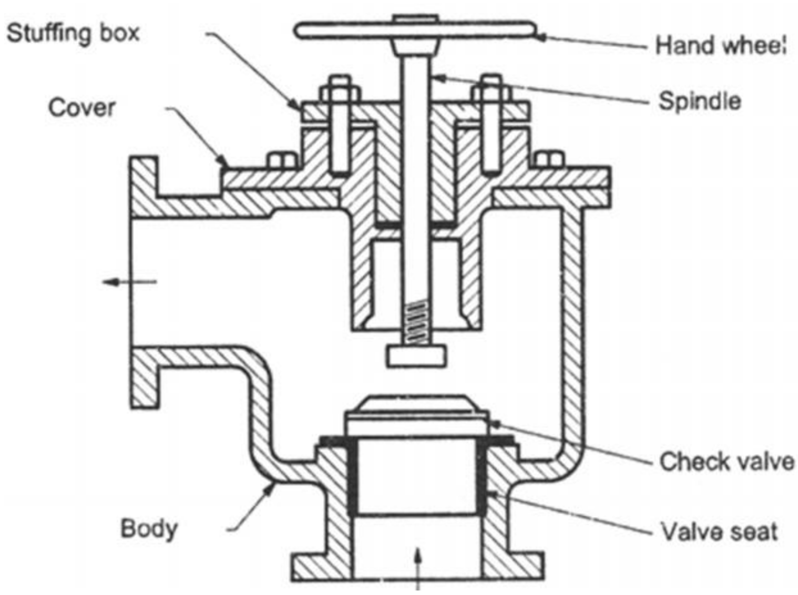


Fig.6.10 Feed Check Valve

6.6.6 Blow off cock

- It performs the two functions:
    1) It may discharge a portion of water when the boiler is in operation to blow out mud, scale or sediments periodically.
    2) It may empty the boiler when necessary for cleaning and repair.

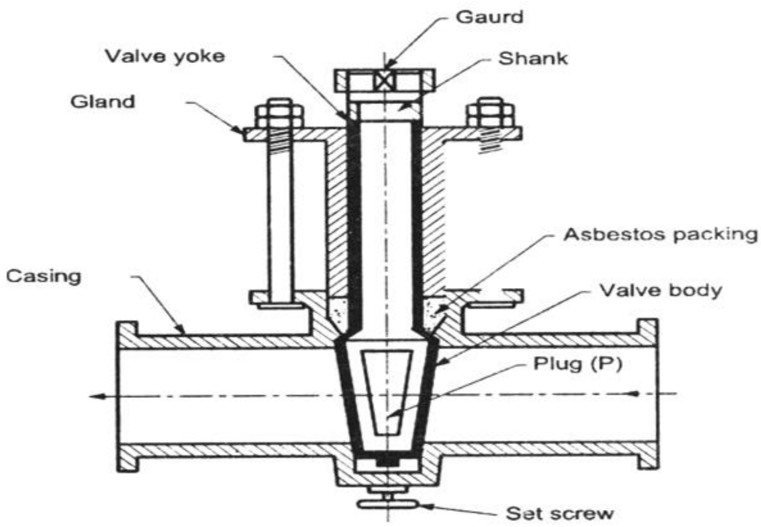


Fig. 6.11 Blow off Cock

- A common type of blow-off cock is shown in fig. 6.11 A conical plug is fitted accurately into a similar casing. The plug has a rectangular opening.
- In the position shown in fig. 6.11 the plug slot is perpendicular to the flow passage. When the plug slot is brought in line with the flow passage of body by rotating the plug, the water from boiler comes out with a great force. If sediments are to be removed, the blow-off cock is operated when the boiler is on. This forces the sediments quickly out of boiler.

6.6.7 Fusible Plug

6.6.7.1 Function

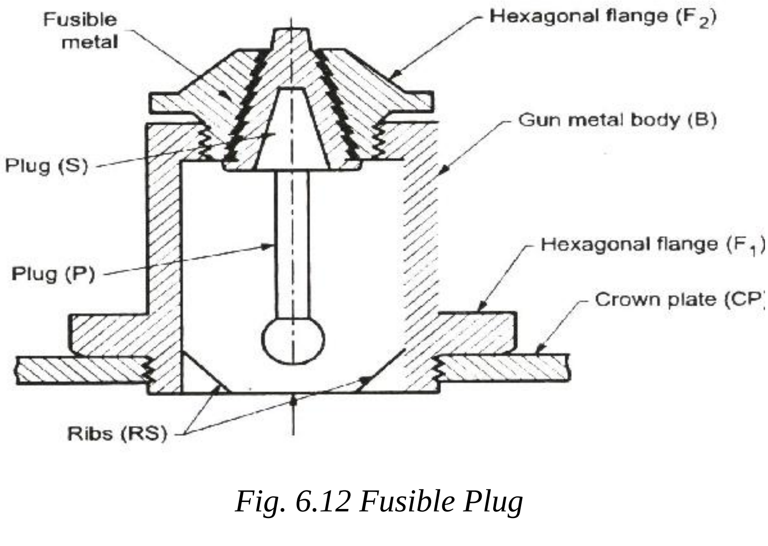


Fig. 6.12 Fusible Plug

- The main function of the fusible plug is to extinguish fire when water level in the boiler falls below an unsafe level.

6.6.7.2. Construction

- The construction of the fusible plug is shown in fig. 6.12.It consists of three plugs P, R and S. The hollow plug having hexagonal flanges (F1) is screwed to the fire box crown plate (CP). The plug R is screwed to the plug P and the plug S is locked into plug R by a metal like tin or lead which has a low melting point. Plugs P and R are made up of gun metal, while the plug S is made up of copper.

6.6.7.3 Working

- In normal working condition, water covers the fusible plug and remains cool. In case the water level falls below the danger levels, the fusible plug gets exposed to steam. This overheats the plug and fusible metal having low melting point melts quickly. Due to this plug S falls. The opening so made allows the steam to rush on to the furnaces and extinguishes the fire or it gives warning to the boiler attendant that the crown of furnace is in danger of being overheated.

6.6.4. Boiler Accessories

6.6.4.1 Economiser

- An economizer is a device in which the waste heat of the flue gases is utilized for heating the feed water.

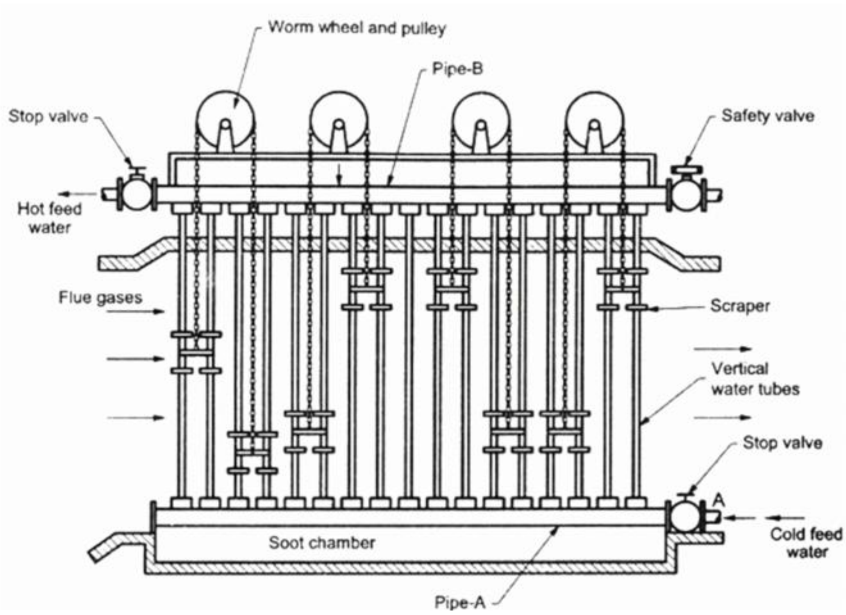


Fig. 6.13 Economiser

6.6.4.1.1. Construction and working

- Fig. 6.13 shows an independent type vertical tube economiser. It is employed for boilers of medium pressure range unto about 25 bar. It consists of a large number of vertical cast iron pipes P which are connected two horizontal pipes, one at the top and other at the bottom. A is the bottom pipe through which the feed water is pumped into the economizer. The water comes into the top pipe B from the bottom pipe and finally flows into the boiler.
- The flue gases flows around the pipes in the direction opposite to the flow of water. Consequently, heat transfer to the surface of the pipes takes place and water is thereby heated.
- A blow off cock is provided at the back end of vertical pipes to remove sediments deposited in the bottom boxes. The soot of flue gases deposited on the pipes reduces the efficiency of economizer. To prevent the soot deposit, the scrapers S move up and down to keep the external surface of pipe clean.
- By-pass arrangement of flue gases enables to isolate or include the economizer in the path of flue gases.

6.6.4.2 Super Heater

- The function of the super heater is to increase the temperature of the steam above its saturation point. They are located in the path of the flue gases so that heat is recovered by the super heater from the hot gases.

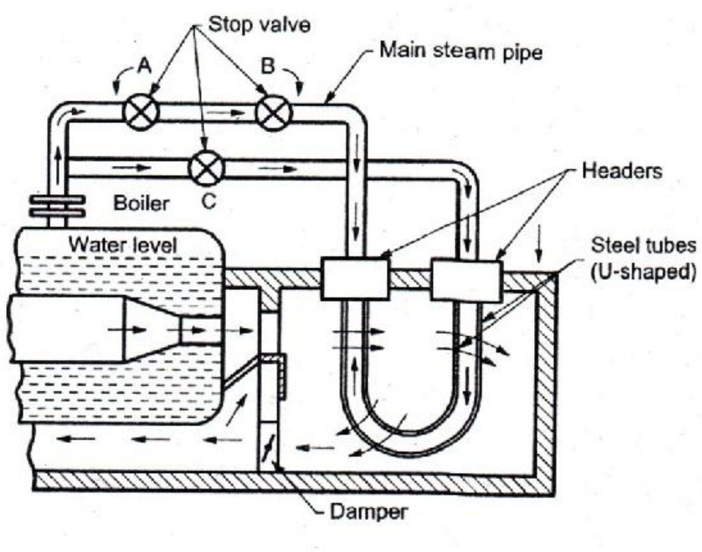


Fig. 6.14 Super Heater

- Fig. 6.14 Shows Sugden's superheater installed in a Lancashire boiler. It consists of two steel headers to which are attached solid drawn 'U 'tubes of steel. These tubes are arranged in groups of four and one pair of the headers generally carries ten of these groups or total of forty tubes.

- The action of the superheater is as follows:
- The stop valve A is closed and stop valves B and C are in open position. The wet steam from boiler flows into right hand header via stop valve C. After superheating of steam in the tubes, it flows into the left hand header, from where it is withdrawn through the stop valve B. If the superheated steam is not needed, the stop valves B and C are closed and the wet steam is directly taken out from the boiler through stop valve A.

7. Internal Combustion Engine

7.1 Introduction

In 1876 four stroke engine based on Otto cycle was developed by a German engineer Nikolous Otto, Which revolutionized the development of internal combustion engines and are even used till date. Diesel engine was developed by another German engineer Rudolf Diesel in the year 1892.

Engine refers to a device which transforms one form of energy into the other form. “Heat engine is a modified form of engine used for transforming chemical energy of fuel into thermal energy and subsequently for producing work."

Heat engines may be classified based on where the combustion of fuel takes place. i.e. whether outside the working cylinder or inside the working cylinder.

(a) External Combustion Engines (E.C. Engines)

(b) Internal Combustion Engines (I.C. Engines)

7.2 Comparison of I.C. Engines and E.C. Engines

S.N.	I.C. Engine	E.C. Engine
1.	Combustion of fuel takes place inside the cylinder.	Combustion of fuel takes place outside the cylinder
2.	Working fluid may be Petrol, Diesel & Various types of gases.	Working fluid is steam
3.	Require less space	Require large space
4.	Capital cost is relatively low.	Capital cost is relatively high.
5.	Starting of this engine is easy & quick	Starting of this engine requires time.
6.	Thermal efficiency is high.	Thermal Efficiency is low.
7.	Power developed per unit weight of these engines is high.	Power Developed per unit weight of these engines is low
8.	Fuel cost is relatively high.	Fuel cost is relatively low.

7.3 Classification of I.C. Engines

I.C. Engines may be classified according to,

a) Type of the fuel used as :
   (1) Petrol engine (2) Diesel engine
   (3) Gas engine (4) Bi-fuel engine (Two fuel engine)
b) Nature of thermodynamic cycle as :
   (1) Otto cycle engine (2) Diesel cycle engine
   (3) Duel or mixed cycle engine

c) Number of strokes per cycle as :
   (1) Four stroke engine (2) Two stroke engine
d) Method of ignition as :
   (1) Spark ignition engine (S.I. engine)
      Mixture of air and fuel is ignited by electric spark.
   (2) Compression ignition engine (C.I. engine)
      The fuel is ignited as it comes in contact with hot compressed air.
e) Method of cooling as :
   (1) Air cooled engine (2) Water cooled engine
f) Speed of the engine as :
   (1) Low speed (2) Medium speed
   (3) High speed
   Petrol engine are high speed engines and diesel engines are low to medium speed engines
g) Number of cylinder as :
   (1) Single cylinder engine (2) Multi cylinder engine
h) Position of the cylinder as :
   (1) Inline engines (2) V – engines
   (3) Radial engines (4) Opposed cylinder engine
   (5) Opposed piston engine

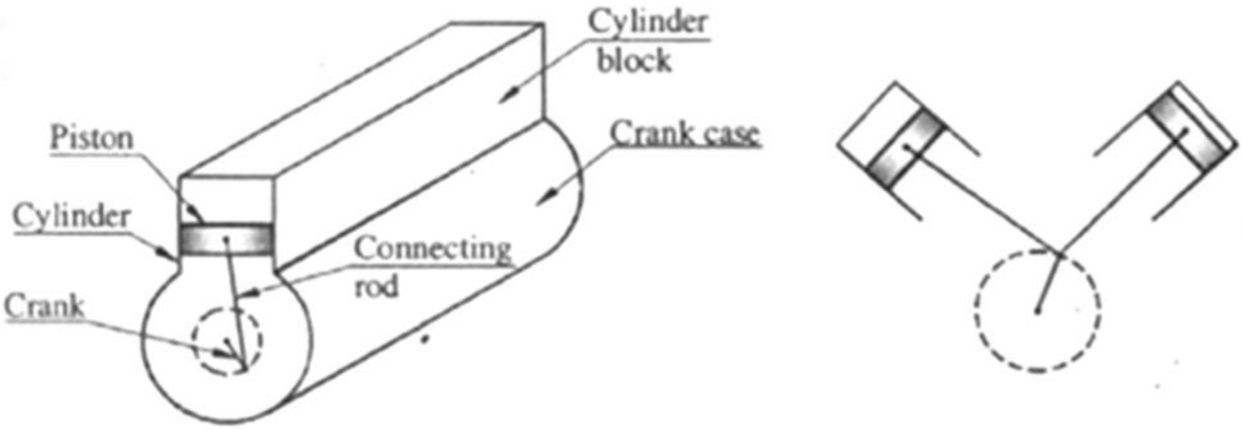


Fig. 7.1 In line engine and V – engine

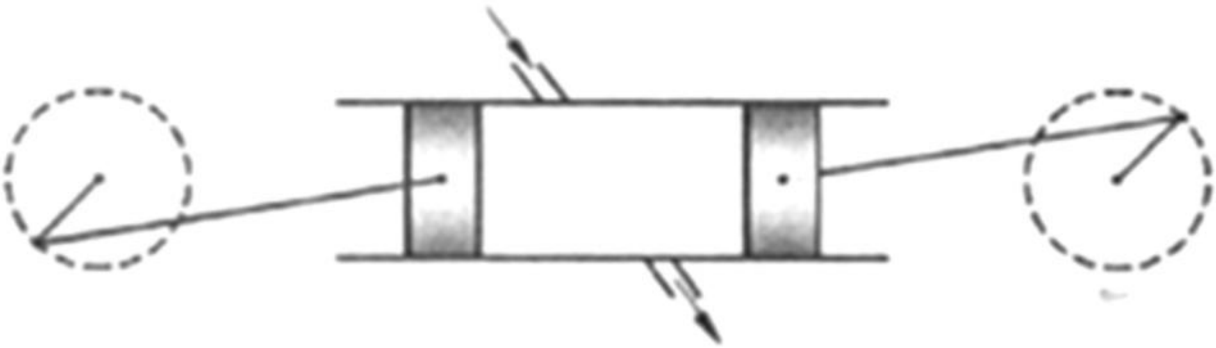


Fig. 7.2 Opposed piston engine

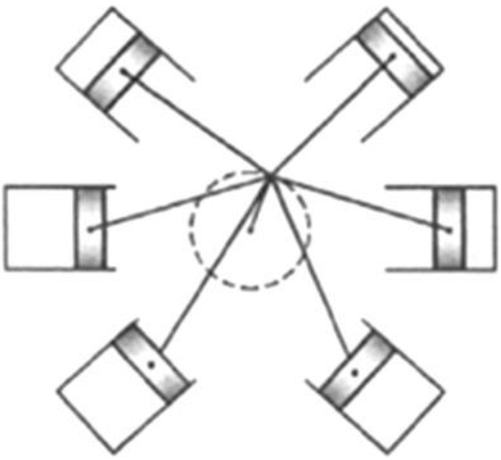


Fig. 7.3 Radial engine

Fig. 7.4 Opposed cylinder engine

7.4 Engine details

The various important parts of an I.C. engine are shown in figure.

1. Cylinder

It is the heart of the engine in which the fuel is burnt and the power is developed. Cylinder has to withstand very high pressure and temperature because the combustion of fuel is carried out within the cylinder. Therefore cylinder must be cooled. The inside diameter is called bore. To prevent the wearing of the cylinder block, a sleeve will be fitted tightly in the cylinder. The piston reciprocates inside the cylinder.

2. Cylinder head

Cylinder head covers top end of cylinder. It provides space for valve mechanism, spark plug, fuel injector etc.

3. Piston

The piston is a close fitting hollow cylindrical plunger reciprocating inside the cylinder. The power developed by the combustion of the fuel is transmitted by the piston to the crank shaft through connecting rod.

4. Piston Rings

The piston rings are the metallic rings inserted into the circumferential grooves provided at the top end of the piston. These rings maintain a gas-tight joint between the piston and the cylinder while the piston is reciprocating in the cylinder.

5. Piston pin or Gudgeon pin

It is the pin joining small end of the connecting rod and piston. This is made of steel by forging process.

6. Connecting Rod

It is the member connecting piston through piston pin and crank shaft through crank pin. It converts the reciprocating motion of the piston into rotary motion of the crankshaft. It is made of steel by forging process.

7. Crank and Crankshaft

The crank is a lever that is connected to the big end of the connecting rod by a pin joint with its other end connected rigidly to a shaft, called crankshaft. It rotates about the axis of the crank shaft and causes the connecting rod to oscillate.

8. Valves

Engine has both intake and exhaust type of valves which are operated by valve operating mechanism (Refer Fig. 5). The valves are the device which controls the flow of the intake and the exhaust gases to and from the engine cylinder.

9. Flywheel

It is a heavy wheel mounted on the crankshaft of the engine. It minimizes cyclic variation in speed by storing the energy during power stroke, and same is released during other stroke.

10. Crankcase

It is the lower part of the engine, serving as an enclosure of the crankshaft and also as a sump for the lubricating oil.

11. Carburetor

Carburetor is used in petrol engine for proper mixing of air and petrol.

12. Fuel pump

Fuel pump is used in diesel engine for increasing pressure and controlling the quantity of fuel supplied to the injector.

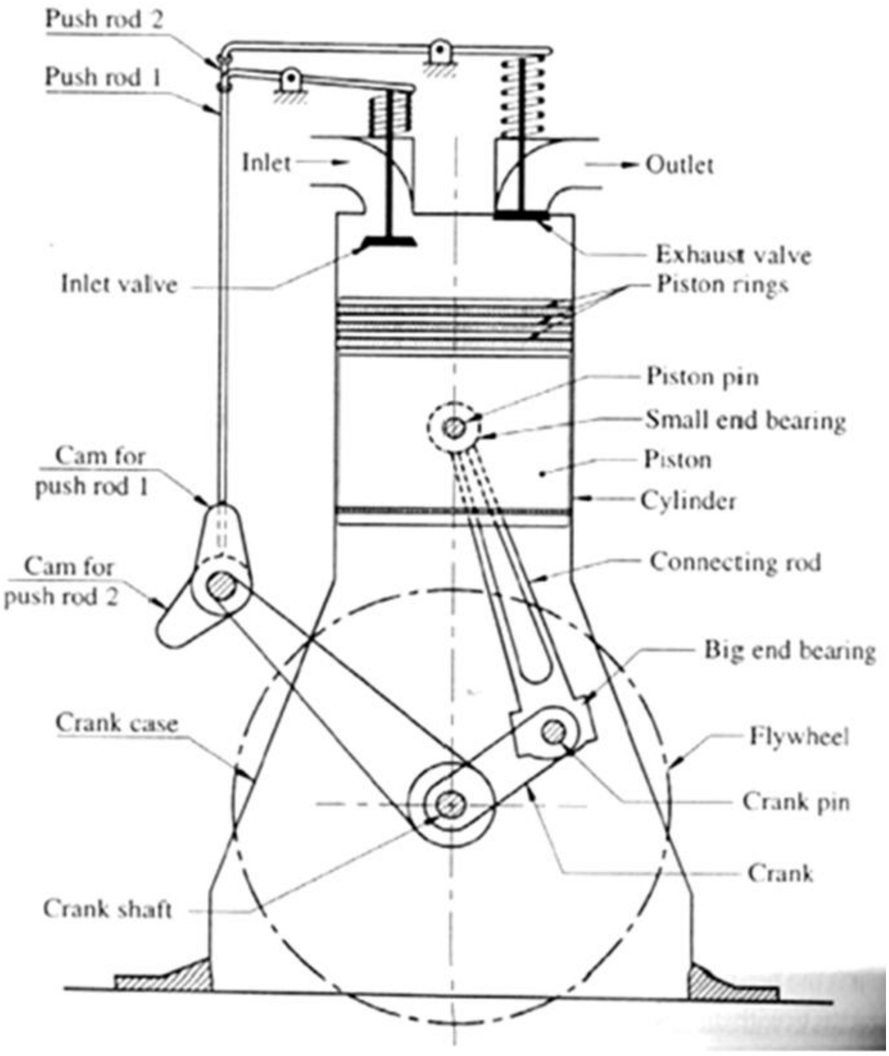


Fig.7.5 I.C. Engine details

13. Fuel injector

Fuel injector is used to inject diesel fuel in the form of fine atomized spray under pressure at the end of compression stroke.

14. Spark plug

Spark plug is used in petrol engine to produce a high intensity spark for ignition of air fuel mixture in the cylinder.

7.5 I.C. Engine Terminologies

1. Bore:

The inner diameter of the engine cylinder is called a bore.

2. Stroke:

It is the linear distance traveled by the piston when it moves from one end of the cylinder to the other end. It is equal to twice the radius of the crank.

Fig. 7.6 Stroke and Bore of the Piston

3. Dead Centers:

In the vertical engines, top most position of the piston is called Top Dead Centre (TDC). When the piston is at bottom most position, it is called Bottom Dead Centre (BDC).

In horizontal engine, the extreme position of the piston near to cylinder head is called Inner Dead Centre (I.D.C.) and the extreme position of the piston near the crank is called Outer Dead Centre (O.D.C.).

4. Clearance Volume, (V_c)

It is the volume contained between the piston top and cylinder head when the piston is at top or inner dead centre.

5. Stroke volume (swept volume)

It is volume displaced by the piston in one stroke is known as stroke volume or swept volume.

Let, V_s = stroke volume, L = stroke length, d = Bore

$$V_s = \frac{\pi}{4} d^2 L$$

6. Compression Ratio

The ratio of total cylinder volume to clearance volume is called the compression ratio (r) of the engine.

Total cylinder volume = $V_c + V_s$

Compression Ratio, $r = \frac{Total\ cylinder\ volume}{Clearance\ volume}$

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

For petrol engine r varies from 6 to 10 and for Diesel engine r varies from 14 to 20.

7. Piston speed

It is average speed of piston. It is equal to 2LN, where N is speed of crank shaft in rev/sec.

$$\therefore Piston\ speed, V_p = \frac{2LN}{60}\ {}^{m}/_{sec}$$

Where,

L = Stroke length, m

N = Speed of crank shaft, RPM

7.6 Otto four stroke cycle OR Four stroke petrol engine or Spark Ignition Four stroke engine

The petrol engines work on the principle of theoretical Otto cycle, also known as constant volume cycle, shown in Figure.

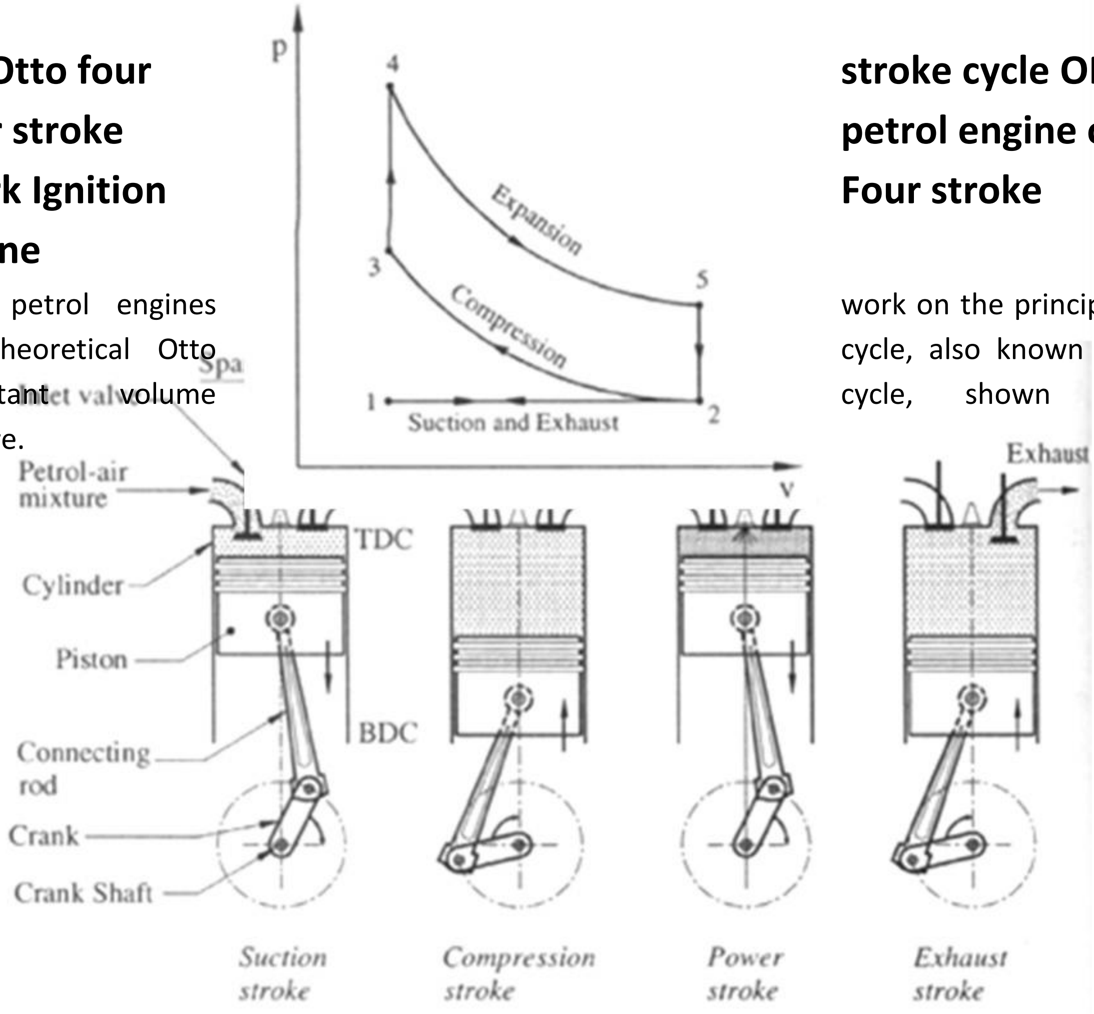


Fig. 7.7 P-V diagram of petrol engine

A four stroke petrol engine is shown in Figure. The valve operating the inlet is called inlet valve and the valve operating the exhaust is called exhaust valve. The spark plug fitted at the top of cylinder head initiates the ignition of the air fuel mixture.

The piston performs four strokes to complete one working cycle. The four different strokes are; (i) Suction stroke (ii) Compression stroke (iii) Power stroke (iv) Exhaust stroke.

Construction and working of four stroke petrol engine as below.

Fig.7. 8 Four stroke petrol engine

(i) Suction stroke

During this stroke, inlet valve opens and exhaust valve is closed, the pressure in the cylinder will be atmospheric. As the piston moves from TDC to BDC, the volume in the cylinder increases, while simultaneously the pressure decreases. This creates a pressure difference between the atmosphere and inside of the cylinder. Due to this pressure difference the petrol and air mixture will enter into the cylinder through carburetor. This stroke is represented by the horizontal line 1-2 on the p-v diagram.

At the end of this stroke, the cylinder will be filled completely with petrol and air mixture called charge and inlet valve is closed.

(ii) Compression stroke

During this stroke both the inlet valve and exhaust valve are closed, the piston moves from BDC to TDC. As this stroke is being performed, the petrol and air mixture contained in the cylinder will be compressed, so pressure and temperature of mixture increases. The process of compression is shown in Fig. by the curve 2-3.

Near the end of this stroke, the petrol and air mixture is ignited by electric spark given out by the spark plug. The combustion of the petrol releases the hot gases which will increase the pressure at constant volume. This constant volume combustion process is represented by the vertical line 3-4 on the p-V diagram.

(iii)Power or Expansion stroke

During this stroke both the inlet valve and exhaust valve are closed, the piston moves from TDC to BDC. The high pressure and high temperature burnt gases force the piston to perform this stroke, called power stroke. This stroke is also known as expansion or working stroke. The engine produces mechanical work or power during this stroke.

As the piston moves from IDC to BDC, the pressure of hot gases gradually decreases and volume increases. This is represented by curve 4-5 on the p-V diagram. Near the end of this stroke, the exhaust valve opens which will release the burnt gases to the atmosphere. This will suddenly bring the cylinder pressure to the atmospheric pressure. This drop of pressure at constant volume is represented by vertical line 5-2 on the p-V diagram.

(iv)Exhaust Stroke

During this stroke, the exhaust valve opens and the inlet valve is closed. The piston moves from BDC to IDC and during this motion piston pushes the exhaust gases (combustion product) out of the cylinder at constant pressure. This process is shown on p-V diagram by horizontal line 2-1 in Figure.

Again the inlet valve opens and a new cycle starts.

7.7 Diesel four stroke cycle OR Four stroke Diesel engine OR Four stroke compression ignition (C.I) engine.

The diesel engines work on the principle of Diesel cycle, also called constant pressure heat addition cycle shown in Fig. The four stroke diesel engine cycle also consists of suction, compression, power, and exhaust strokes. Fig. 10 shows the working and construction of a four stroke diesel engine.

The basic construction of a four stroke diesel engine is same as that of four stroke petrol engine, except instead of spark plug, a fuel injector is mounted in its place as shown in Fig. 10. A fuel pump supplies the fuel oil to the injector at higher pressure.

(i) Suction Stroke

During this stroke, inlet valve opens and exhaust valve is closed, the pressure in the cylinder will be atmospheric. As the piston moves from TDC to BDC, the volume in the cylinder increases, while simultaneously the pressure decreases. This creates a pressure difference between the atmosphere and inside of the cylinder. Due to this pressure difference only the atmospheric air will enter into the cylinder through air filter and inlet. This stroke is represented by horizontal line 1-2 on p- V diagram shown in Fig.

At the end of this stroke, the cylinder will be filled completely with air and inlet valve will be closed.

(ii) Compression stroke

During this stroke, both inlet valve and exhaust valve remain closed. The piston moves from BDC to IDC. As this stroke is being performed, the air in the cylinder will be compressed, so pressure and temperature of air increases.

The compression ratio of this engine is higher than petrol engine. Due to higher compression ratio, air will have attained a higher temperature than self ignition temperature of the diesel fuel.

Near the end of this stroke, a metered quantity of the diesel fuel is injected into the cylinder. As the diesel fuel particles come in contact with high temperature air, it will ignite automatically. This is called auto-ignition or self-ignition. In this engine compressed air ignites the diesel fuel; this type of engine is also called as compression Ignition engine or C.I. engine.

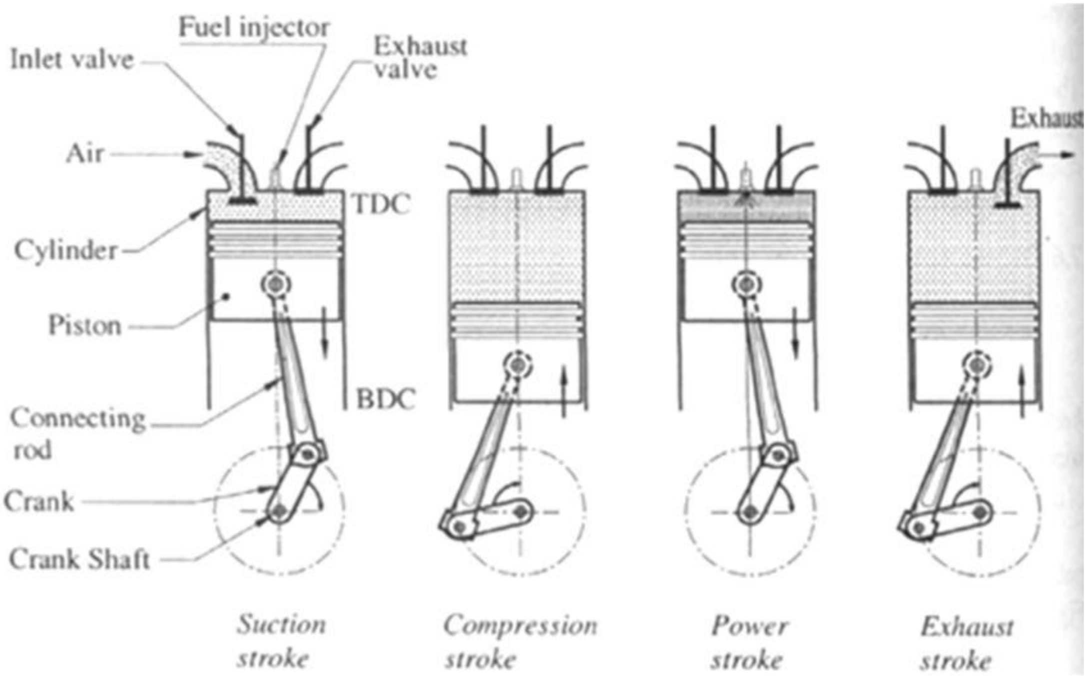


Fig. 7.9 Four stroke diesel engine

(iii) Power or Expansion stroke

During this stroke, both the inlet valve and the exhaust valve are closed. The piston moves from TDC to BDC. The fuel injection starts nearly at the end of compression stroke, but the rate of fuel injection is such that combustion maintains constant pressure. This constant pressure expansion with simultaneous combustion is represented by horizontal line (3-4) on the p- V diagram shown in Fig. The piston is forced further during the remaining part of this stroke only due to the expansion of the burnt gases. The engine produces mechanical work or power during this stroke.

As the piston moves from IDC to BDC, the pressure of hot gases gradually decreases and volume increases. This is represented by curve (4-5) on the p-V diagram shown in Fig.

(iii) Exhaust stroke

During this stroke, the exhaust valve opens and inlet valve is closed. The piston moves from BDC to TDC. During this motion, piston pushes the exhaust gases (combustion product) out of cylinder at constant pressure. This process is shown on p- V diagram by horizontal line 2-1 in Fig. Again inlet valve opens and a new cycle starts.

7.8 Difference between Otto cycle and Diesel cycle OR Difference between Petrol (S.I.) engine and Diesel (C.I.) engine

Sr. No	Principle	Petrol engine	Diesel engine
1.	Thermodynamic cycle	Works on Otto cycle (Constant volume cycle)	Works on Diesel cycle (Constant pressure cycle)
2.	Fuel used	Petrol (Gasoline)	Diesel
3.	Supply of fuel	In carburetor, fuel gets mixed with air and then	Diesel is pressurized with the help of fuel pump and

		mixture enters the cylinder during suction stroke	then injected into the engine cylinder by the fuel injector at the end of compression stroke
4.	Compression ratio (r)	Low (6 to 10)	High (14 to 20)
5.	Charge drawn during the suction stroke	Mixture of air and petrol	Only air
6.	Fuel ignition	Compressed charge is ignited by spark plug	Due to higher compression ratio, temp of air is higher than self ignition temp of diesel at the end of compression stroke. Diesel will ignite automatically when comes in contact with hot air
7.	Governing	Quantity governing method is used for controlling speed	Quality governing method is used for controlling speed
8.	Engine speed	High (3000 RPM)	Low to medium (500 to 1500 RPM)
9.	Thermal efficiency	Lower due to lower compression ratio	Higher due to higher compression ratio
10.	Weight of the engine	Lighter	Heavier
11.	Initial cost	Less	More
12.	Maintenance cost	Less	Slightly higher
13.	Running cost	Higher because petrol is costlier	Less because diesel is cheaper
14.	Starting of engine	Easier starting even in cold weather	Difficult to start in cold weather

7.9 Two stroke cycle engine

As the name itself implies, all the processes in the two stroke cycle engine are completed in two strokes. In four stroke engine two complete revolutions of crank shaft is required for completing one cycle. The cycle of operations, i.e. suction, compression, expansion and exhaust are completed in one complete revolution of the crank shaft in two stroke engines. These engines have one power stroke per revolution of the crank shaft. In two stroke engines, there are two openings called *ports* are provided in place of valve of four stroke engines. These ports are opened and closed by reciprocating motion of the piston in the cylinder. One port is known as inlet port and another port is known as exhaust port. Two stroke engines consist of a cylinder with one end fitted with a cylinder head and other end fitted with a hermetically sealed crankcase which enables it to function as a pump in conjunction with the piston.

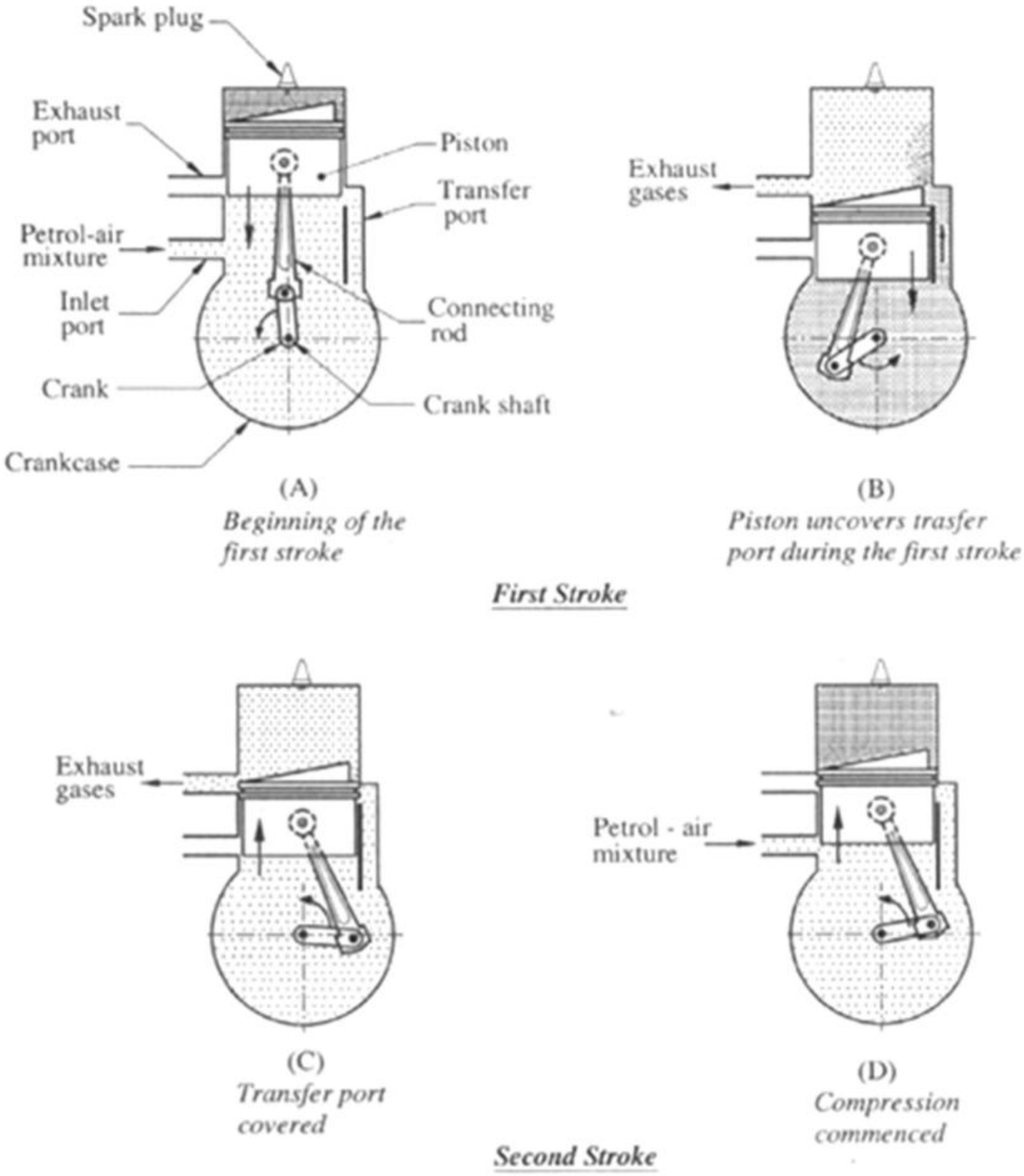


Fig.

11 Two stroke petrol engine

7.9.1 Working of two stroke petrol engine

In this type of engine, since suction of petrol and air mixture into the cylinder will not take place in a separate stroke, the technique involved in the intake or suction of petrol and air mixture must be well understood before knowing the actual working of a two stroke petrol engine.

Intake of petrol and air mixture:

When the piston moves upward, as shown in Fig. A partial vacuum is created in the crankcase until its lower edge uncovers the inlet port completely as shown in Fig. 11(A). The pressure difference set up between the atmosphere and crankcase will suck the petrol and air mixture through the carburetor fitted (not shown in Fig.) to inlet port, into the crankcase as shown in Fig. The suction will be continued till the inlet port is covered by the piston during its next downward stroke. After the inlet port is covered by the piston during its next downward stroke. After the inlet port is covered by the piston as shown in Fig. its further downward motion will compress the charge in the crankcase up to top edge of the piston uncovers the transfer port as shown in Fig. The compressed charge flows from the crankcase to cylinder through transfer port. This will continue till the piston covers the transfer port during its next upward stroke as shown in Fig.

First stroke

At the beginning of the first stroke the piston is at TDC as shown in Fig. Piston moves from TDC to BDC. The electric spark ignites the compressed charge. The combustion of the charge will release the hot gases which increases the pressure and temperature in the cylinder. The high pressure combustion gases force the piston downwards. The piston performs the power stroke till it uncovers the exhaust port as shown in Fig.

The combustion gases which are at a pressure slightly higher than the atmospheric pressure escape through the exhaust port. The piston uncovers the transfer port as shown in Fig. The fresh charge flows from the crankcase into the cylinder through transfer port. The fresh charge which enters the cylinder pushes the burnt gases, so more amount of exhaust gases comes out through exhaust port as shown in Fig. This sweeping out of exhaust gases by the incoming fresh charge is called ***scavenging***. This will continue till the piston covers both the transfer and exhaust ports during next upward stroke.

Second stroke

In this stroke the piston moves from TDC to BDC. When it covers the transfer port as shown in Fig. the supply of charge is stop and then when it moves further up it covers the exhaust port completely as shown in Fig. 11(D) stops the scavenging. Further upward motion of the piston will compress the charge in the cylinder. After the piston reaches TDC the first stroke repeats again.

7.9.2 Working of Two stroke diesel engine

Fig. 12 shows the construction and working of a two stroke diesel engine. The construction of diesel engine is similar to two stroke petrol engine except the fuel pump and fuel injector are there instead of carburetor and spark plug as in petrol engine. The working of diesel engine is similar to two stroke petrol engine except that only air is supplied into crank case in case of diesel engine and diesel fuel is injected at the end of compression of air.

Fig. 12 Two stroke diesel engine

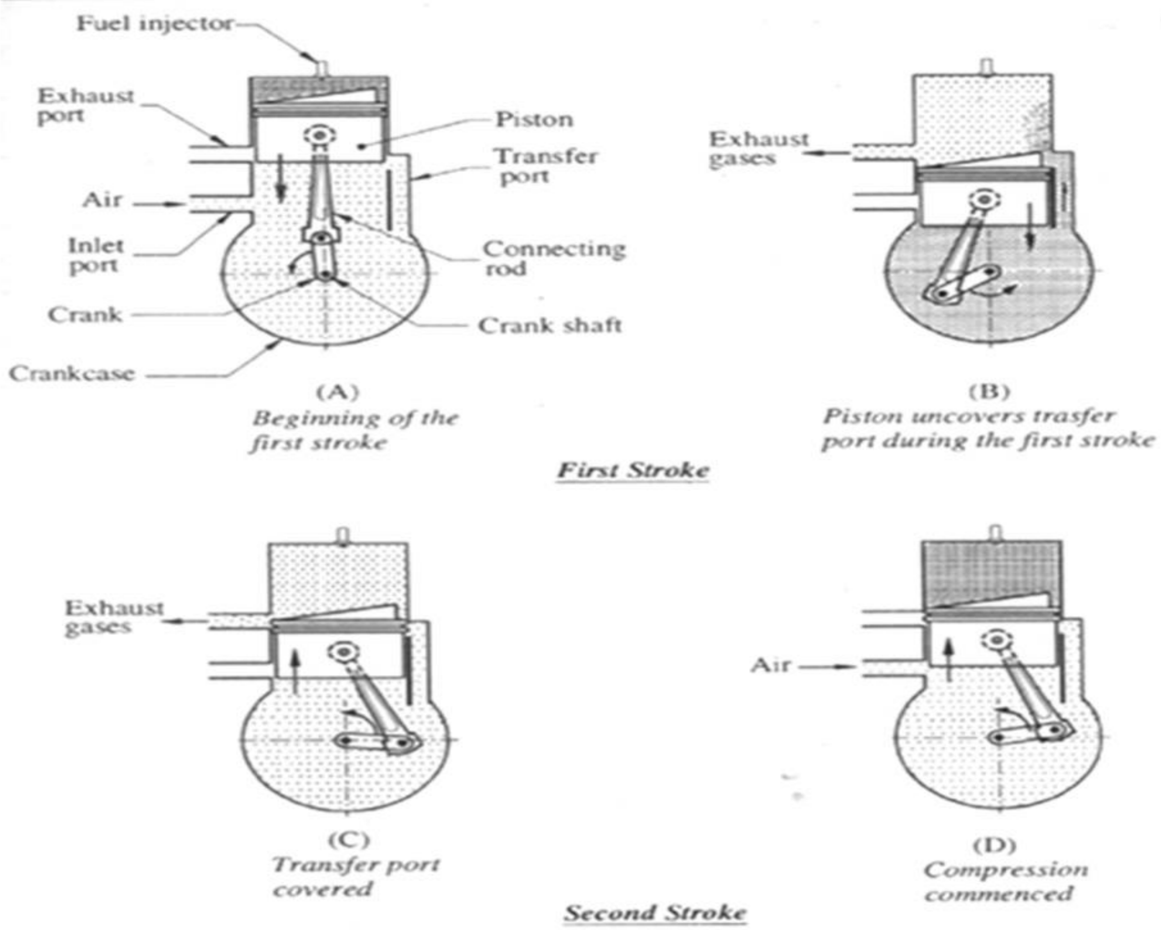


Fig. 12 Two stroke diesel engine

First stroke

At the beginning of the first stroke, the piston is at TDC as shown in Fig. Piston moves from TDC to BDC. At TDC piston is at the end of compression, so the compressed air will attain a temperature higher than the self ignition temperature of the diesel.

The injector injects a metered quantity of the diesel into the cylinder as a fine spray. As diesel is injected, it auto ignites. The combustion of the diesel will release the hot gases which increases the pressure and temperature in the cylinder. The piston performs the power stroke till it uncovers the exhaust port as shown in Fig. The hot gases have slightly higher pressure than the atmosphere. Due to this pressure difference burnt gases come out from the exhaust port. The top edge of the piston uncovers the transfer port as shown in Fig. the air flows from the crank case into the cylinder through transfer port. The fresh air entering the cylinder, it pushes the burnt gases, so burnt gases come out from exhaust port as shown in Fig. This pushing out of the exhaust gases is called ***scavenging***. This will continue till the piston covers both the exhaust and the transfer ports during next upward stroke.

Second stroke

In this stroke the piston moves from BDC to IDC. When it covers the transfer port as shown in Fig. the supply of air is stop and then when it moves further up it covers the exhaust port completely as shown in Fig. stops the scavenging. Further upward motion of the piston will compress the air in the cylinder. After the piston reaches IDC the first stroke repeats again.

7.10 Difference between two stroke and four stroke cycle engines

Sr. No	Principle	Four stroke engine	Two stroke engine
1.	No of piston strokes per cycle	4 piston strokes require to complete one cycle	Only 2 piston strokes require to complete one cycle
2.	No of crank rotation per cycle	Two complete revolutions of crank shaft is required to complete one cycle	Only one complete revolutions of crank shaft is required to complete one cycle
3.	No of power stroke per min	Equal to half of the speed of engine crank shaft (n = N/2)	Equal to the speed of engine crank shaft (n = N)
4.	Power	Power is developed in every alternate revolution of crank shaft	Power is developed in every revolution of crank shaft (hence for same cylinder dimension and speed, 2 stroke engine develops almost double power than 4 stroke engine)
5.	Flywheel	The power is developed in every alternate revolution, hence heavy flywheel is required	The power is developed in every revolution, hence lighter flywheel is required
6.	Size for same power output	These engines are heavier, larger and require more space	These engines are lighter, more compact and require less space
7.	Admission of charge	The charge is directly admitted into the engine cylinder during suction stroke	The charge is first admitted into the crankcase and then transferred to the engine cylinder
8.	Valves	The inlet and exhaust valves are required and	In place of valves, ports are there which opens

		they are operated by valve operating mechanism	and closes by motion of piston itself
9.	Crankcase	Crankcase is not hermetically sealed	Crankcase is hermetically sealed because charge is admitted into it
10.	Direction of rotation of crank shaft	The crank shaft rotates only in one direction	The crank shaft can rotates in both directions
11.	Lubricating oil consumption	Less	More
12.	Thermal efficiency	Higher, because there is no mixing of fresh charge with exhaust gases	Less, because there is mixing of fresh charge with exhaust gas, hence loss of fresh charge
13.	Mechanical efficiency	Less, because of more no of moving parts	Higher, because of less no of moving parts
14.	Uses	These engines are used in high power applications where more space is available like cars, trucks, tractors, buses, stationary uses etc.	These engines are used for low power applications where less space is available like mopeds, scooters, motor cycles, etc.

7.11 Engine performance parameters

7.11.1 Indicated power

The power produced inside the engine cylinder by burning of fuel is known as Indicated power (I.P.) of engine. It is calculated by finding the actual mean effective pressure.

$$Actual\ mean\ effective\ pressure, \qquad P_m = \frac{sa}{l}\ N/_{m^2}$$

Where,

a = Area of the actual indicator diagram, cm^2

l = Base width of the indicator diagram, cm

s = Spring value of the spring used in the indicator, $N/m^2/cm$

Indicated power of a Four-stroke engine

Let,

P_m = Mean effective pressure, N/m^2

L = Length of stroke, m

A = Area of cross section of the cylinder, m^2

N = RPM of the engine crank shaft

n = Number of power strokes per minute

Work produced by the engine per cycle,

= [Mean force acting on the piston] X [Piston displacement in one stroke]

$= P_m \times A \times L \quad N.m$

Work produced by the engine per minute,

= [Work produced by the piston per cycle] X [Number of power stroke per minute]

$= P_m \times A \times L \times n \quad {}^{Nm}/_{min}$

In four-stroke I.C. engines, number of power stroke per minute will be equal to half of RPM because we get one power stroke in two revolutions of the crank shaft.

i.e. $n = N/2$

Work produced by the engine per minute,

$= P_m \times A \times L \times {}^{N}/_{2} \quad {}^{Nm}/_{min}$

$$Indicated\ power\ (I.P.) = \frac{P_m LAN}{60 \times 2} \quad {}^{Nm}/_{sec} \ or \ {}^{Joule}/_{sec} \ or \ Watt$$

$$\therefore \boldsymbol{I.P.} = \frac{\boldsymbol{P_m LAN}}{\boldsymbol{60000 \times 2}} \quad \boldsymbol{KW}$$

Indicated power of a two stroke I.C. engine

In two stroke I.C. engine, the number of power strokes per minute will be equal to RPM of crank shaft

i.e. n = N

Indicated power of a two stroke I.C. engine is given by

$$\therefore \boldsymbol{I.P.} = \frac{\boldsymbol{P_m LAN}}{\boldsymbol{60000}} \quad \boldsymbol{KW}$$

7.11.2 Brake Power (B.P.)

It is the power available at engine crank shaft for doing useful work. It is also known as ***engine output power.*** It is measured by dynamometer.

It can be calculated as follows:

Let,

W = Net load acting on the brake drum, N

R = Radius of the brake drum, m

N = RPM of the crank shaft

T = Resisting torque, Nm

P_{mb} = Brake mean effective pressure

$$\therefore T = W \times R \quad Nm$$

And

$$\boldsymbol{B.P. = \frac{2\pi NT}{60000} = \frac{P_{mb}LAn}{60000} \quad KW}$$

- The piston connecting rod and crank are mechanical parts, moving relative to each other. They offer resistance due to friction. Therefore a certain fraction of power is lost due to friction of the moving parts. *The amount of the power lost in friction is called **friction power**.* The friction power is the difference between the I.P. and B.P.

$$\boldsymbol{Friction\,power = I.P. - B.P.}$$

Measurement of Brake Power (B.P.)

The power output (B.P.) of the engine is measured by coupling a dynamometer to engine crank shaft. Various dynamometers are listed below:

I. Rope brake dynamometer
II. Prony brake dynamometer
III. Hydraulic dynamometer
IV. Eddy current dynamometer

7.11.3 Efficiencies

1) Mechanical efficiency:

It is defined as the ratio of the brake power and the indicated power. Mechanical efficiency is indicator of losses due to friction.

$$\eta_{mech} = \frac{B.P.}{I.P.}$$

2) Thermal efficiency:

It is the efficiency of conversion of the heat energy produced by the actual combustion of the fuel into the power output of the engine. It is the ratio of work done to heat supplied by fuel.

i. **Indicated thermal efficiency** = Indicated Power/ Heat supplied by fuel

$$\eta_{it} = \frac{I.P.}{m_f \times CV}$$

Where, m_f = mass of fuel supplied, Kg/sec and CV = calorific value of fuel, J/kg

ii. **Brake thermal efficiency** = Brake Power/ Heat supplied by fuel

$$\eta_{bt} = \frac{B.P.}{m_f \times CV}$$

Also $\eta_{bt} = \eta_{mech} \times \eta_{it}$

3) **Relative efficiency:**

It is the ratio of indicated thermal efficiency of an engine to air standard cycle efficiency

$$\eta_{rel} = \frac{\eta_{it}}{\eta_{air}}$$

4) **Air standard efficiency:**

It is the efficiency of the thermodynamic cycle of the engine.

For petrol engine,

$$\eta_{air} = 1 - \frac{1}{(r)^{\gamma-1}}$$

For diesel engine,

$$\eta_{air} = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right]$$

5) **Volumetric efficiency:**

It is the ratio of the volume of charge/air actually sucked at atmospheric condition to swept volume of engine. It indicates breathing capacity of the engine.

$$\eta_{vol} = \frac{Actual\ volume\ of charge\ or\ air\ sucked\ at\ atm.condit\mathit{on}}{Swept\ volume}$$

6) **Specific output:**

The specific output of the engine is defined as the power output per unit area.

$$Specific\ output = \frac{B.P.}{A}$$

7) **Specific fuel consumption:**

Specific fuel consumption (SFC) is defined as the amount of fuel consumed by an engine for one unit of power production. SFC is used to express the fuel efficiency of an I.C. engine.

$$SFC = \frac{m_f}{B.P.}\ Kg/KWh$$

Where,

m_f = Mass of fuel consumed in kg/hr and B.P. = Power produced in KW

8. Pumps

8.1 Introduction

The pump is a mechanical device which conveys liquid from one place to another place. It can be defined as machines which converts the mechanical energy of motor or engine in to kinetic energy, potential energy and thermal energy.

8.2 Applications

(1)Thermal engineering

- To feed water into the boiler
- To circulate the water in condenser
- To circulate lubricating oil in the proper place

(2) Agriculture and irrigation

- To lift water from deep well
- To convey water from one place to another

(3) Chemical industries:

- To convey liquid chemical from one place to another

(4) Municipal water works and drainage system

(5) Hydraulic control system.

8.3 Classification of pumps

The pump can be classified according to principle by which the energy is added to the fluid and their design feature as shown below.

(A) Positive displacement pumps

These pumps operate on the principle of a definite quantity of liquid is discharged or displaced due to the positive, or real displacement of working elements (i.e. piston, gear, vane, screw)

(1) Reciprocating pump

(i) Piston pumps

- Single cylinder - single acting, double acting
- Double cylinder - single acting, double acting

(ii) Plunger pump

(iii) Bucket pump - Hand pump

(2) Rotary pump (positive displacement with circular motion)

- Gear pump
- Screw pump
- Vane pump

(B) Roto dynamic pump

These pumps operate on the principle of the rise in pressure energy of liquid by dynamic action of liquid. The dynamic action of liquid is carried out by revolving wheel which has curved vanes on it. This wheel is known as impeller.

(1) Centrifugal pump

- Single stage
- Multi stage

(2) Propeller (Axial flow) pump

(3) Mixed flow pump

(C) Other

- Jet pump
- Air lifts pump

8.4 Terminology for pumps

(1) Head

In the pumps, different forms of energy are expressed in terms of height which is called "head'.

(2) Suction Head (h_s)

It is the vertical height of the centre line of pump shaft above the surface of liquid

OR

it is energy required to lift liquid from sump to pump.

(3) Delivery Head (h_d)

It is the vertical height measured from the centre line of pump shaft to where the liquid is delivered or energy required to lift the liquid from pump to end of delivery pipe.

(4) Velocity Head (h_v)

It is kinetic energy carried away by the liquid at the end of delivery pipe.

Mathematically, $h_v = V^2/2g$

Where, V= velocity of liquid in pipe.

(5) Static Head (h_{st})

It is sum of suction and delivery heads.

Mathematically, $h_{st} = h_s + h_d$

(6) Manometric Head (H_m)

It is the total head required to be developed by the pump.

Mathematically, $H_m = h_s + h_d + h_{fs} + h_{fd} + h_{fp} + h_v$

Where,

h_{fs} = friction head loss in suction pipe

h_{fd} = friction head loss in delivery pipe

h_{fp} = friction head loss inside the pump.

(7) Water power (P_w)

It is the power required by pump to handle the liquid to develop nometric head.

Mathematically, $P_w = \rho g Q H_m$

Where,

ρ = density of liquid (kg/m^3)

Q = liquid discharge by pump (m^3/s)

H_m = manometric head in meter

g = 9.81 m/s^2

(8) Shaft power (Ps)

It is the power input to shaft of the pump by motor.

(9) Efficiency of pump (η_p)

It is ratio of water power to shaft power.

Mathematically, $\eta_p = P_w / Ps$

8.5 (A) Reciprocating pump

Reciprocating pump is a positive displacement pump. In this pump, the liquid is discharged due to the simple to and fro motion or reciprocating motion of the piston or plunger

8.5.1 Components of reciprocating pump

The different components parts and their function in a reciprocating pump are as follows.

- Suction pipe: Connects source of liquid to the cylinder.
- Suction valve: Opens during suction stroke and closes at the beginning of delivery stroke.
- Cylinder: Accommodates liquid during suction stroke and discharges during delivery stroke of piston or plunger.
- Piston or plunger: This is a reciprocating part which creates negative and positive pressure due to it's to and fro motion.
- Delivery valve: Closes during suction stroke and opens at the beginning of delivery stroke.
- Crank and connecting rod: Converts the rotary motion of the prime mover into the reciprocating motion of the piston or plunger.
- Delivery pipe: Connects pump cylinder to the storage tank.
- Prime mover: To drive the pump.

8.5.2 Operation of single acting reciprocating pump

- **Construction**

In the single acting pump, anyone side of piston/plunger act upon the liquid (fluid). The pump consists of piston or plunger, cylinder, suction pipe with suction valve, delivery pipe with delivery valve and prime mover which drives the pump.

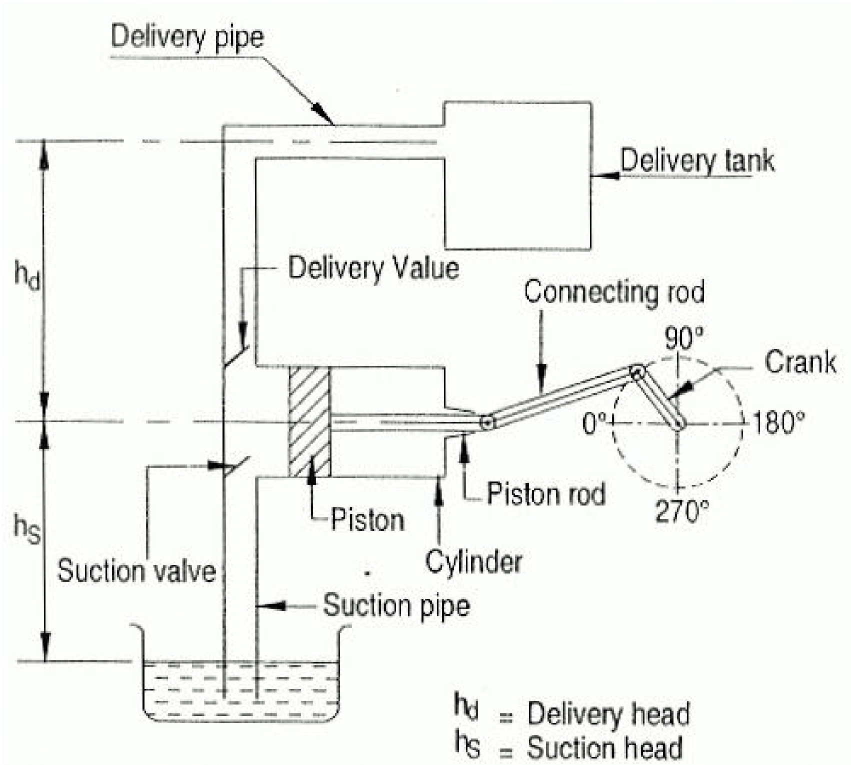


Figure 8.1 Single acting reciprocating pump

- **Working**

Forward stroke (Suction stroke):

The piston moves towards right, crank moves from 0° to 180", shown in Fig 8.1. This creates vacuum in the cylinder on the left side of piston causing the suction valve to open. The liquid enters the cylinder and fills it.

Reverse stroke (delivery stroke):

The piston moves towards left, crank moves from 180" to 360°. This causes increase of pressure in the left side of cylinder. The delivery valve open and the liquid are forced to delivery pipe. The suction and delivery valves are non-return valve, they opens or closes automatically according to pressure difference across them.

8.5.3 Operation of double acting reciprocating pump

In this pump, suction and delivery takes place simultaneously on opposite sides of piston.

- **Working**

Forward stroke:

The piston moves towards right side of cylinder, the liquid is sucked from p through suction valve S_A as shown in Figure. At this moment, the liquid on right side of piston is compressed, the delivery valve D_B opens and liquid is discharged through this valve.

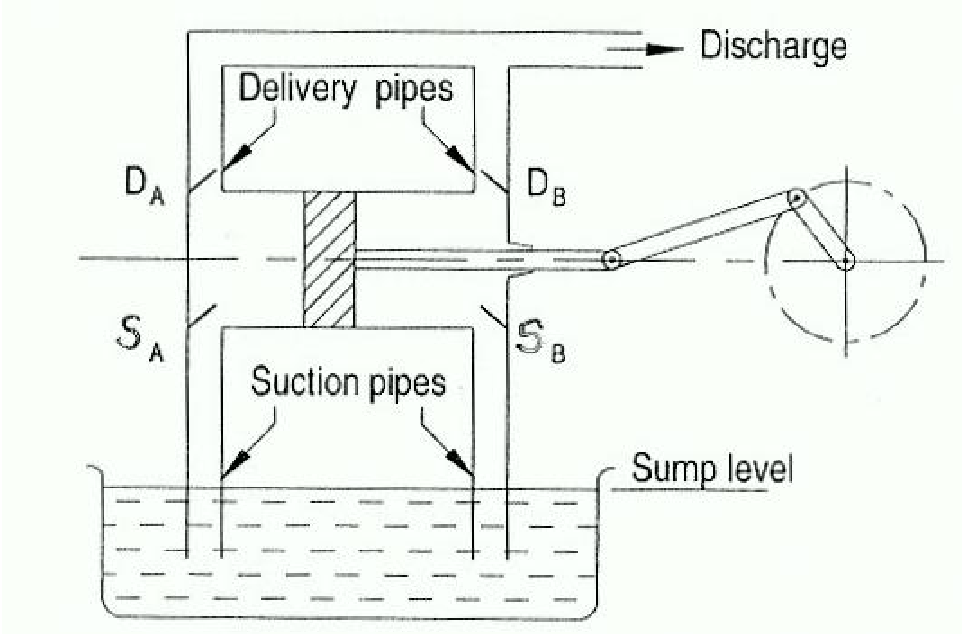


Figure 8.2 Double acting reciprocating pump

Reverse stroke:

The piston moves towards left side of cylinder, the liquid is sucked from through suction valve S_B, at this moment, the liquid on left side of piston is compressed and delivered through valve D_A

- **Advantage**

It gives more uniform discharge than single acting pump, as fluid is delivered in both strokes of piston.

8.5 (B) Plunger pump

- **Construction**

A hand operated plunger pump consists of plunger, stuffing box, suction valve, delivery valve and handle as shown in fig. 8.3. The pump is operated by handle. In order to prevent leakage of the liquid, the stuffing box, gland and pickings are used. Non-return valves fitted at the suction and delivery pipes preventing back flows.

- **Working**

Intake stroke: Plunger moves up, vacuum is created in the cylinder, suction valve open and liquid enters into cylinder.

Discharge stroke: Plunger moves down, suction valve closes and delivery valve open through which high pressure liquid is delivered to the delivery pipe.

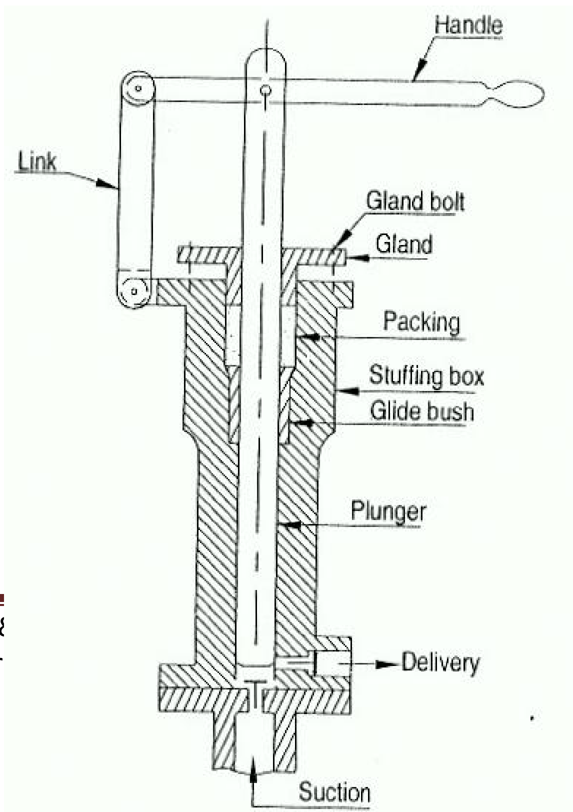


Figure 8.3 Plunger pump

8.5 (C) Bucket pump

➢ **Construction**

A bucket pump is single acting vertical reciprocating pump. It consists of an open cylinder and a piston with bucket type valve as shown in fig. 8.4. A bucket type valve works as a non return valve, packing, Stuffing box, glide bush.

Intake stroke:

Piston moves up the bucket valve remains closed. During this stroke liquid enters into the cylinder through suction valve. Simultaneously, the liquid above the bucket is forces into delivery pipe through delivery valve.

Discharge stroke:

Piston moves down, the bucket valve open. In this stroke neither suction nor delivery of water takes place, but the water which previously sucked in cylinder moves on upper side of piston.

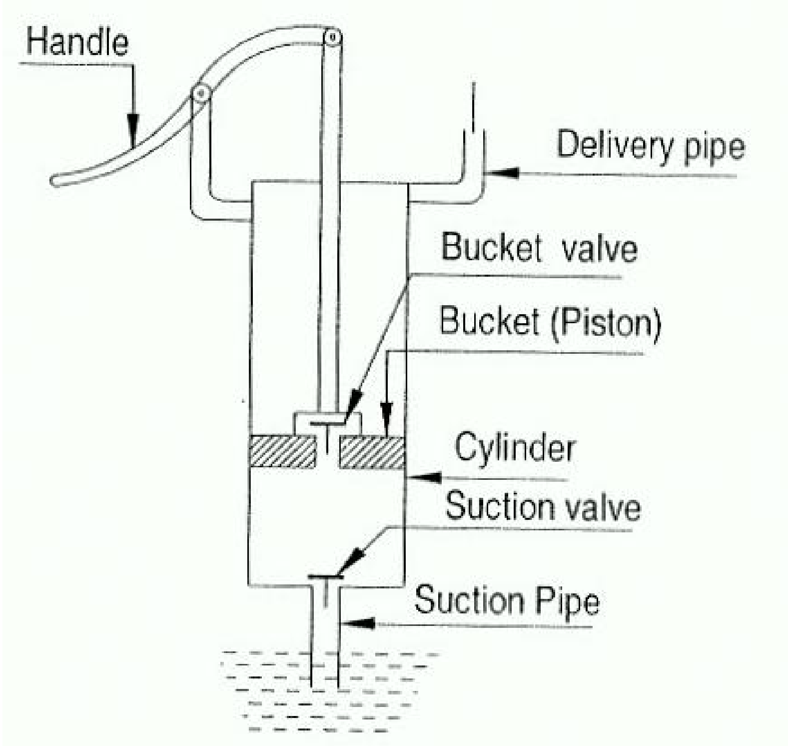


Figure 8.4 Bucket pump

8.6 Air chamber or air chamber

In case of single acting pump, the flow in delivery pipe as well as in suction pipe is n continuous.

In double acting or multi cylinder pump, the flow is continuous but velocity varies in suction as well as in delivery pipe.

8.6.1 Objectives to use air chamber are,

- To obtain a continuous supply of liquid at a uniform rate.
- To save a considerable amount of work in overcoming the frictional resistance in· the suction and delivery pipes, and
- To run the pump at a high speed without cavitation or separation.

➢ **Construction**

An air vessel or air chamber is fitted to the suction pipe and to the delivery pipe at a point close to the cylinder of a single acting reciprocating pump as shown in fig. 8.4. The top of the chamber contains compressed air which can contract or expand. The vessel has an opening at its base through which the liquid may flow into or out of it.

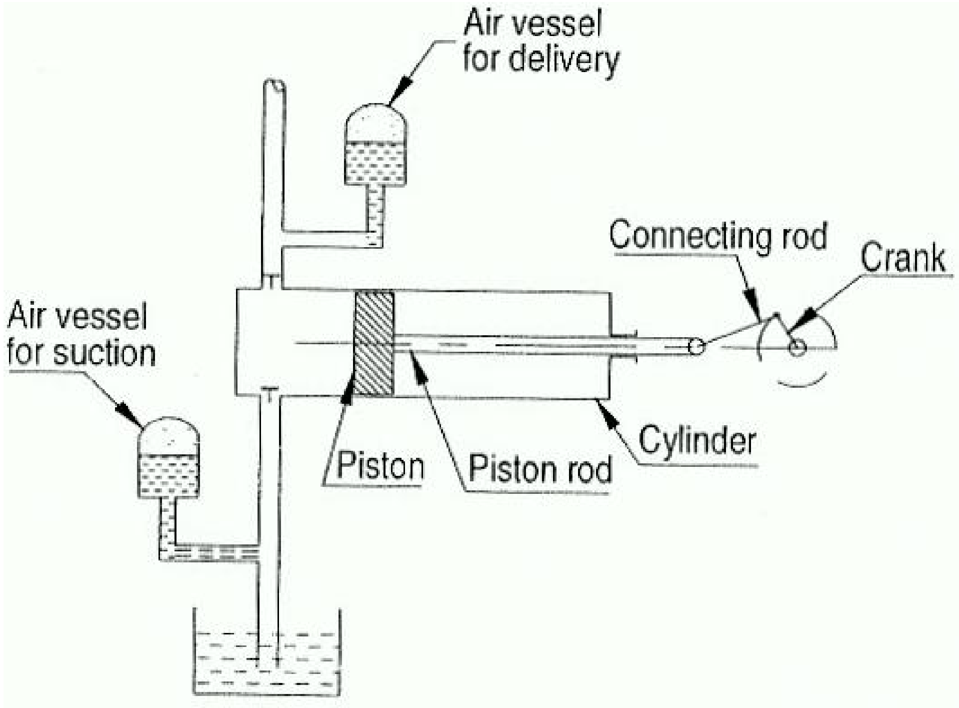


Figure 8.5 Single acting reciprocating pump Air chamber

- **Working**

During delivery stroke, suction valve gets closed and flow from the suction pipe is taken into the air chamber fitted on suction side of the cylinder where it is temporarily stored.

Similarly during suction stroke, delivery, valve is closed but the delivery of flow to the discharge tank is continuous by liquid discharged from air chamber fitted on the discharge side. Thus the air vessel (chamber) works as an intermediate reservoir maintaining constant discharge by maintaining constant velocity of flow in suction and delivery pipes.

If mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, for conveying liquids from one place to other such device is called a centrifugal pump. It is similar to a reversed water turbine in action. Here kinetic energy of the leaving liquid from the impeller is converted into potential energy in the casing which is utilized to increase the delivery head of the pump. When impeller rotates inside the casing, the liquid is discharged by centrifugal force from centre, so vacuum is produced at the suction eye which is connected with the suction pipe and liquid from sump flows to the impeller.

8.7 Priming of centrifugal pump

When a pump is first put into service, its passageways (suction pipe, casing, delivery pipe) are filled with air. If pump is running with air, pressure head generated is in terms of meter of air. If pump is running with water the pressure head generated in terms of meter of water. But density of air is very low, therefore pressure head generated by pump with air is negligible compared to pressure head generated by pump with water. Hence, initially water may not be sucked by pump from sump. Therefore, to avoid this, before first time start the pump air must removed from passageways.

The priming is operation of filling passage ways (suction pipe, casing and delivery pipe up to delivery valve) from outside source with the liquid to be raised before starting the pump. Thus the air from passageways is removed and filled with the liquid to be pumped.

8.7.1 Types of priming

1. Priming by hand
2. Priming with vacuum pump
3. Priming with jet pump
4. Priming with separator

(1) Priming by hand

For small pump priming is done by pouring liquid directly in the casing through funnel air vent cock open provided on the casing. When all air is evacuated from the casing, suction pipe and portion of delivery pipe, the system is filled with liquid. The cocks are closed and pump started.

(2) Self priming

When the pump is idle and liquid level in the pump remains full in the suction pipe & casing the pump can removed the air by their own pumping action. This is called self priming.

The pumps can be primed by any of the following methods.

8.7.2 Main parts of centrifugal pump

The impeller, casing, suction pipe, foot valve and strainer is main parts of centrifugal pump shown in fig. and are explained as under.

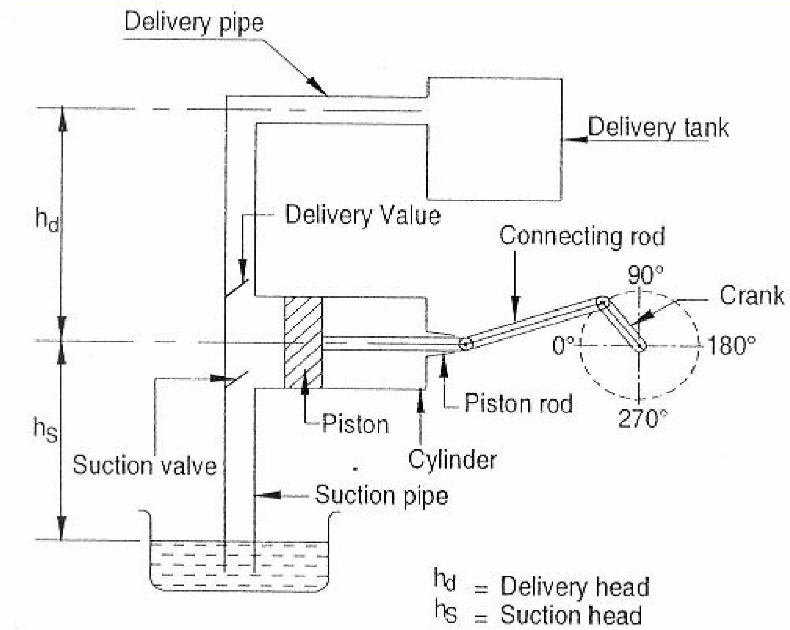


Figure 8.6 Centrifugal pump

1. Impeller: It is rotating part of a centrifugal pump and increases kinetic energy of liquid. It consists of a series of backward curved vanes. The impeller is mounted on a shaft which is connected to the shaft of an electric motor.
2. Casing: It is an airtight passage surrounding the impeller and is designed in such a way that the kinetic energy of the liquid discharged at the outlet of impeller is converted into pressure energy before the delivery pipe.
3. Suction pipe: It is a pipe whose one end is connected to the inlet of the pump and other end is into liquid in a sump.
4. Foot valve: It is a non-return valve or one way type valve. It is fitted at the lower end of suction pipe. The foot valve is essential for all types of roto dynamic pumps. It helps in allow the liquid to enter into pump in upward direction only and does not allow the liquid to flow downwards.
5. Strainer: The strainer is essential for all types of pumps. It protect pump against foreign material which passes through the pump. Without strainer pump may be chocked.
6. Delivery pipe: A pipe whose one end is connected to the outlet of the pump and other end extend to deliver the liquid at a required height is known as delivery pipe.
There are three types of the casing are used in centrifugal ump as shown below:

8.7.3 Classification of centrifugal pump

(A) According to type of casing,

a. Volute or spiral casing type pump
b. Vortex or whirlpool chamber type pump
c. Diffuser type (casing with guide blades) pump

(a) Volute type pump

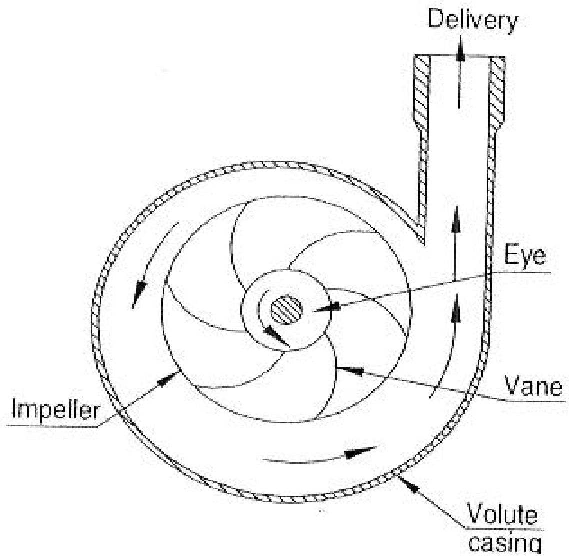


Figure 8.7 Volute type centrifugal pump

In this type of centrifugal pump, impeller is surrounded by the spiral casing known volute chamber as shown in figure. Volute chamber provides a gradual increase in area to the discharge pipe. The liquid leaving the impeller enters the volute chamber with high velocity, then gradually reduced and pressure increases due to gradually increasing area of casing. This volute casing useful for effective conversion of kinetic energy of water in to pressure energy.

- **Disadvantage**

  Volute casing has greater eddy losses which decrease overall efficiency.

(b) Vortex type pump

This vortex type of pump is modified type of volute casing. In this casing, circular chamber (annular space) is inserted between the impeller and volute chamber and is formed a combination of spiral and circular chamber as shown in fig. 8.8. This chamber is known as vortex or whirlpool chamber.

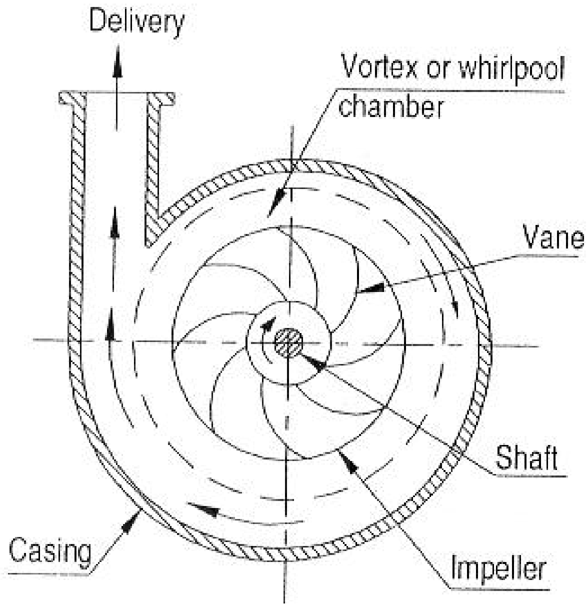


Figure 8.8 Vortex type centrifugal pump

The water leaving the impeller moves freely in this vortex chamber and its velocity head is gradually converted into pressure head and afterwards the liquid is collected in the volute chamber and is discharged through the discharge pipe. This arrangement reduces eddies to a considerable extent and improves the performance of the pump.

(c) Diffuser type pump

In this pump, the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser as shown in fig. 8.9.

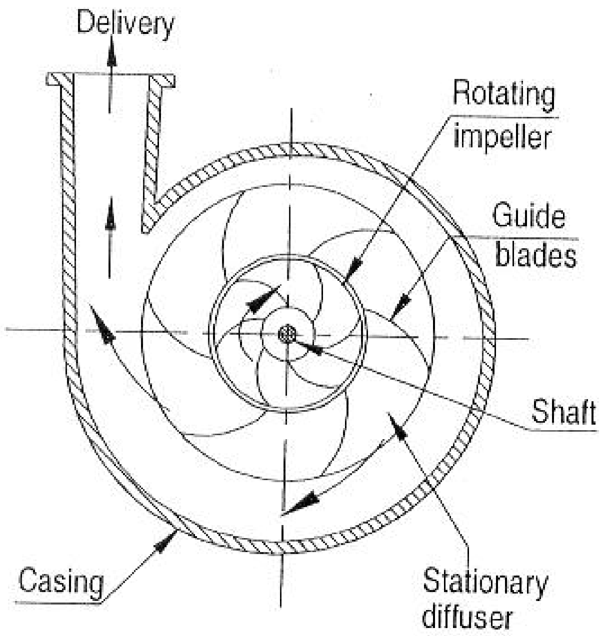


Figure 8.9 Diffuser type centrifugal pump

The liquid leaving the impeller flows through diffuser. The passage of diffuser is gradually increasing area. In the diffuser, the velocity of waterfalls and the pressure increases. In this type of pump more pressure head is developed compared to vortex type and volute type pump.

- **Advantage**

  It has higher efficiency. These pumps are also called turbine pumps.

(B) According to number of stages,

a. Single stage
b. Multi-stage
   - Impeller in series
   - Impeller in parallel

(a) Single stage centrifugal pump

If the pump has only one impeller then the pump is called a single stage pump. A single stage cannot produce sufficient high pressure head efficiently. It is mostly used for lower head and lower discharge.

(b) Multi-stage centrifugal pump

- **Impeller in series**
  - If the pump has more than one impeller and all the impellers are keyed to a single shaft, arranged serially one after the other and enclosed in the same casing is known as multistage pump of impellers in series.
  - Use: for high working pressure head.
- **Impellers in parallel**
  - Impellers are arranged in parallel. One impeller on each shaft and keeping the shafts parallel to one other.
  - Use: for high discharge.

8.8 Rotary pumps

Rotary pumps are positive displacement pumps. It consists of fixed casing with a rotor which may be in the form of gears, vanes, lobes, screws, cams etc.

Centrifugal pump operates on principle of centrifugal action of rotation, the pressure is developed by the centrifugal action of liquid while rotary pumps the pressure is developed by positive displacement of the liquid.

Rotary pump is suitable for pumping viscous fluids like vegetable oil, lubricating oil, alcohol, grease, tar etc.

8.8.1 Types of rotary pumps

There are main three types of rotary pumps as,

a. Gear pump
b. Vane pump
c. Screw pump

(a) Gear pump

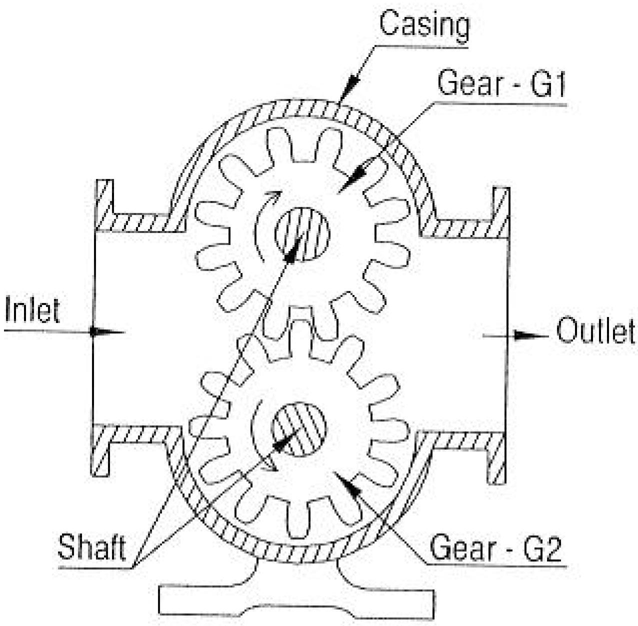


Figure 8.10 Gear pump

- **Construction & Working**

Gear pump are consist of two or more gears which mesh each other. The rotation of these gears provides pumping action. Spur, helical, herringbone type of gear may use for the purpose but spur gears are most commonly used. Two spur gears are in mesh with each other and one of the gears is driving gear and other driven gear. The mechanical contact between the gears teeth and casing seal space between the teeth of gears at suction side. With the rotation of gears entrapped liquid between teeth and casing is carried to the discharge side and squeezed to discharge side.

(b) Vane pump

- **Construction & Working**

It consists of stationary casing and a cylindrical rotor. The cylindrical rotor contains the sliding vanes which fitted to the radial grooves of rotor as shown in figure.

The rotor is mounted eccentrically in relation to cylindrical casing. The vanes are free to move away from the centre of the rotor due to the spring action or due to gravity and centrifugal force of rotation. These make tight contact between vanes and casing during rotation.

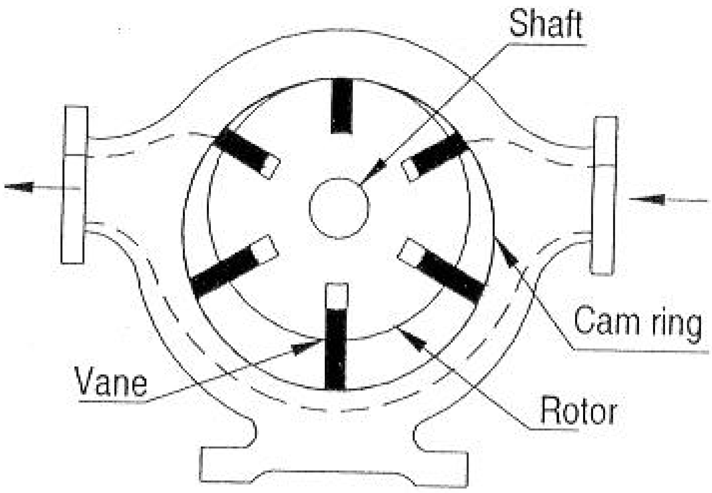


Figure 8.11 Gear pump

When the rotor rotates, the liquid enters from the suction side is entrapped in the pocket between the vanes and casing. This liquid is carried on by the vanes and finally discharged to the delivery side.

(c) Screw pump

- **Construction & Working**

It consists of pair of screws; one of the screw rotors drives other screw rotor in the stationary casing as shown figure.

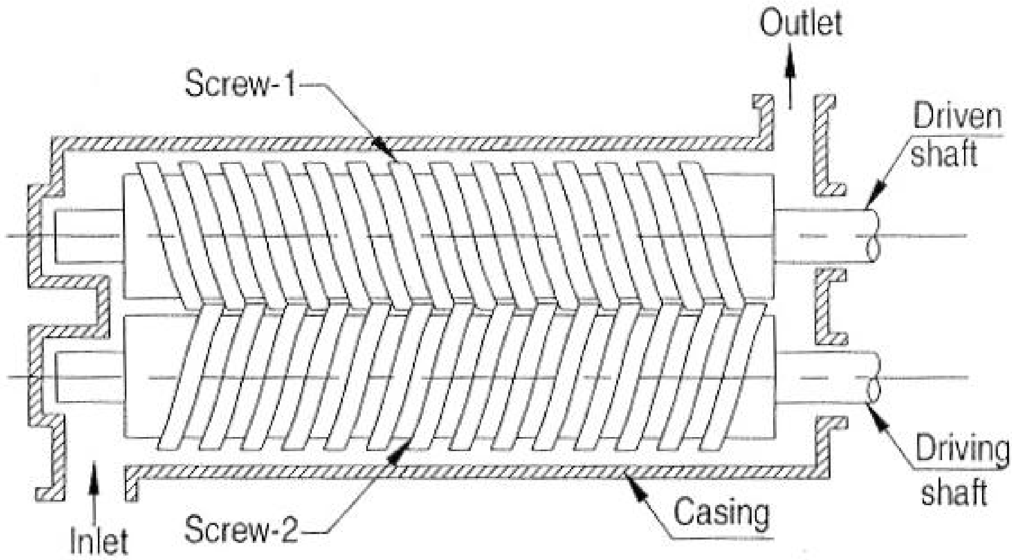


Figure 8.12 Screw pump

The liquid is carried between screw threads in pair of screws in mesh and is displaced axially as the screws rotate.

9. Air compressors

9.1 Introduction

The machines which take in air or any other gas at low pressure and compress it to high pressure are called compressors. Compressors are driven by electric motors, I.C. engines gas turbines.

A compressor is used for increasing the pressure of air is called air compressor.

Following are the uses of compressed air,

1. Operating pneumatic tools like drill, hammers, riveting machine etc.
2. Filling the air in automobile tyres.
3. Spray painting.
4. Increasing inlet pressure of I.C. Engine.
5. To operate air motor in mines where fire risks are more.
6. Pumping of water.
7. Gas turbine power plant.
8. Conveying the materials like sand and concrete along a pipe line.
9. For sand blasting.
10. Operating blast furnaces.
11. Operating air brakes used in buses, trucks, trains etc.

9.2 Classification of compressors

The compressors may be classified according to,

(1) According to method of compression

- Reciprocating compressor:
  This type of compressor compresses air by reciprocating action of piston inside a cylinder. It is suitable for producing high pressure.
- Rotary Compressor:
  In a rotary compressor, air or gas is compressed due to the rotation of impeller or blades inside a casing similar to a rotary pump.
- Centrifugal compressor:
  A machine in which compression of air to desired pressure is carried out by a rotating impeller as well as centrifugal action of air.

(2) According to method delivery pressure

- Low pressure - up to 1.1 bar
- Medium pressure - 1.1. to 8 bar
- High pressure – 8 to 10 bar
- Very high pressure - above 10bar

(3) According to principle of operation

(a) Positive displacement

In this type pressure of air is increased by reducing the volume of it. Here air is compressed by positive displacement of air with piston or with rotating element.

Example: Reciprocating compressor, Root Blower etc.

(b) Roto dynamic or steady flow compressor

In this type compression of air is carried out by a rotating element imparting velocity to the flowing air and developed desired pressure. Here compression is achieved by dynamic action of rotor.

Examples: Centrifugal, Axial flow, etc.

(4) According to the number of stages

- Single stage compressor - pressure up to 5 bar
- Multistage compressor - pressure above 5 bar

(5) According to method the number of cylinder

- Single cylinder
- Multi cylinder

(6) According to method the pressure limit

- Fans - pressure ratio 1 to 1.1
- Blowers - pressure ratio 1.1 to 2.5
- Compressor - pressure ratio above 2.5

(7) According to volume of air delivered

- Low capacity - volume flow rate up to 9 m^3/min
- Medium capacity - volume flow rate 10 m^3/min to 300 m^3/min
- High capacity: Volume flow rate above 300 m^3/min.

(8) According to fluid to be compressed

- Air compressor
- Gas compressor
- Vapour compressor

9.3 Reciprocating air compressor

➢ **Construction**

It consists of the cylinder in which a piston reciprocates. The piston is driven by crank through connecting rod. The crank is mounted in a crankcase. The valves are generally pressure differential type. Thus they operate automatically by the difference of pressure across the valve.

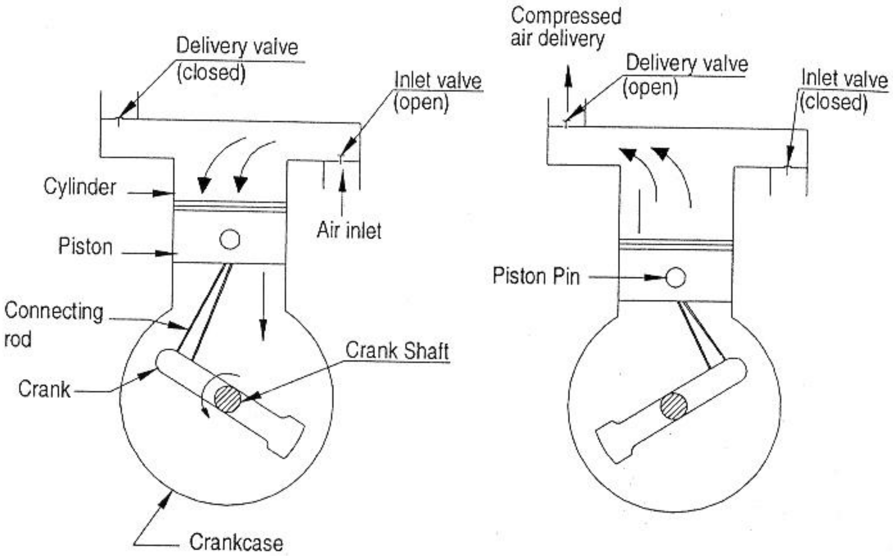


Figure 9.1 Reciprocating air compressor

- **Operation of a compressor**

Case- (1) Operation without clearance

It is assumed that in an ideal compressor there is no clearance volume at the end of the stroke.

In this type of compressor, when piston is moving away from IDC, pressure inside cylinder will decrease and volume will increase. Hence pressure difference across the valve is created. The spring operated inlet valve will be opened automatically for intake of air. Therefore the atmospheric air enters into the cylinder at constant pressure P_1 with increase in volume. This process is shown by (4-1) on p- V diagram.

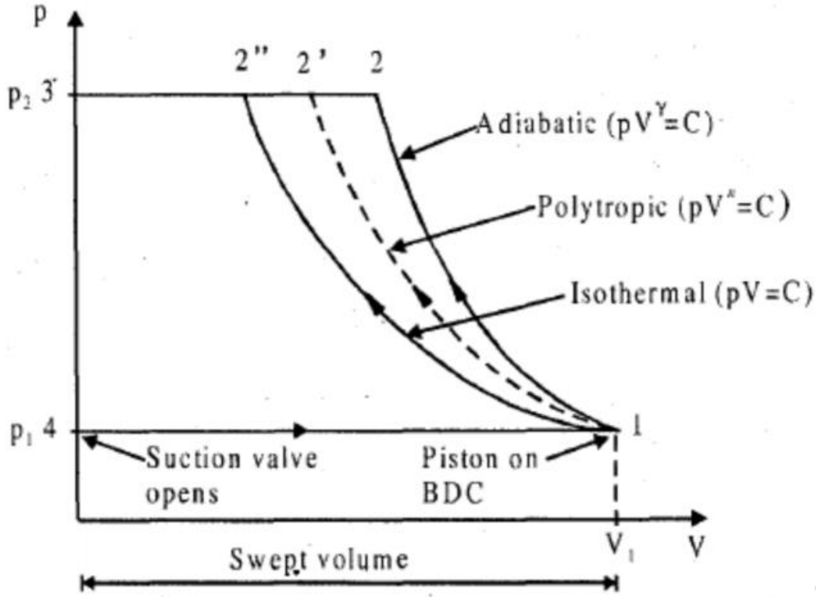


Figure 9.2 Compression without clearance volume

The piston moves towards the IDC from BDC during the second stroke. The air is compressed adiabatically with increase of pressure. This is shown by the curve (1-2). When the pressure of compressed air becomes equal to the pressure of receiver in which the air is delivered, the spring operated delivery valve opens automatically and the air is forced into the receiver at constant pressure P_2 from the cylinder. This process is shown by horizontal line 2-3.

Again piston moves away from TDC. Thus the cycle is completed and the same cycle will be repeated. Area of the diagram (1-2-3-4) represents the work required to compress air from pressure P_1 to P_2 for adiabatic compression.

Work require for compression is given as under.

(A) If the compression is follow $PV^{¥} = C$

Adiabatic work done per cycle,

W = Area under 1-2-3-4

W = Area under 2-3 + Area under 1-2 + Area under 4-1

$$W = P_2V_2 - \frac{P_2V_2 - P_1V_1}{¥ - 1} - P_1V_1$$

$$W = \frac{¥}{¥ - 1}\left(P_2V_2 - P_1V_1\right)$$

$$W = \frac{¥}{¥ - 1} mR\left(T_2 - T_1\right)$$

$$W = \frac{¥}{¥ - 1} P_1V_1\left(\frac{P_2V_2}{P_1V_1} - 1\right)$$

But for adiabatic process, $P_1V_1^{¥} = P_2V_2^{¥}$

$$\frac{V_2}{V_1} = \left(\frac{P_2}{P_1}\right)^{-1/¥}$$

By putting the value $W =$ we get,

$$W = \frac{¥}{¥ - 1} P_1V_1\left\{\left(\frac{P_2}{P}\right)^{¥-1/¥} - 1\right\}$$

(B) If the compression is follow $PV^{n} = C$

$$W = \frac{¥}{¥ - 1} P_1V_1\left\{\left(\frac{P_2}{P}\right)^{n-1/n} - 1\right\}$$

(C) If the compression is follow $PV \quad = C$

$$W = P_2V_2 + P_1V_1 \log_e \frac{V_1}{V_2} - P_1V_1$$

$$P_1V_1 = P_2V_2 = PV = C$$
$$W = PV \log_e r$$

Case- (2) Operation with clearance

In actual compressor there is always clearance volume at the end of stroke. The small clearance is required because of,

(1) Preventing striking of piston at cylinder head,

(2) Thermal expansion due to high temperature at the end of compression,

(3) Maintaining machine tolerance.

(A) If the compression is follow $PV^{\gamma} = C$

The clearance volume is denoted by V_c or V_3.The residual compressed air at a pressure $P_2 = P_3$ is filled in clearance volume at the end of upward stroke of piston. So during the suction stroke this residual compressed air expands and denoted by the curve (3-4) on p-V diagram in figure.

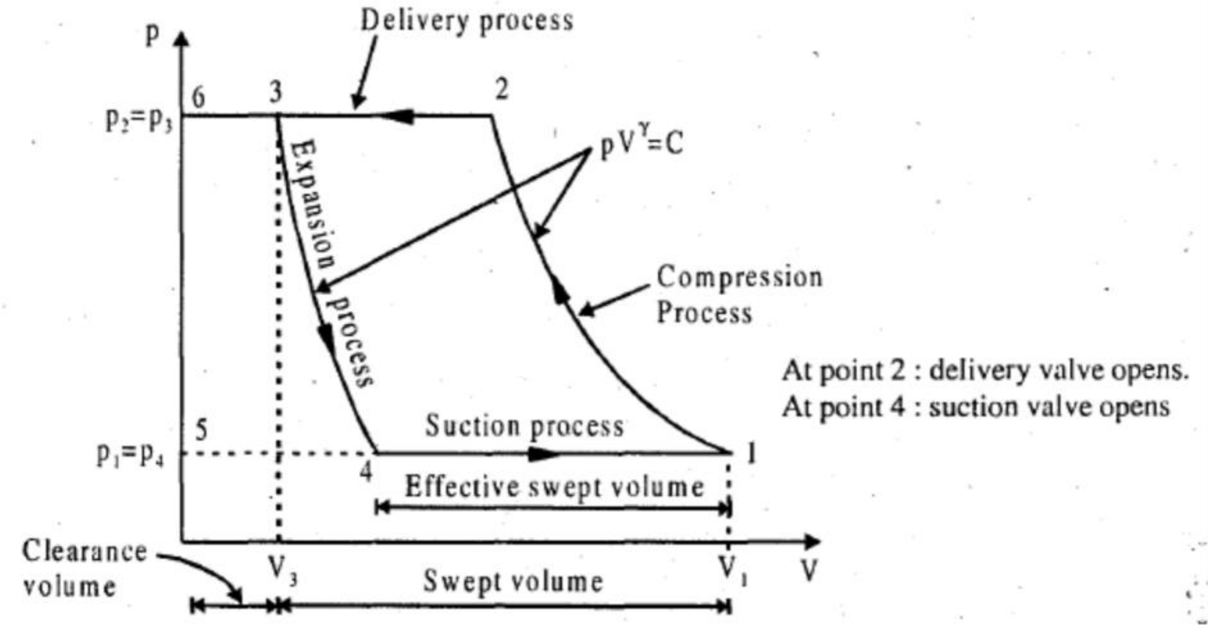


Figure 9.3 Compression with clearance volume

This expansion will reduce pressure from $P_2 = P_3$ to intake pressure $P_4 = P_1$. Due to this reduction in pressure the in valve will begin to open. This will permit the intake of a fresh air. The volume (V_1 - V_4) known as suction volume or effective swept volume or free air delivery at suction condition.

The work required to drive compressor per cycle is represented by area (4-1-2-3). At point 4 suction valve opens, at point 2 delivery valve opens.

$W =$ Area under (5-4-1-2-3-6) - area under (3-4-5-6)

$$= \left[\frac{\gamma}{\gamma - 1} P_1 V_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right] - \left[\frac{\gamma}{\gamma - 1} \left(P_3 V_3 - P_4 V_4 \right) \right]$$

$$= \left[\frac{\gamma}{\gamma - 1} P_1 V_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right] - \left[\frac{\gamma}{\gamma - 1} P_4 V_4 \left(\frac{P_3 V_3}{P_4 V_4} - 1 \right) \right]$$

But for process 3-4, $P_3 V_3^{\gamma} = P_4 V_4^{\gamma}$, thus $\frac{V_3}{V_4} = \left(\frac{P_3}{P_4} \right)^{-1/\gamma}$

$$W = \left[\frac{\gamma}{\gamma - 1} P_1 V_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right] - \left[\frac{\gamma}{\gamma - 1} P_4 V_4 \left\{ \left(\frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right]$$

Now from the graph put $P_3=P_2$ and $P_4=P_1$ in above equation,

$$W = \left[\frac{\gamma}{\gamma - 1} P_1 V_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right] - \left[\frac{\gamma}{\gamma - 1} P_1 V_4 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right]$$

$$W = \left[\frac{\gamma}{\gamma - 1} P_1 \left(V_1 - V_4 \right) \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right]$$

$$W = \left[\frac{\gamma}{\gamma - 1} P_1 \left(V_{as} \right) \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right] J / cycle$$

Where V_{as} is called actual or effective swept volume.

9.5 Definitions

1. Mechanical efficiency (η_m)

It is defined as the ratio of indicated power to brake power.

$$\eta_m = \frac{\text{I.P}}{\text{B.P}}$$

2. Isothermal efficiency (η_{iso})

It is defined as the ratio of isothermal work to polytropic work.

$$\eta_{iso} = \frac{\text{Isothermal work}}{\text{Polytropic work}}$$

3. Free Air Delivery (FAD)

The free air delivery is the volume of air delivered by the compressor when reduced to intake temperature and pressure.

4. Volumetric efficiency (η_v)

$$\eta_V = \frac{\text{Effective swept volume } (V_{as})}{\text{Swept volume } (V_s)}$$

$$\eta_V = \frac{V_1 - V_4}{V_1 - V_3}$$

$$= \frac{V_C + V_s - V_4}{V_s}$$

$$= 1 + \frac{V_C}{V_s} - \frac{V_4}{V_s}$$

Now $P_3V_3^n = P_4V_4^n$, where $V_3 = V_c$, thus put $V_4 = V_c\left(\frac{P_3}{P_4}\right)^{1/n}$ and $\frac{V_C}{V_s} = C$ (Clearance ratio) in above equation,

$$= 1 + C - C\left(\frac{P_3}{P_4}\right)^{1/n}$$

$$= 1 + C\left[1 - \left(\frac{P_2}{P_1}\right)^{1/n}\right]$$

$$\eta_V = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right]$$

Factors are responsible for reduction in volumetric efficiency,

1. The presence of clearance volume,
2. The throttling of the air when it passes through the inlet and outlet valves,
3. Heating of the incoming air, and leakages.

9.6 Multistage reciprocating compressors

In a single stage compressor, if the pressure ratio is increased, the volumetric efficiency decreases. When the pressure ratio is increase maximum, the volumetric efficiency becomes zero, thus multistage compression is needed.

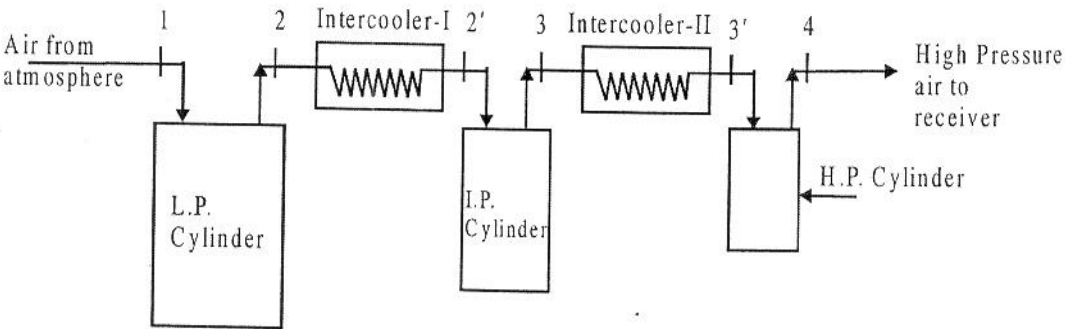


Figure 9.2 Multistage stage reciprocating compression

- **Problems with single stage compression are,**
  1. The higher the delivery pressure, the higher will be delivery temperature. This increase in temperature causes increase in specific volume and energy loss. So compressor has to handle more volume of air at higher temperature.
  2. The increase in temperature of air causes reduction in density of air, hence the mass flow through compressor decreases.
  3. The operation at high pressure and temperature will need heavy working parts.
- **Working**

In low pressure (L.P.) cylinder, air is compressed adiabatically from point 1 to 2. This compressed air is passed through intercooler-l where it is cooled from 2 to 2'. The air coming from intercooler-l is then admitted into the intermediate pressure (J.P.) cylinder where it is compressed adiabatically from 2' to 3. The compressed air from J.P. cylinder is cooled from 3 to 3' in the intercooler-2. Finally air enters into high pressure (H.P.) cylinder for getting higher pressure.

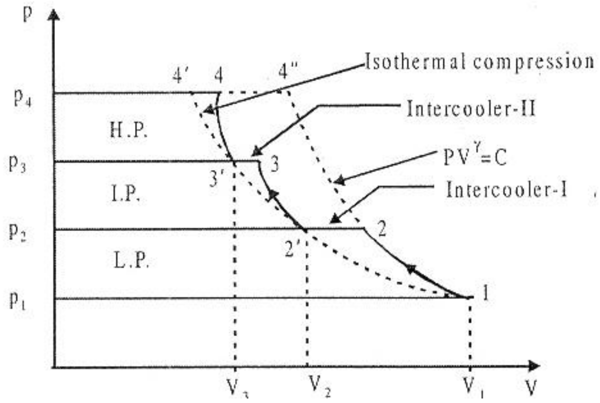


Figure 9.3 P-V diagram of multistage stage reciprocating compression

- **Advantages**
  1. Without intercooling, the curve of compression will follow the path (1- 4"), hence the saving in work input due to intercooling.
  2. Volumetric efficiency is increased due to the smaller pressure range, as the effect of expansion of air in the clearance volume is less.
  3. Less shaft power is required for a given pressure ratio due to the saving in work input.
  4. Due to smaller working temperature, better lubricating effect is provided.
  5. Better mechanical balance and smoother torque-angle diagram is obtained.
  6. In a multistage compressor, the low pressure cylinder is lighter.
  7. There is less leakage problems due to less pressure difference for each stage.

10. Refrigeration and Air conditioning

10.1 Introduction

In heat engine, heat flow from hot body to cold body and produce useful work.

If it operates in the reverse direction, it takes heat from a cold body and rejects it to a hot body by the external mechanical work known as reversed heat engine. This principle is used in two devices.

(1) Heat pump

It is device which absorbs heat from cold body (surrounding) and deliver to hot body and maintain constant temperature of hot body for useful purpose. In this device, external work required to convey heat from cold body to hot body.

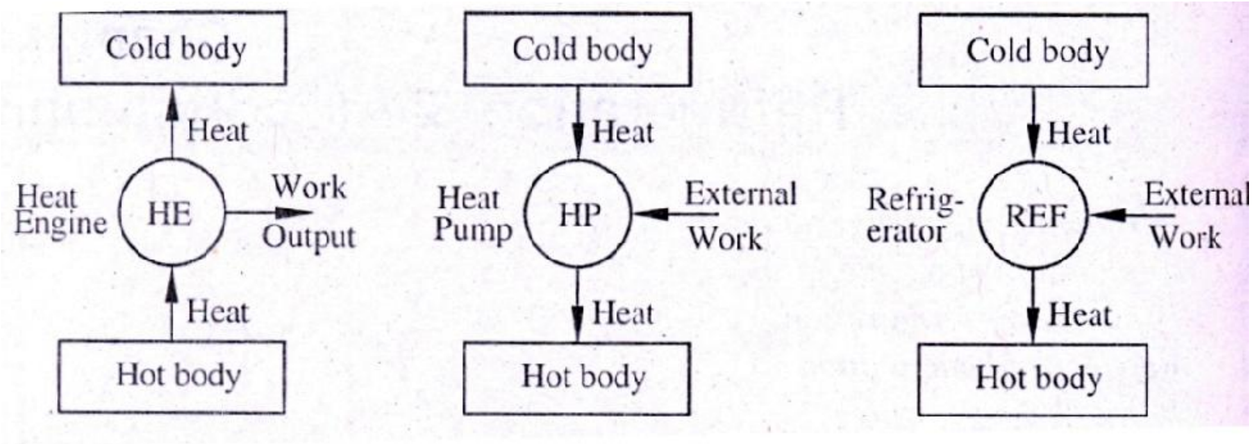


Figure 10.1 Heat engine, Heat pump and Refrigerator

(2) Refrigerator

It is a device which removes heat from cold body and reject to hot body (surrounding) and maintains low temperature for useful purr this device, external work is required to convey heat from cold body to hot body.

"It is a device or system used to maintain the low temperature below the atmosphere temperature within required space."

10.2 Application of refrigeration

1. Storage and transportation of food stuffs as dairy products, fruits, vegetables, meat, fishes etc.
2. Preservation of medicines and syrups.
3. Manufacturing of ice, photographic films, rubber products.
4. Processing of petroleum and other chemical products.
5. Liquefaction of gases like N_2, O_2, H_2 etc.
6. Cooling water

7. Comfort air conditioning of auditoriums, hospitals, residence, offices, factories, hotels, computer rooms etc.

10.3 Principle of refrigeration

In refrigeration, the heat is to be removed continuously from a system or space at a lower temperature and transfer to the surrounding at a higher temperature. In this process, according to second law of thermodynamics external work is required to convey heat from cold body to hot body. Therefore in refrigeration, power is required to cool the space below the atmospheric temperature.

Refrigeration is defined as "the method of reducing the temperature of a system below surrounding temperature and maintains it at the lower temperature by continuously abstracting the heat from it. In simple, refrigeration means the cooling or removal of heat from a system.

10.4 Refrigerants

The refrigerant is a heat carrying medium which absorbs heat from space (desired to cool) and rejects heat to outside the refrigerator (in atmosphere).

10.4.1 Properties of a good refrigerant are,

1. High latent heat of evaporation and low specific volume.
2. Good thermal conductivity for rapid heat transfer.
3. Non-toxic, non-flammable and non-corrosive.
4. Low specific heat in liquid state and high specific heat in vapour state.
5. Low saturation pressure.
6. High co-efficient of performance.
7. Economical in initial cost and maintenance cost.

10.4.2 Refrigerants commonly used in practice are,

1. NH_3 (Ammonia)

Properties:

- Highly toxic
- Flammable
- Good thermal properties
- Highest refrigerating effect per kg of refrigerant

Uses:

- Large industrial and commercial refrigeration system.
- Vapour absorption refrigeration cycle like ice plants, cold storage, packing plants etc.

2. CO_2 (Carbon dioxide)

Properties:

- Colorless
- Non-toxic, non-flammable and non-corrosive gas.
- low refrigeration effect

Uses: Marine refrigeration system

3. Air

Properties:

- Colorless
- Non-toxic, non- flammable
- Non corrosive
- Low COP

Uses: aircraft air-conditioning system.

4. R-11 (Trichloro monofluoro methane) or Freon-ll

Properties:

- Non-toxic,
- Non-flammable
- Non-corrosive

Uses: Small office buildings and factories for refrigeration.

5. R-12 (Dichlaro - difluro methane) or Freon -12

Properties:

- Non toxic, Non-flammable, Non-explosive
- High COP
- Most suitable refrigerant

Uses: in domestic vapour compression refrigeration.

6. R-22 (Monochloro - ditiuro methane) or Freon -22

Properties:

- Non-toxic, Non-flammable, Non-explosive
- Required less compressor displacement

Uses: in commercial and industrial low temperature applications (in air conditioning).

10.5 Refrigeration effect and unit of refrigeration

10.5.1 Refrigeration effect

It is define as the amount of heat absorbed by refrigerant from the space to be cooled. The capacity of refrigeration system is expressed in tons of refrigeration which is unit f refrigeration.

10.5.2 A ton of refrigeration

It is defined as "refrigerating effect produced by melting of 1 ton of ice from and at 0°C in 24 hours."

OR

"Amount of heat required to remove in order to form one ton of ice in 24 hours from water at temperature 0C".

The latent heat of ice is 335 kJ/kg, the refrigeration effect produced by 1 ton ice in 24 hours is,

$$= \frac{335 \times 1000}{24} KJ/hr = 14000\, KJ/hr = \frac{14000}{60} KJ/\min = 232.6\, KJ/\min = \frac{232.6}{60} KJ/s = 3.8888 KW$$

In actual practice, 1 ton = 900 kg considered for calculation of 1 ton of refrigeration,

$$\therefore 1 \text{ ton} = \frac{335 \times 900}{24} KJ/hr = 210\, KJ/\min = 3.5 KW$$

$$\therefore 1 \text{ ton of refrigeration} = 210\, KJ/\min = 3.5 KW$$

10.5.3 Co-efficient of performance

It is defined as the ratio of refrigerating effect to work required compressing the refrigerant in the compressor. It is the reciprocal of the efficiency of a heat engine. Thus the value of COP is greater than unity.

$$\text{Mathematically, COP} = \frac{\text{Refrigerating effect}}{\text{Work of compressor}}$$

10.6 Types of refrigerators

The refrigerator can be classified as follows.

(A) Natural refrigerator

In natural refrigerator, the cooling effect produced by evaporation of liquid or sublimation of solids. When liquid evaporate, it absorbs heat from surrounding and produces cooling. Similarly, in sublimation (melting) of solid, it absorbs heat from surrounding and produces cooling effect.

(B) Mechanical refrigerator

In mechanical refrigerator, refrigeration effect produced by, external source of mechanical energy or heat energy.

It is further classified as,

1. Vapour compression refrigerator
2. Vapour absorption refrigerator
3. Air refrigerator

10.6.1 Vapour Compression Refrigeration system (VCR)

- **Construction**

This system consist of (l) Evaporator (2) compressor (3) condenser and (4) expansion device.

In vapour compression refrigerator, vapour used as the refrigerant. It is circulated in system in which it alternately evaporates (liquid to vapour) and condenses (vapour to liquid) thus it undergoes a change of phase. In the evaporation it absorbs the latent heat from the space to be cooled. In the condensing or cooling, it rejects heat to atmosphere.

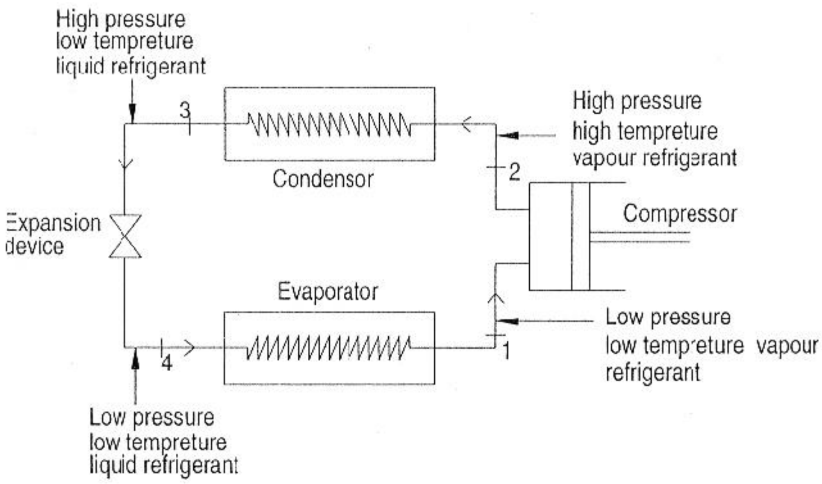


Figure 10.2 Vapour Compression Refrigeration system

Functions of main parts of vapour compression system are,

(1) Compressor

Function of compressor is to remove the vapour from the evaporator and increases its pressure and temperature up to it can be condensed in the condenser. Pressure of refrigerant coming from compressor should be such that the saturation temperature of vapour (corresponding to this pressure of vapour) is higher than the temperature of cooling medium in condenser. So that high pressure vapour can reject heat to cooling medium in the condenser.

(2) Condenser

The function of condenser is to facilitate a heat transfer surface through which heat transfer takes place from the hot refrigerant vapour to the condensing medium. In domestic refrigerator condensing medium is atmospheric air.

(3) Expansion valve or device

The function of expansion valve is to meter the proper amount of liquid refrigerant and reduces pressure of liquid refrigerant entering the evaporator. Hence liquid will vaporize in the evaporator at the desired low temperature and absorb heat from the space.

(4) Evaporator

An evaporator provides a heat transfer surface through which low temperature liquid refrigerant can absorb heat from space and it vaporized.

- **Working**

Process 1-2: Inlet of compressor (at point 1), low pressure and low temperature vapour enters the compressor. Compressor compresses the vapour at high temperature and pressure. The condition of refrigerant at exit to compressor (at point 2) is high pressure and high temperature vapour.

Process 2-3: High pressure, high temperature vapour coming from compressor condenses in the condenser by the rejecting heat to cooling medium. Cooling medium is usually air or water. The condition of refrigerant at exit to condenser (at point 3) is low temperature saturated liquid.

Process 3-4: The saturated liquid coming from condenser passes through expansion device (throttling valve) where pressure of saturated liquid decreases from condenser pressure to evaporator pressure. The condition of refrigerant after throttling is low temperature and low pressure liquid.

Process 4-1: Liquid refrigerant coming from expansion device enters into evaporator where it absorbs latent heat of evaporation from space to be cooled (refrigerator compartment). Due to absorption of heat liquid refrigerant converted into saturated vapor or superheated vapour at low pressure and low temperature. Again this vapour enters into compressor and the cycle is repeated.

10.6.2 Domestic vapour compression refrigerator

➢ **Construction**

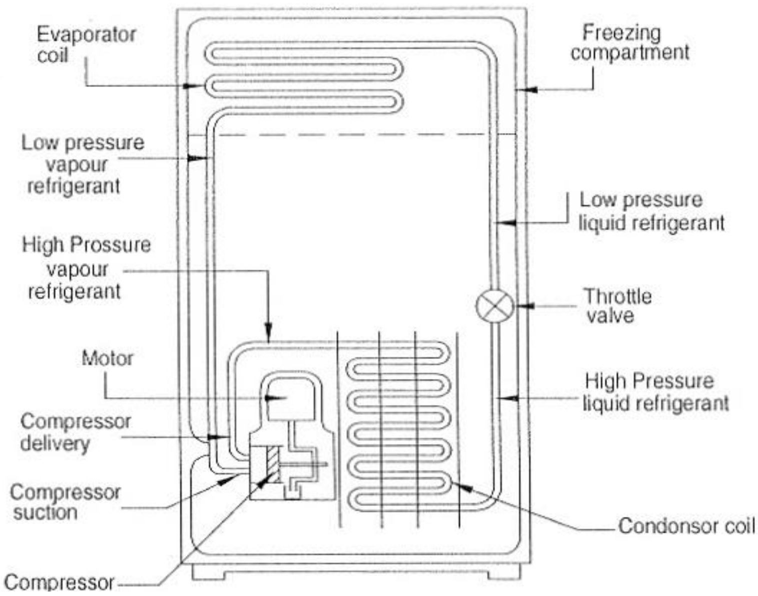


Figure 10.3 Domestic vapour compression refrigerator

It consists of an evaporator installed in the freezing compartment of the refrigerator. One end of evaporator connected to the suction side of the compressor and other end connected to condenser through throttle valve. Normally condenser installed at the backside of refrigerator. The delivery side of compressor is connected to a condenser.

Examples…available in capacities of 65 liters, 100 liters, 165 liters, 275Iitres,1000 liters.

10.6.3 Vapour Absorption Refrigeration System (VAR)

➢ **Construction**

This system is shown in figure consists of (i) evaporator, (ii) condenser, (iii) generator, (iv) absorber, (v) pump and (vi) expansion device.

In this system the refrigerant coming from evaporator is absorbed by absorber. The absorbing medium may be solid or liquid. In VAR system, the compressor is replaced by an absorber and generator.

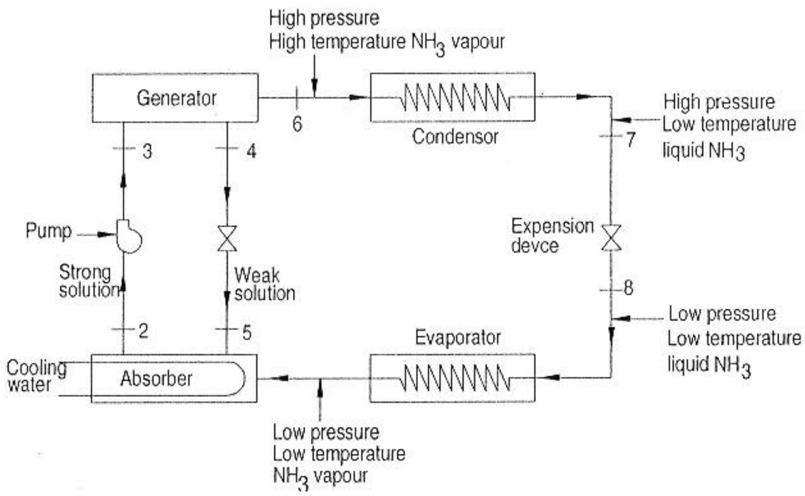


Figure 10.4 Vapour Absorption Refrigeration system

Ammonia is refrigerant has characteristic as it is easily absorbed by water at low pressure and temperature, but at high pressure and temperature, the solubility of ammonia in water is reduced. Therefore when mixture of water and ammonia is heated by generator, the ammonia vapour is separated from water. This principle is used in the vapour absorption refrigeration system. Here the ammonia is refrigerant and water is absorbent.

- **Working**

Low pressure and low temperature vapour ammonia coming from evaporator enters in the absorber where ammonia is absorbed by weak solution coming from generator through throttle valve at point 5. Due to absorption of NH_3 in water, solution becomes strong. [In the mixture of NH_3 and water, if amount of NH_3 is less than water is called weak solution and if amount of NH_3 is more than the water is called strong solution.] During absorption process heat is released and rejected to cooling water.

The strong solution from absorber is pumped into generator, where it is heated and NH_3 vapour separated from solution. In generator is supplied from external source. The weak solution at point 4 is flowing back to absorber through throttle valve. Again weak solution in absorber absorbs NH_3 vapour coming from evaporator.

NH_3 vapour coming from generator (at point 6) passes through condenser and condensed in condenser and reject heat to cooling medium. Then liquid NH_3 (at point 7) throttled through expansion device and it enters into evaporator (point 8). In the evaporator NH_3 evaporates by absorbing latent heat of evaporation to produce refrigerating effect. Thus the cycle is completed.

10.6.4 Air refrigerator

- **Construction**

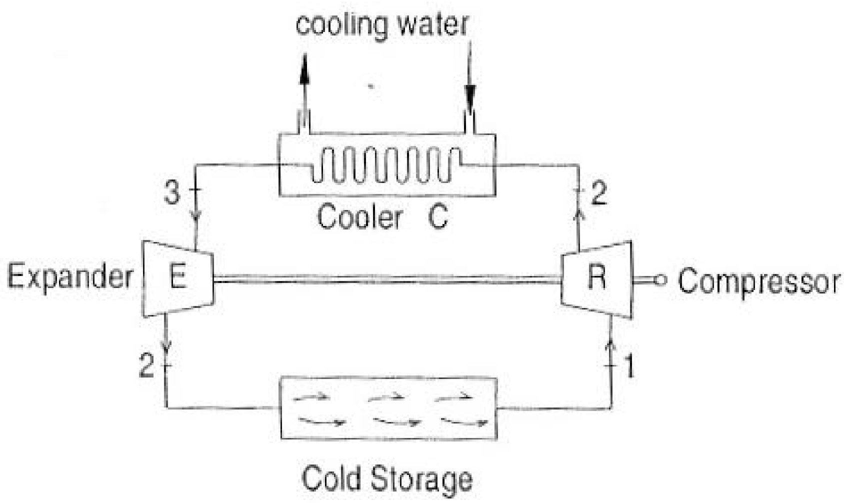


Figure 10.5 Air refrigerator

The Air refrigerator is one of the oldest types of refrigerator. In this system air is used as refrigerant and operates on Bell Coleman cycle. It consists of (1) compressor (R) (2) expander (E) (3) Cooler (C) and (4) Cold storage as shown in figure.

- **Working**

Process 1-2: Air from cold storage is sucked by air compressor. Air is compressed isentropically in compressor, pressure and temperature of air increases.

Process 2-3: The hot air from the compressor is cooled at constant pressure in the cooler. The temperature of air is reduced.

Process 3-4: High pressure and low temperature air is expanded isentropically in the expander. Temperature and pressure of air decreases. During the expansion of air work is produced. This work is utilized to run compressor. But this work is not sufficient for compressor and so extra work to compressor.

Process 4-1: The cold air from the expander passes into the cold storage where the air sorbs heat from the bodies that is required to be cooled. Then it again enters into the compressor, cycle is completed and it is repeated again and again.

- **Advantages**
  1. Air is freely available from the nature.
  2. As compared to the other refrigerator, weight of air refrigerator per ton of refrigeration capacity is low. Therefore it is used in air crafts and missiles cooling.
- **Disadvantages**
  1. COP is very low
  2. Requires large power
  3. Requires more space.
  4. The volume of air required to be circulated is more compared to refrigerant is in other refrigerator. Thus it cannot be used for large capacity plants.

10.7 Comparison between vapour compression and vapour absorption systems

Sr.	Particulars	Vapour compression	Vapour Absorption

No		system (VCR)	system (VAR)
1.	Working method	Refrigerant vapour is compressed	Refrigerant is absorbed and heated
2.	Type of the energy supplied	Mechanical work supply to compressor	Heat energy supply to generator
3.	Input work required	More compression work is required	Less mechanical energy is required to run pump
4.	COP	High (Approx. 3)	Low (Approx. 0.6)
5.	Capacity	Limited up to 1000 tons for single compressor	It may be above 1000 tons
6.	Noise	More	Quiet operation
7.	Leakage	More leakage due to high pressure	Almost there is no leakage
8.	Operating cost	High because of compressor consumes more work	Less because of less heat energy is required
9.	Suitable refrigerant	R-12	Ammonia

10.8 Air conditioning

The basic function of air conditioning system is,

- Cooling or heating of air.
- Addition of moisture in air (Humidification) or removal of moisture from (dehumidification).
- Purification, control movement or distribution of air and addition of fresh air from outside.

10.8.1 Definition

It is the simultaneous control of temperature, air humidity, air movement and air cleanliness.

10.8.2 Applications

For Human comfort:

To provide cooling or heating and conditioning of air as per comfort of human being. This is known as comfort air conditioning.

For commercial use:

To provide cooling or heating and conditioning air as per required in some engineering manufacturing and processing. This is known as industrial air conditioning.

The comfort air conditioning means conditioning of air in such a way that the human being can feel good.

➢ Standard comfort conditions for human being are,
  - Temperature of air: Dry bulb temperature (DBT) 17° to 25° C
  - Moisture level: Relative humidity (RH) 30 to 70 %
  - Velocity of air 0.1 m/s to 0.25 m/s

10.8.3 Principle of air conditioning

In air conditioning system, the device or unit provides air conditioning is called air conditioner. This device continuously draws air from an indoors space which is required to cool, it cools in refrigeration system and discharge back into the same indoor space. This continuous cyclic process of drawing, cooling, and recirculation of the cooled air maintains indoor space cool at the required lower temperature which is required for comfort cooling or industrial cooling.

The basic components of air-conditioning system are,

1. Fans: For circulation of air
2. Filters: For cleaning air
3. Heating element: Heating of air (It may be electric heater, steam, hot water)
4. Control system: It regulates automatically the amount of cooling or heating.
5. Grille: It adjusts the direction of conditioned air to the room.
6. Tray: It collects condensed water
7. Refrigerating plant: Provide cooling. It consists of compressor/generator and absorber, evaporator, condenser, expansion device (capillary tube).

10.9 Classification of Air conditioning system

(A) According to arrangement of equipments

(1)Unitary system

In this system different component of air conditioning system is manufactured and assembled as unit in a factory. This unit is installed in or near to space to be conditioned.

1. Window air conditioner
2. Split air conditioner
3. Packaged air conditioner

(2) Central system

In this system different components are manufactured in factory and assembled at the site. This type of system is used for conditioning of air in theatres, cinemas, restaurants, exhibition halls, big factory space etc.

(B) According to the purpose

1. Comfort air conditioning system
2. Industrial air conditioning system

(C) According to season of year

1. Winter air conditioning system: Air is heated and humidified
2. Summer air conditioning system: Air is cooled and dehumidified

10.9.1 Window air conditioner

- **Basic function**

It mainly used for conditioning of air in the room. The basic function of window air conditioner is to provide comfort cooling, dehumidification, filtering and circulation of air.

- **Construction**

Refrigerating unit: evaporator/cooling coil, condenser, compressor, and expansion device (throttle valve or capillary tube).Air circulation fan each for evaporator and condenser.

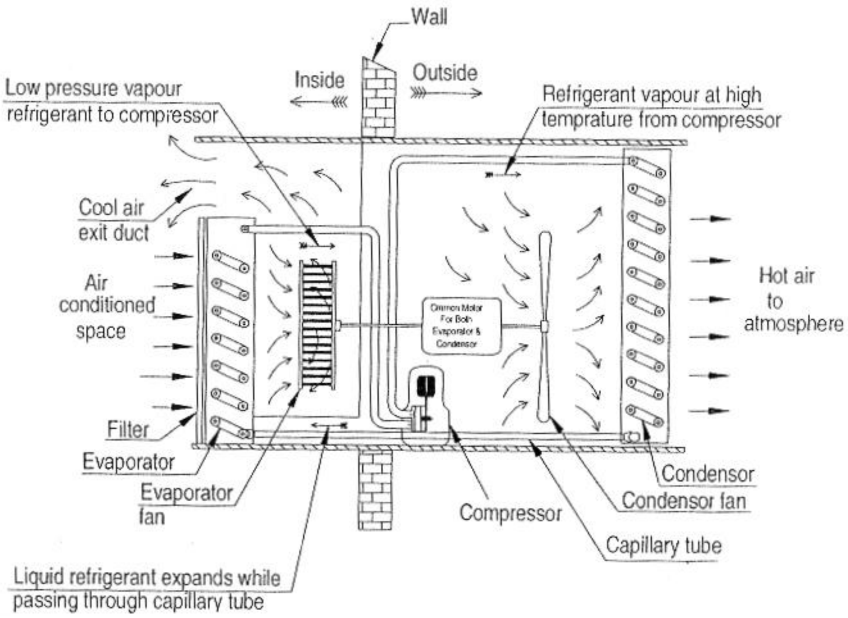


Figure 10.6 Window air conditioner

- **Working**

The hot air coming from room is flowing on the evaporator (cooling coil), the cooling coil absorbs heat from air. The moisture of air gets removed on the cooling coil surface by process of condensation of air. Thus the air is cooled and dehumidified to meet the requirement comfort air conditioning in the room. The filter clean the air coming from room before passes through the cooling coil. The tray is provided below the cooling coil (evaporator) to collect moisture which condenses from recirculation of air.

The flow of hot air (from room) and cooled air (to room) is taking place by the evaporator blower. The refrigerating unit provides cooling effect at evaporator. The condenser fan circulates air on outside of condenser tubes, the refrigerant in condenser reject heat to outside atmospheric air. Necessary fresh air is allowed to mix with the recalculated room air to meet the ventilation requirement. Ventilation air is controlled by ventilation damper. The room -temperature is controlled by a thermostat using on-off power supply to compressor motor.

It available in size up to 2 tons capacity.

- **Limitations**

1. It produce noise in the room because of compressor is very near to the room.
2. The evaporator and condenser are enclosed in single unit. Therefore evaporator cannot be used as an interior of room because condenser requires outside air for cooling.
3. It requires appropriate size of window or hole in wall to fit the conditioner.
4. Most of window A/C doesn’t provide heating for winter.
5. No provision for humidification is possible in window AC.
6. It has no control over humidity through it carries out dehumidification.

10.9.2 Split air conditioner

It is modification of window air conditioner.

➢ **Construction**

This unit differs from window air conditioner. In terms of split of unit into two parts. In split air conditioner, the window air conditioner divided (split) into two parts.

First part: Includes the evaporator, filter, evaporator fan and grille (cooling coil). They placed inside the room.

Second part: Includes condenser, condenser fan, and compressor. This placed outside the room.

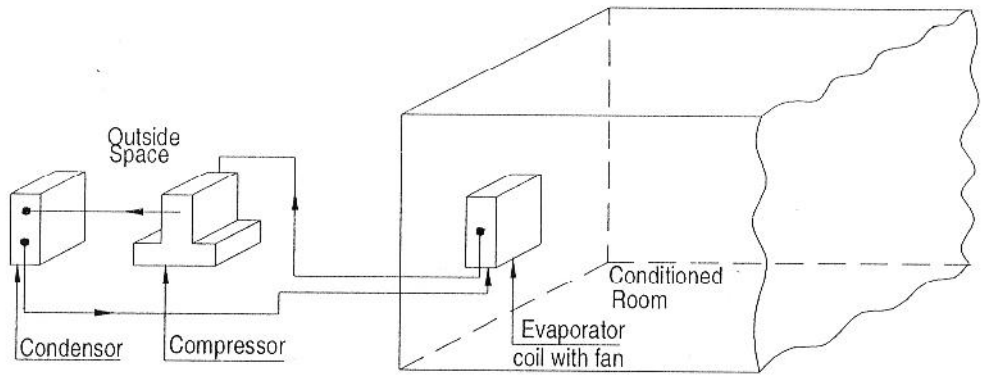


Figure 10.7 Split air conditioner

First part (inside of room) and second part (outside of room) is connected by small diameter tubes. Therefore, small hole required in wall for installation of split air conditioner.

10.9.3 The advantages of split air conditioner over window air conditioner

1. The compressor is outside of room, therefore no compressor noise in the room.
2. No window opening and fixing needed.
3. The first part can be located in the room with decorative display. The first unit can be mounted on floor, ceiling, and wall or behind a decorative structure.

11. Brakes, Clutches and Couplings

11.1 Introduction

Coupling and clutches are power transmission elements. It is used for transmitting power from one shaft to the other shaft.

A coupling is a device used to connect or couple two shafts while clutch is device which facilitate engage and disengage of driving shaft and driven shaft whenever required even it may rotate.

The brake is frictional device whose primary function is to control the motion of machine member. It is used to bring machine member into rest or slow down.

11.2 Couplings

Shafts are mostly available up to 7 meter length due to transport difficulty. To get a greater length, it is necessary to joint two or more pieces of the shaft using coupling.

Purposes of Coupling used are,

1. To connect shafts of motor and generator which are manufactured separately and to provide for disconnection for repairs.
2. To reduce the transmission of shock loads from one shaft to another.
3. To allow misalignment of the shaft or to introduce mechanical flexibility.
4. To introduce protection against overloads.

11.2.1 Types of couplings

Couplings are divided into two main groups as follows,

(1) Rigid coupling

It is used to connect two shafts which are perfectly in axial alignment. These couplings do not allow any relative rotation between the two shafts.

There are basic three types of rigid coupling as follows,

a. Sleeve or muff coupling
b. Clamp or split muff or compression coupling
c. Flange coupling: - (1) Unprotected type (2) protected type

(a) Sleeve or Muff coupling

Figure 11.1 shows sleeve or muff coupling.

➢ **Construction**

This is the simplest type of rigid coupling. It is made from cast iron and very simple to design and manufacture. It consists of a hollow cylinder (muff) whose inner diameter is the same as diameter of the shaft.

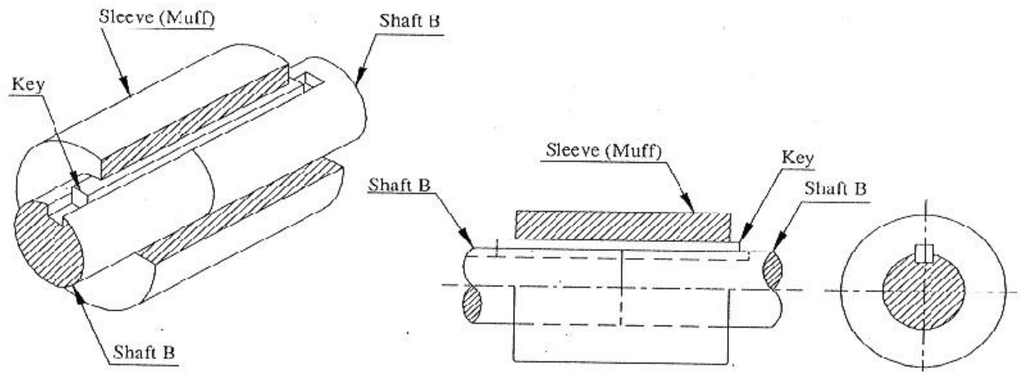


Figure 11.1 Sleeve or muff coupling

The hollow cylinder (muff) is fitted over the ends of the two shafts with the help of taper sunk key. A key and sleeve (muff) useful to transmit rower from one shaft to the other shaft. It has no projecting parts.

➢ **Disadvantage**

It is difficult to assemble when there is no perfect alignment between shafts.

(b) Split muff coupling (clamp coupling)

Figure 11.2 shows split muff coupling.

➢ **Construction**

In this coupling, the muff or sleeve is made into two halves parts of cast iron and they are join together by bolts as shown in Figure. Both the halves are held together by means of M.S stud OR nut/Bolts.

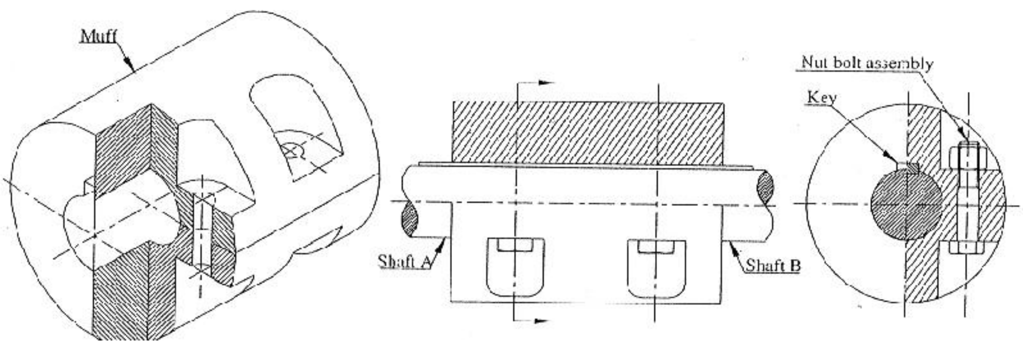


Figure 11.2 Split muff coupling

➢ **Advantages**

1. Assembling or disassembling of the coupling is possible without change the position of shaft.
2. It is used for heavy power transmission at moderate speed.

(c) Flange coupling

There are basic two types,

(1) Unprotected type flange coupling

This coupling is having two separate cast iron flanges as shown in fig. 11.3.

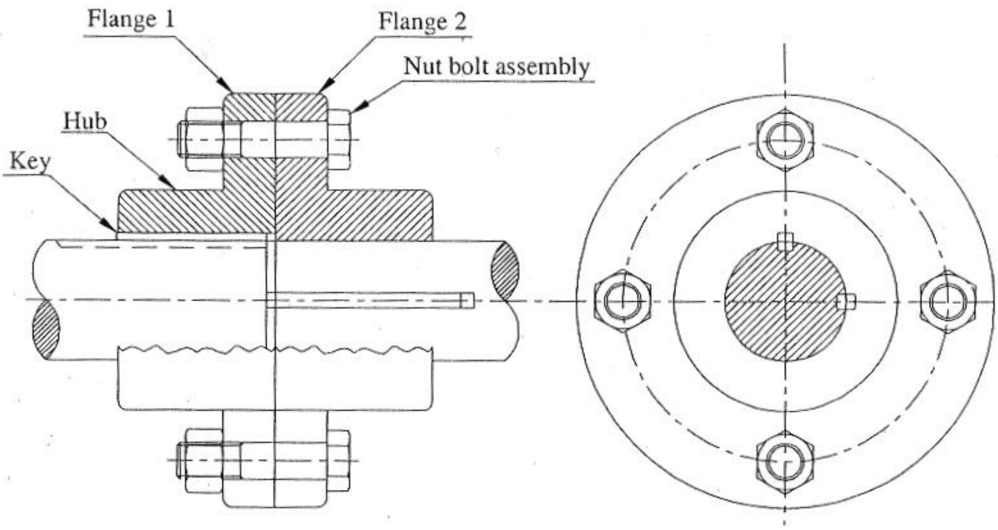
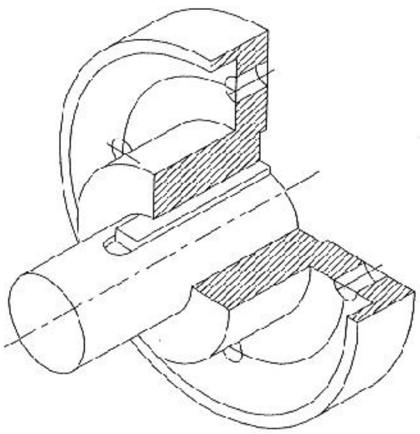


Figure 11.3 Unprotected type flange coupling

Each flange is mounted on the shaft end and keyed to it. The two flanges are coupled together by help of bolts and nuts. The projected portion of one of the flange and corresponding recess on other flange are help to bring the shafts into line and to maintain alignment.

(2) Protected type flange coupling



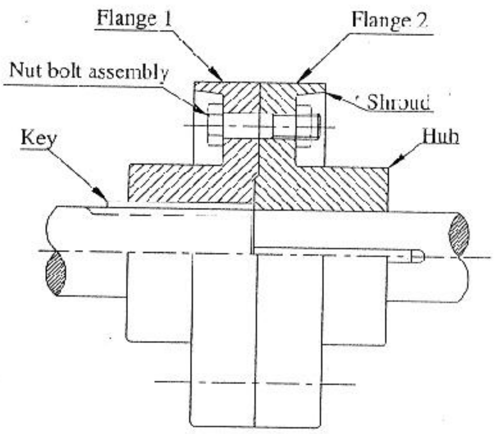


Figure 11.4 Protected type flange coupling

In order to prevent catching clothes of workmen in coupling the flange is provided with a shroud which shelters the bolt head & nuts as shown in figure 11.4. This coupling is called protected type flange coupling.

(2) Flexible couplings

This coupling is used to protect the driving and driven machine members against harmful effects produce due to misalignment of shafts, vibration, and sudden shock load or shaft expansion.

There are basic three types of flexible coupling as follows,

a. Bushed pin type flange coupling
b. Oldham coupling
c. Universal coupling

(a) Bush pin type flange coupling

This is a modified form of protected type flange coupling as shown in *figure 11.5.*

- **Construction**

This type of coupling has a pins and it work as a coupling bolts. The rubber or leather bushes are used over the pins. The coupling is having two halves are dissimilar in construction. The pins are rigidly fastened by nuts to one of the flange and kept loose in the other flange.

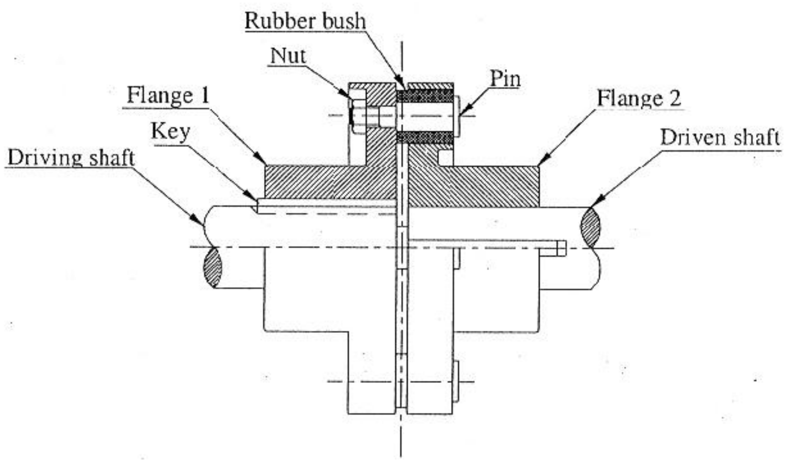


Figure 11.5 Bush pin type flange coupling

- **Advantage**

  In this coupling rubber bush absorbs shocks and vibration during its operation.

- **Use**

  Connection of shafts which having the small parallel misalignment, angular misalignment and axial displacement.

- **Application**

  Electric motor and machine

(b) Oldham's coupling

- **Construction**

It consists of two flanges A and B with slots and a central floating disc as shown in fig. 11.6.

The disc E having tongues T_1 and T_2 at right angles. The tongue $T_1$is fitted into the slot of flange A and allows horizontal sliding relative motion while the tongue T_2 is fitted into the slot of the flange B and allows for vertical sliding relative motion. These right angle motions of tongues on the slots will accommodate lateral misalignment of shaft when they rotate.

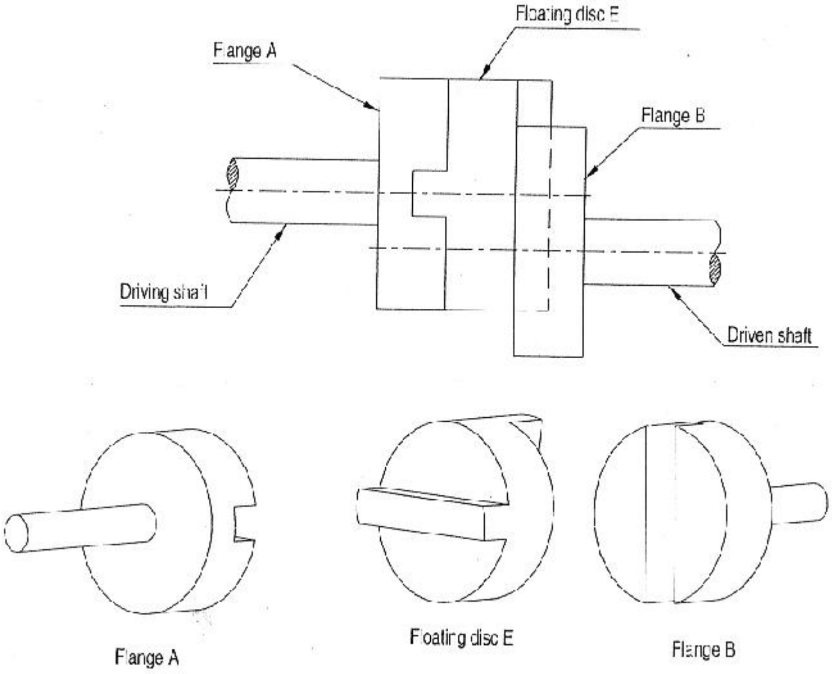


Figure 11.6 Oldham's coupling

- **Use**

Connecting two parallel shafts but not in alignment, and their axes are at small distance apart.

(c) Universal coupling

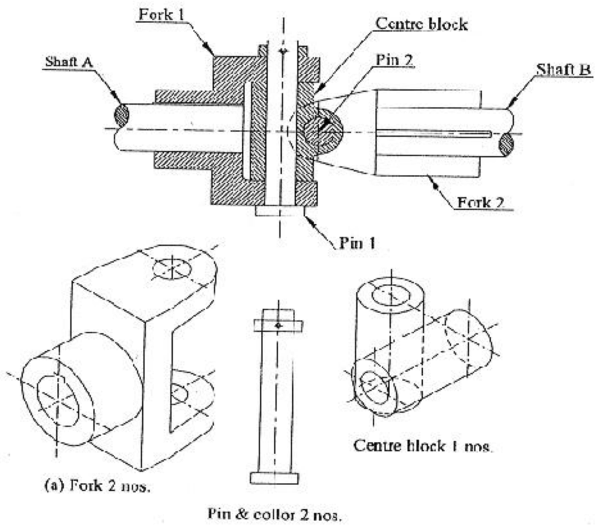


Figure 11.7 Universal coupling

- **Construction**

It consists of two similar forks keyed on the ends of the two shafts. These two forks are assembled to a central block by pin. A central block having two arms at right angle to each other.

- **Use**
  1. To connect two shafts whose axis are intersects.
  2. To connect two shafts where the angle between two shafts may be varied when they rotate.
- **Application**

  In automobile and machine tools

11.3 Clutches

- The clutch is a mechanical device used to connect or disconnect from the driving shaft at wheel of the operator while power is transmitted from driving to driven shaft.
- In automobiles, where vehicle can be stopped for a while or to change the gear, requirement is that the driven shaft should stop but the engine should run naturally under the no load condition. This is achieved by using clutch mounted between engine shaft and gearbox shaft and which is operated by a lever.

11.3.1 Classification of clutches

Detail classification of clutches given as under.

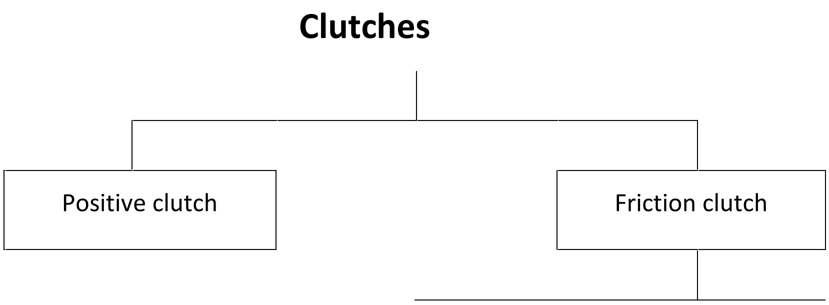


Plate or Disc clutch

Cone clutch

Centrifugal clutch

(A) Positive clutches

When positive drive is required then positive clutches are used. The simplest type of positive clutch is the jaw clutch which transmits the torque from one shaft to another shaft through interlocking jaws.

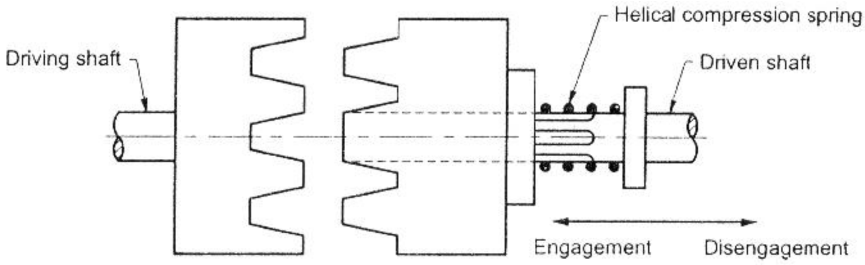


Figure 11.8 Positive engagement gear tooth Jaw clutch

- **Construction**

  Jaw clutch consist of two segments as shown in Fig. 11.8. One segment is permanently fastened to the driving shaft and the other segment is free to slide axially on the splined driven shaft, thus permitting it to be engaged or disengaged by sliding.

  The shapes of the jaws may be square, gear toothed or spiral.

- **Advantages**
  1. Positive clutches do not slip.
  2. No heat is generated at clutch surface during the engagement.

- **Disadvantages**
  1. Shock and noise is there when engaged in motion.
  2. They cannot be engaged at high speeds and sometimes cannot be engaged at rest unless the jaws are aligned.

- **Applications**

  In agricultural equipments like tractor, thresher etc.

(B) Friction Clutches

- **Construction**

It consists of two plates. One of them is keyed to the driving shaft and other is free to slide axially on the driven splined shaft. Friction lining is provided on the driven shaft. Axial force applied by the compression spring will held the two plates together.

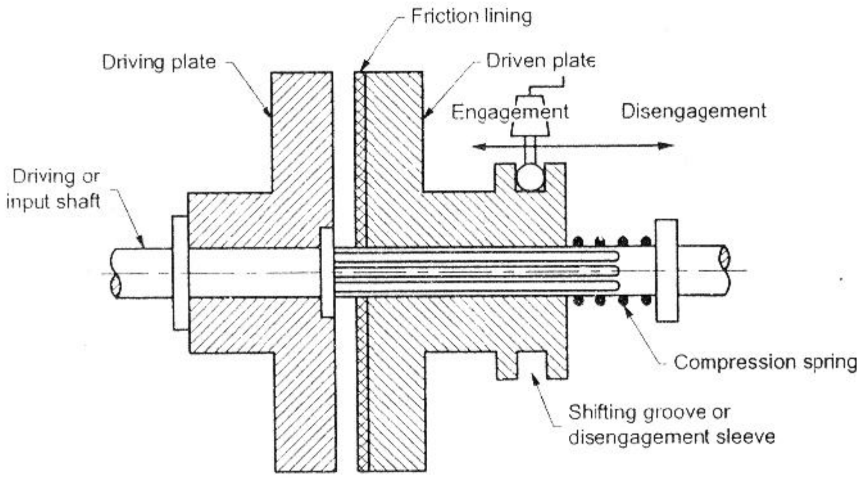


Figure 11.9 Friction clutch

The torque or power is transmitted between driving and driven shaft because of frictional force in between surfaces in contact.

It can be engaged while the driving member is rotating and the member is stationary.

- **Use**

  It is used where partial or full power to be frequent engagement and disengagement is required.

- **Advantages**
  1. Frequent engagement and disengagement is possible.
  2. It can transmit partial or full power.
  3. It can be engaged when driving shaft is rotating and driven shaft is stationary.
  4. It is very easy to operate.

- **Disadvantages**
  1. It will not give positive engagement.
  2. Due to slip between contacting surfaces, heat is generated during engagement

(a) Single plate clutch OR Disc clutch

- **Construction**

  It consists of various elements, such as pressure plate, friction plate (clutch plate), driving shaft, splined driven shaft, splined hub, brass bush etc.

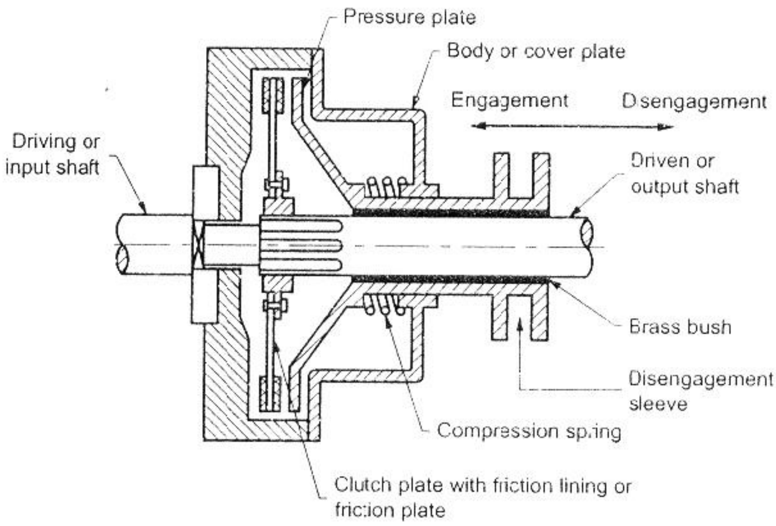
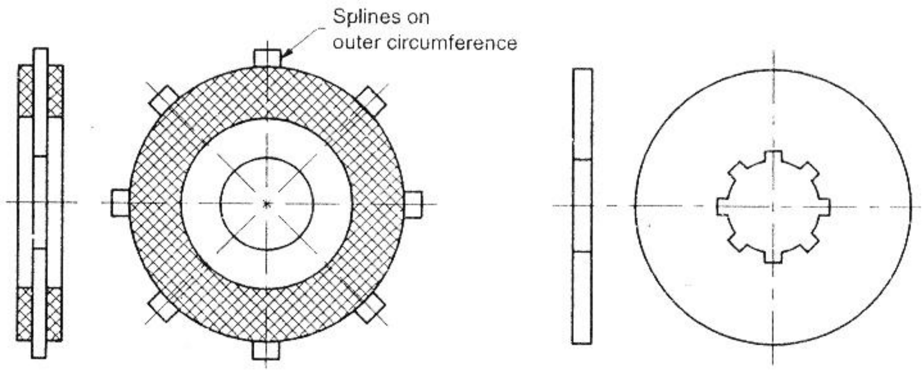


Figure 11.10 Single plate clutch at disengage position

Friction plate has a ring of friction material on either side. Friction plate is attached to splined hub which is free to slide axially on splined driven shaft and rotates along with driven shaft.

The spring is placed between pressure plate and cover. Brass bush is press fitted inside the pressure plate so that it can rotate freely on driven shaft.



(a) Friction plate *(b) Pressure plate*

- **Working**

When clutch pedal is pressed, the disengagement sleeve moves to the right and the clutch is disengaged. Under these conditions there is no axial force between friction plate and the pressure plate. Hence, the driving shaft rotates without driving the clutch plate and the driven shaft. When the clutch pedal is released, it moves the sleeve to the left and the clutch plate gages to driven shaft. Axial spring force compresses friction plate and pressure plate.

When the clutch pedal is released, it moves the sleeve to the left and the clutch plate gages to driven shaft. Axial spring force compresses friction plate and pressure plate.

- **Application**

  It is used where large radial space is available such as trucks, buses, cars etc.

(b) Multi plate clutch

- **Construction**

It consists of two sets of plates the driving plates and driven plates arranged alternately, driving shaft, spring, splined driven shaft etc. It consists of more than one driving as well as driven plates. So the number of pair of contacting surfaces is more than two.

Friction plates are splined on their outer circumference and engage with corresponding splines on the casing. Friction plates having ring on friction lining on both sides except the first plate which is adjacent to casing. This plate is having friction lining on one side.

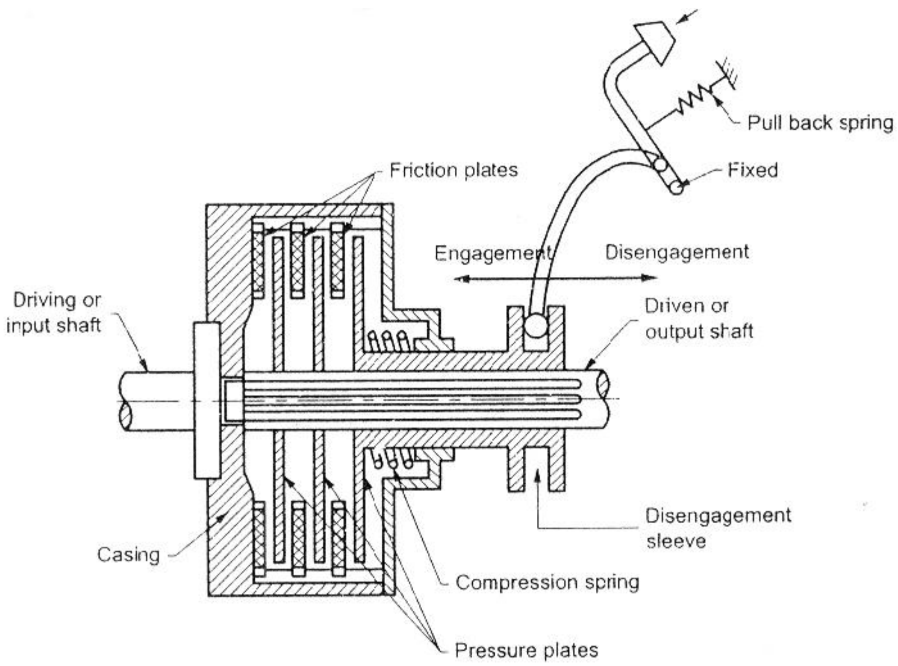


Figure 11.11 Multi plate clutch

The pressure plates are splined on their inner circumference and engage with corresponding splines on the driven shaft. Both friction plates and pressure plates are free to slide axially.

- **Working**

When clutch pedal is pressed, clutch is disengaged since the sleeve moves to the right. No axial force is developed between friction plates and pressure plates. Also, the driving shaft rotates without driving the driven shaft.

When clutch pedal is released, clutch is engaged. The force due to spring will press the pressure plates to come into contact with friction plates. The power will be transmitted from driving shaft to the driven shaft due to friction.

- **Advantages**

1. Torque transmitting capacity of multi plate clutch is higher because of more number of contacting surfaces.
2. For given torque capacity radial size of multi plate clutch is smaller than that of single plate clutch. Therefore, it is compact in construction.

- **Disadvantages**

The heat dissipation is a serious problem because of compact arrangement.

- **Application**

1. It is used when large torque is to be transmitted e.g. motor cars and machine tools.
2. It is used where compact construction is required e.g. scooters and motor cycles.

(c) Cone clutch

- **Construction**

It consists of driving shaft, splined driven shaft, outer cone (cup), inner cone (cone), helical compression spring etc. The outer cone (cup) is keyed to the driving shaft and inner cone is free to slide axially on the splined driven shaft.

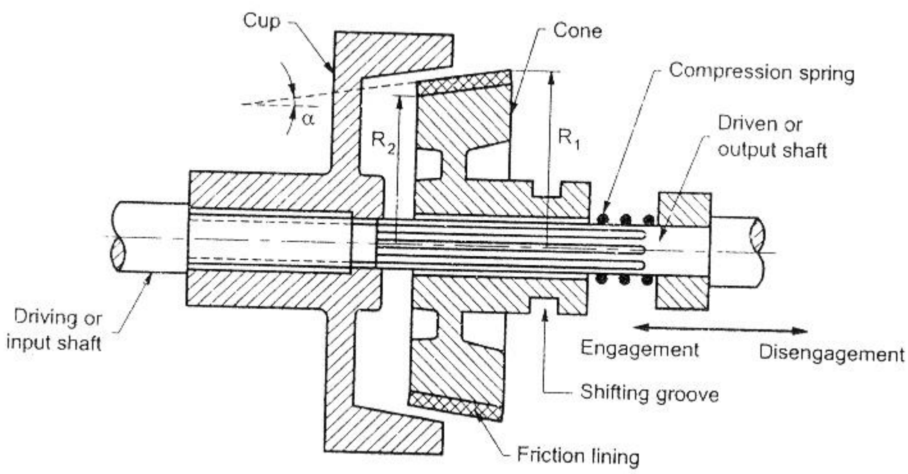


Figure 11.12 Cone clutch

To engage the clutch axial force is provided by a helical compression spring. Clutch is disengaged by means of fork fitted in shifting collar or groove on the outer surface of cone, leather, cork or asbestos is used as friction lining.

- **Working**

The wedging action due to conical working surfaces results into considerable normal pressure and friction force with small engaging force. Thus the torque is transmitted from driving to the coaxial driven shaft.

- **Advantage**

It has large torque transmitting capacity for a smaller axial force as compared to plate clutches.

(d) Centrifugal clutch

It is works on the principle of centrifugal force. Centrifugal force is increases with the increase in speed.

- **Construction**

It consists of spider having radial guide, sliding shoes, helical tension springs co-axial drum as show in figure 11.13. The spider having four equally spaced radial guides is keyed to the driving shaft. Sliding shoes can slide radially in guides. The sliding shoes are covered with frictional material from outer side. These shoes are held against spider on driving shaft by helical tension springs and all these assembly is enclosed in coaxial drum which is mounted on driven shaft.

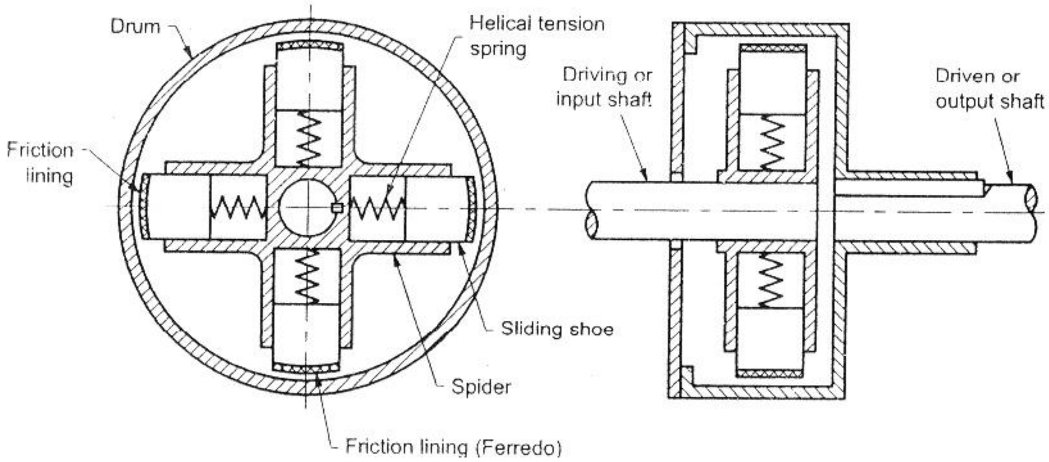


Figure 11.13 Centrifugal clutch

- **Working**

When the driving shaft starts rotating, the sliding shoe also rotates with spider. Due to mass, when driving shaft revolving the mass of shoes causes radially outward centrifugal force. This centrifugal force is directly proportional to square of angular speed. When these two centrifugal and spring force becomes equal the shoe start floating (at low speed) and there is just contact between shoe and inner surface of drum.

When the centrifugal force will be greater than spring force shoes starts moving radially outwards, then come in to contact with the driven member and pressed against it. The torque is transmitted from driving shaft to driven shaft because of frictional force between shoe lining and inside surface of drum.

- **Use**

It is used when it is required to engage the driven member automatically after the driving member has attained certain speed.

11.4 Brakes

Brake is a device by means of which an artificial frictional resistance is applied to a moving body in order to retard or stop the motion of a body. Clutches and brakes work on the same principle of friction but the functional difference between clutch and brake is that the clutch connects one moving part to another moving part, whereas the brake connects one moving part to another stationary part.

During braking process, the brake absorbs either kinetic energy or potential energy or both by an object. In automobiles brake absorbs kinetic energy of moving vehicles. In case of elevators and hoists brake absorb potential energy released by the objects during braking period.

The energy absorbed by the brake is converted in the form of heat which is dissipated to the surrounding air or water which is circulated through the passage in the brake drum.

11.4.1 The capacity of brake depends on,

- Unit pressure between braking surfaces,
- Coefficient of friction
- Peripheral velocity of brake drum
- Projected area of friction surfaces
- Heat dissipating capacity of the brake

11.4.2 Properties of brake lining materials

1. It should have high coefficient of friction. It should remain constant with change in temperature.
2. Low wear rate.
3. High heat resistance.
4. High heat dissipation capacity.
5. Adequate mechanical strength.
6. It should not be affected by moisture and oil.

➢ **Materials used for braking lining**

- Bronze on cast iron
- Steel on cast iron
- Wood on cast iron
- Fiber on metal
- Asbestos on metal
- Leather on metal

11.4.3 Classification of brakes

Brakes

- Shoe or block brake
  - Single block brake
  - Double block brake
  - Pivoted block brake
- Band brake
  - Simple band brake
  - Differential band brake
- Band & block brake
- Internal expanding shoe brake

(A) Block or shoe brake

There are two types of shoe brake,

a. Single block or shoe brake
b. Double block or shoe brake

(a) Single block or shoe brake

➢ **Construction**

It consists of blocks which are pressed against the surface of a rotating drum by means of lever.

The block which is rigidly attached or pivoted to the level is lined with friction material. The friction between friction lining on the block and drum retards the rotation of the drum. The block or shoe is made up of softer material than the rim of the drum.

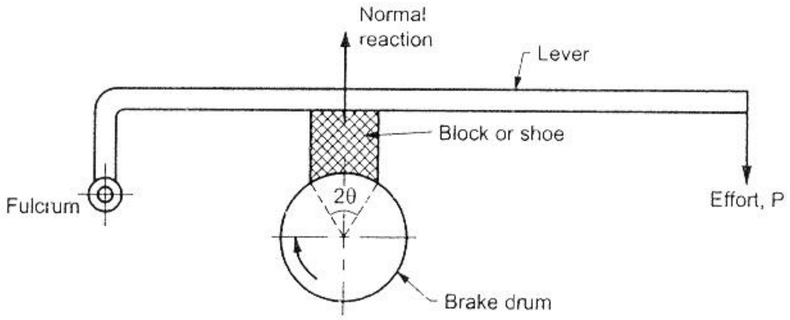


Figure 11.14 Single block or shoe brake

The material of the block for light and slow vehicles is wood and rubber and for heavy and fast vehicles it is cast steel.

(b) Pivoted block brake

- **Construction**

A pivoted block brake is shown in figure 11.15. Unlike single block brake, in this the shoe is pivoted to lever to get uniform wear.

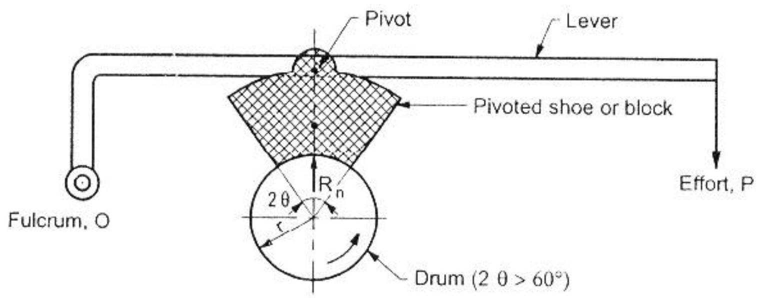


Figure 11.15 Pivoted block brake

- **Advantage**

  These brakes have more life and higher braking torque.

- **Disadvantage**

  When a single block brake is pressed against the rotating drum, an unbalanced load on the bearing of the shaft supporting the drum will act.

(c) Double block or shoe brake

- **Working & Construction**

This load produces the bending of the shaft. It can be prevented by using a double block or shoe brake having two blocks on the two sides of the drum.

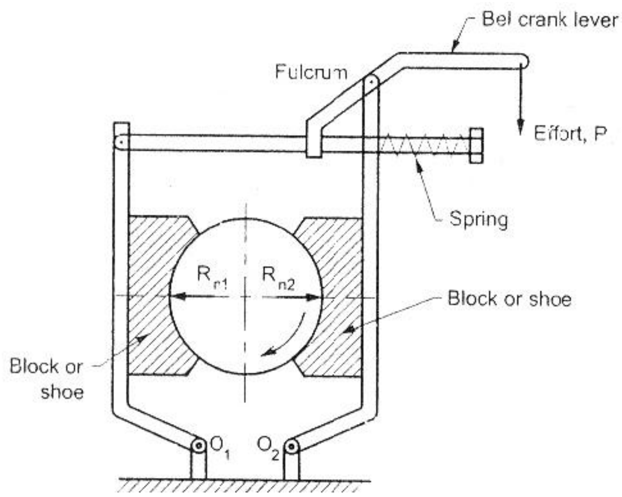


Figure 11.16 Double block or shoe brake

When effort P is applied to bell crank lever, then spring gets compressed and brake released. When there is no force P on bell crank lever, the brake is engage automatically.

- **Advantage**

  There is no unbalanced load on the bearing of the shaft supporting the drum will act.

- **Application**

  It is used in electric cranes.

(B) Band brake

- **Construction**

It consists of a rope, belt or flexible steel band lined with frictional material which is wrapped partly round the drum.

- **Working**

When band is pressed against the external surface of drum, the frictional force between drum and band will induce braking torque on the drum.

There are two types of band brake,

(a) Simple band brake

(b) Differential band brake

(a) Simple band brake

- **Construction**

In this brake one end of the band is attached at the fulcrum of the lever while the other end is at a distance 'b' from fulcrum.

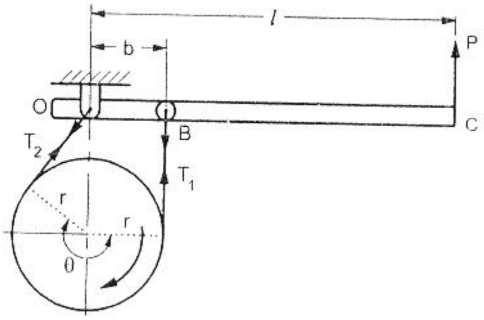


Figure 11.17 Simple band brake

- **Working**

When the force P is applied at the free end of the lever, it turns about the fulcrum O. It tightens the band on the drum and brakes are applied. The braking force is provided by the friction between the band and the drum.

(b) Differential band brake

- **Construction**

In a differential band brake, neither end of the band is attached to the fulcrum of the lever. The two ends of band are attached to the two points on opposite side of the fulcrum as shown in figure 11.18.

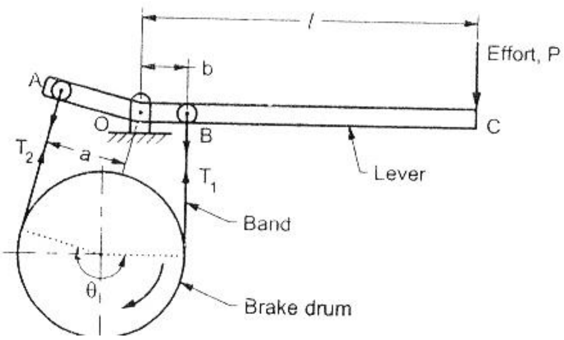


Figure 11.18 Differential Band Brake

The lever AOC is pivoted at fulcrum '0' and two ends of band are attached at points A and B.

- **Advantage**

It can provide higher braking torque compared to simple band brake for the same amount of effort P.

(c) Band and block brake

➢ **Construction**

It consists of number of wooden blocks fixed inside a flexible steel band.

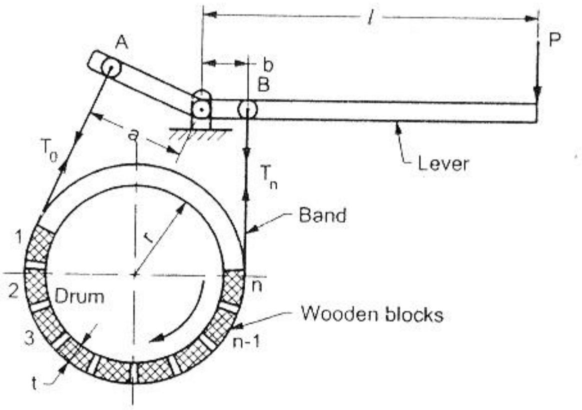


Figure 11.19 Band and block brake

➢ **Working**

When the brake is applied, the blocks are pressed against the drum. The friction between block and drum provides the braking action.

➢ **Advantages**

1. A wooden block provides a higher coefficient of friction and Increases effectiveness.
2. It can be easily replaced after being worn out.

(C) Internal expanding shoe brake

➢ **Construction**

It consists of two semicircular shoes S_1 and S_2 pivoted at the fixed fulcrum O_1 and O_2 respectively. The outer surfaces of the shoes are lined with friction material like Ferodo.

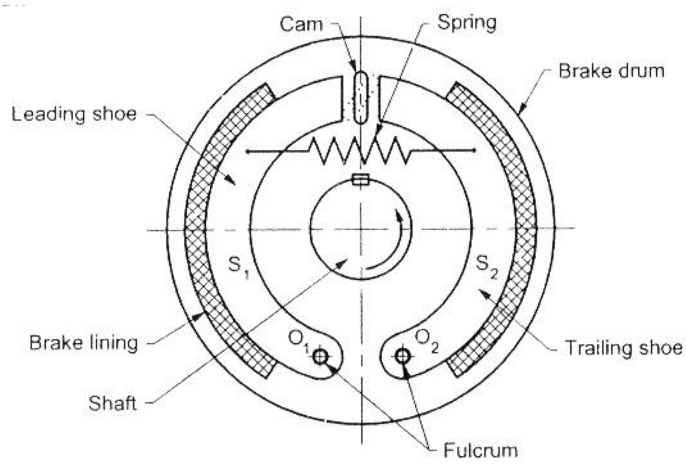


Figure 11.20 Internal expanding shoe brake

One end of the shoe is pivoted at fulcrum while the other end is subjected to the actuating force. The actuating force on both the shoes is applied by hydraulic cylinder or cam mechanism. The drum encloses the entire system to keep out of dust and moisture.

- **Working**

When the cam rotates the shoes are pushed outward against the rim of the drum. Friction between shoes and the drum produces braking torque causing the drum to retard or stop completely.

When this actuating force through the rotation of cam is released, the helical tension spring retracts the shoes to the original position.

For anticlockwise rotation of drum, the left shoe is known as leading or forward or primary shoe and right shoe as trailing or rear or secondary shoe.

- **Application**

It is used in motor cars and light trucks.

11.4.4 Difference between brake and clutch

1. A brake is used to slow down or stop the motion of a moving body, whereas a clutch is used to transmit the motion of a moving body to another body by means of engagement.
2. When brake in action kinetic energy of moving parts is converted into frictional resistance, while in a clutch the torque or motion is gradually transmitted from one shaft to another shaft.
3. During the operation of a brake the energy of the moving members is lost in friction, but in a clutch no such loss occurs (except in case of slip).
4. A brake always remains disengaged and may be engaged whenever necessary to stop or slow down the moving elements, whereas a clutch always remains engaged and may be disengaged whenever necessary to disconnect driven shaft from driving shaft.

12. Transmission of motion and power

12.1 Introduction

The mechanisms which are used to transmit the required motion and power from one shaft to another shaft are called mechanical drives.

These drives are extensively used in automobiles, workshops, processing and transport industry.

12.2 Types of mechanical drives

1. Belt and rope drives
2. Chain drives
3. Gear drives

12.2 Methods of drive

There are basically two methods of drive.

A. Individual drive
B. Group drive

(A) Individual drive

In this system, each machine tool has its own electric motor which drives the machine through belt, chain, gearing or by direct coupling. The system is also called as self contained drive.

- **Advantages**

1. Individual machines can be run and stopped at operator will.
2. System is simple and compact.
3. Failure of motor affects the working of a particular machine only without affecting the working of other machines in the workshop.
4. Overhead cranes can be installed.
5. Lighting of the workshop is not affected by belts and overhead shafts.
6. Power consumption is low and efficiency of the system is high since the transmission power losses are low.
7. Flexibility for layout of machine tools.

- **Disadvantage**

Initial cost of system is high.

(B) Group drive

This system uses a high powered motor which drives an overhead shaft called main shaft by means of chain or belt. The main shaft runs across the workshop from one end to other end. The main shaft drives another shaft called counter shaft. Finally the countershaft drives the group of machines through belting. The countershaft also carries cone pulleys to give wide range of speeds.

- **Advantages**

1. It is suitable when all machines are required to run simultaneously. It reduces the size of the motor required.
2. The initial capital investment is low.
3. A set of cone pulleys give wide range of speed.
4. It will be more economical when utilization factor is high.
5. Maintenance is easy.

- **Disadvantages**

1. Efficiency of the system is low due to additional frictional power required to run all the shafts simultaneously.
2. In case of motor failure all machines have to be shut down.
3. The possibility of accidents is more due to large number of shafts, pulleys and belts.
4. Lighting of the workshop is affected due to its layout.
5. Gives greater power cost.
6. Installation of overhead travelling cranes is difficult.
7. The layout of the system is complicated and the flexibility in layout of machines is greatly reduced.

(C) Comparison between Individual drive and Group drive system

Sr No.	Individual drive	Group drive
1	It is suitable for small size workshop where machines may be moved frequently and machines are scattered over large area.	It is suitable for medium and large size workshop where machines are not scattered over large area.

2	Speed of a machine can control separately.	A set of cone pulleys gives wide range of speed.
3	Individual machine does not affect other machines when failure of an any motor.	Failure of main motor will stop entire group of machines.
4	Less power is wasted if less machines in working.	More power wasted if the less machines in running but more economical when all machines are working in full load.
5	High initial capital investment.	Less initial capital investment.
6	Lightening of workshop is not affected.	Lightening of workshop is affected due to more number of shafts.

12.3 Elements of power transmission

The main elements of power transmission system are,

- The nuts, bolts, pins, keys and couplings, etc. are provided to hold the two components of machine elements together.
- Driving and driven shafts.
- Belts, chains, gears are as connectors for transmission of motion and power from driving to driven shaft.
- Axles, bearings, brackets etc. to provide support to other elements of a machine.

12.3.1 Shaft, spindle and axle

1. Shaft

A shaft is a rotating machine element which transmits power. The power is delivered to the shaft by the application of tangential force and the resulting turning moment set up in the shaft allows the power to be transmitted from one point to another point.

Shape of shafts

Generally shafts are cylindrical in shape are used but shafts with square and hexagonal cross section are also used in practice.

Hollow shafts are preferred since these are 50% lighter in weight compared to solid shafts for the same rigidity and stiffness. And also used whenever it is required to pass through components of a machine.

2. Spindle

A spindle is a short revolving shaft that transmits motion either to a cutting tool or a work piece.

3. Axle

An axle is machine element which is used for transmitting bending moment and carries such rotating parts as wheels and gears. An axle may be stationary or it may be rotating.

12.4 Types of mechanical drives

1. Belt and rope drives
2. Chain drives
3. Gear drives

12.4.1 Belt drives

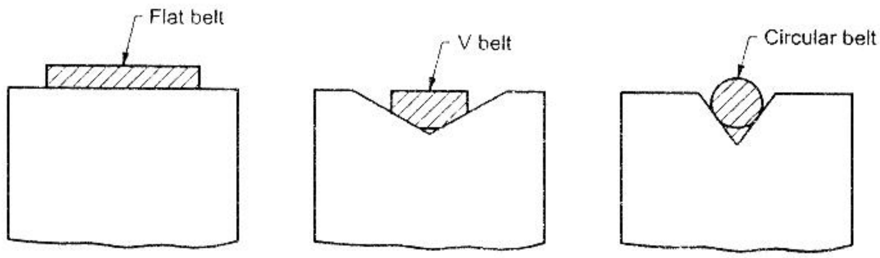
Types of belts

(a) Flat belt

It is mostly used in factories and workshops, where a moderate amount of power is to be transmitted. The distance between two pulleys is not more than 8 meters apart.

(b) V –belt

It is mostly used in factories and workshops, where a moderate amount of power is to be transmitted. The distances between two pulleys are very near to each other.



12.1 Types of belts

(c) Circular belt or rope belt

It is mostly used in the factories and workshops, where a greater amount of power is to be transmitted. The distance between two pulleys is more than 8 meters.

12.4.2 Difference between Flat belt and V- belt

Sr No.	Flat belt drive	V-belt drive
1	It is suitable for moderate power transmission when the distance between the shafts is large.	It is suitable for high power transmission when the distance between the shafts is small.
2	There is chance of slip due to less frictional grip between pulley and belt. Hence it is not a positive drive.	There is less chance of slip due to more frictional grip between belt and pulley.
3	Require large space	Due to compactness, required less space.
4	High velocity ratio may not obtain.	High velocity ratio may be obtained.
5	For same value of co-efficient of friction, angle of lap and allowable tension the power transmission by flat belt is less than that of V -belt drive.	For same value of co-efficient of friction, angle of lap and allowable tension the power transmission by V-belt is higher than that of flat belt.

12.4.3 Types of belt drives

(a) Open belt drive

- **Use**

It is used when the driven pulley is to be rotated in the same direction as the driving pulley.

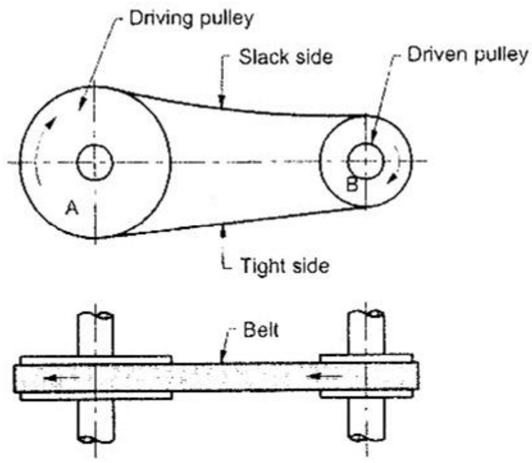


Figure 12.2 Open belt drive

➢ **Construction**

In this driving pulley pulls the belt on one side and drives it to the other side. So the tension on pulled side will be more than other side. The tension on pulled side is known as tight side and other side is known as slack side.

(b) Crossed belt drive

➢ **Use**

It is used when the driven pulley is to be rotated in the opposite direction to that of driving
pulley.

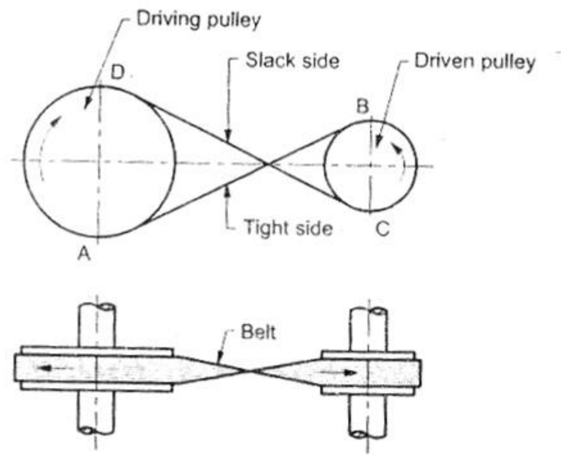


Figure 12.3 Crossed belt drive

➢ **Construction**

In cross belt drive the belt bents in two different planes, it therefore wears more rapidly. In this case driving pulley pulls the belt from one side (i.e. BA.) and delivers it to the other side (i.e. DC). So the tension on side AB is more called tight side as compare to tension on the side of belt CD which is known as slack side.

(c) Compound belt drive

- **Use**

  It is used when the distance between input and output shaft is very large.

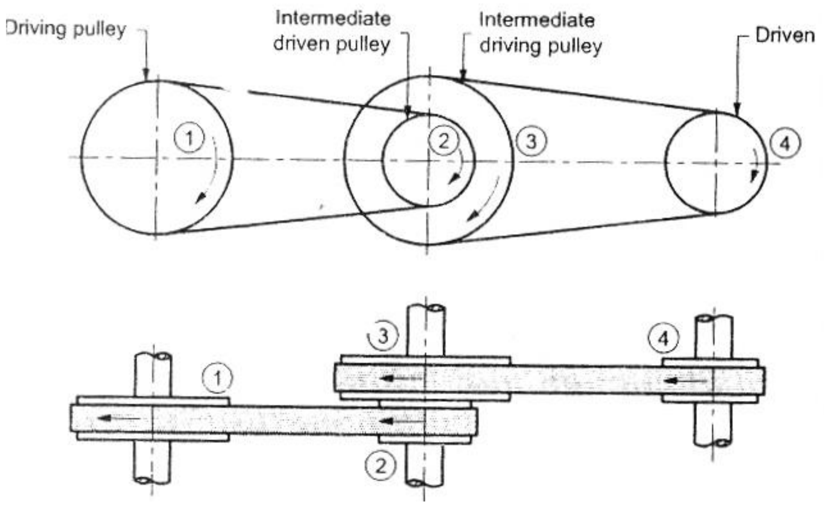


Figure 12.4 Compound belt drive

In this drive intermediate or compound shaft pulley is used.

(d) Quarter turn belt drive or Right angle belt drive

- **Use**

  This belt drive is used when two shafts are at right angles and rotating in one direction only.

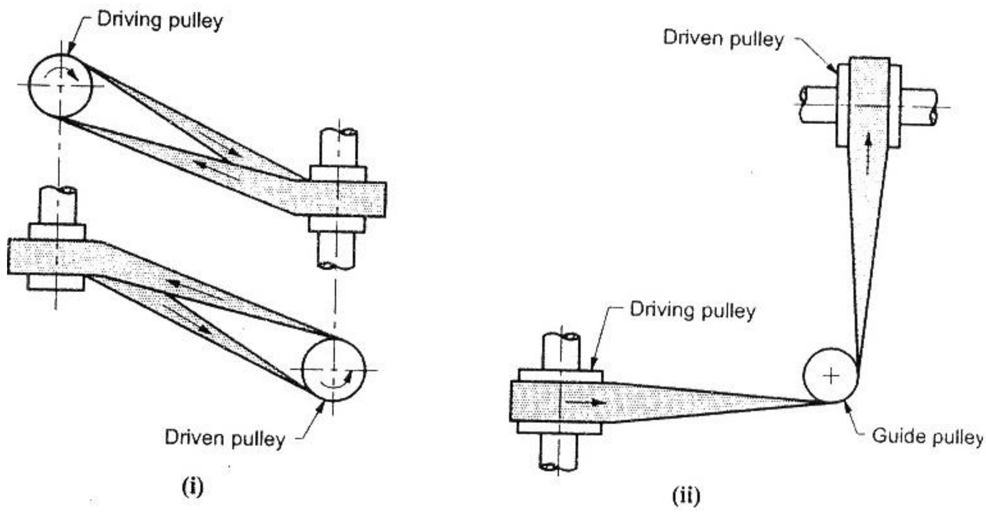


Figure 12.5 Quarter turn belt drive

A guide pulley is used when motion is required in either direction.

(e) Belt drive with idler pulleys

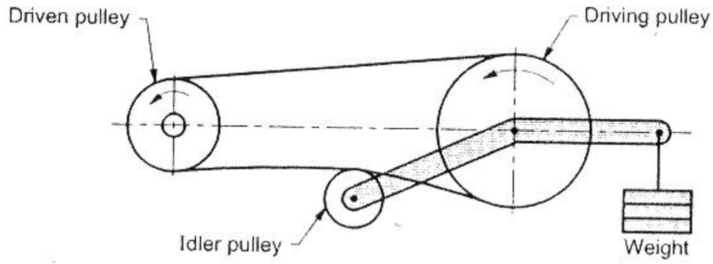


Figure 12.6 Belt drive with idler pulleys

- **Construction**

Material of belt is elastic due to which after prolonged use the belt is permanently stretched in length. This reduces the tension in the belt which leads to lower power transmission capacity.

Hence to maintain the tension in drive the some arrangement is made with the help of additional pulley called idler pulley. By adjusting the weight the tension is belt is maintained. Motion of one shaft can be transmitted to two or more than two shafts by using a number of idler pulleys.

(f) Stepped or Cone pulley drive

- **Use**

To run the driven shaft at different speed whereas the driving shaft runs at a constant speed through a motor.

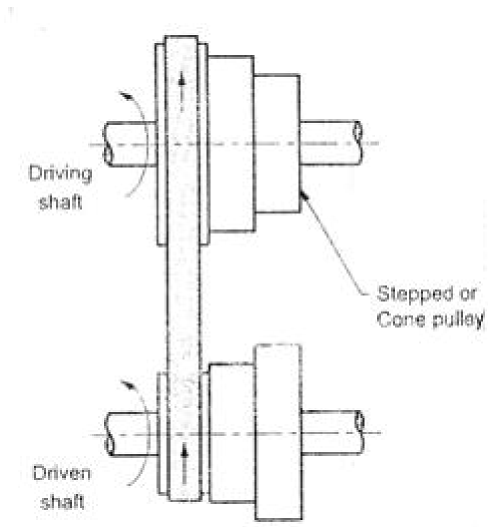


Figure 12.7 Stepped or cone pulley drive

➢ **Construction**

Both driving and driven pulleys has steps of equal radius so that the same belt can be used for varying the speed.

(g) Fast and loose pulley drive

➢ **Use**

Many times it is required to drive many machines from one driving shaft or main shaft. It is used to start or stop one machine without interfering other machines.

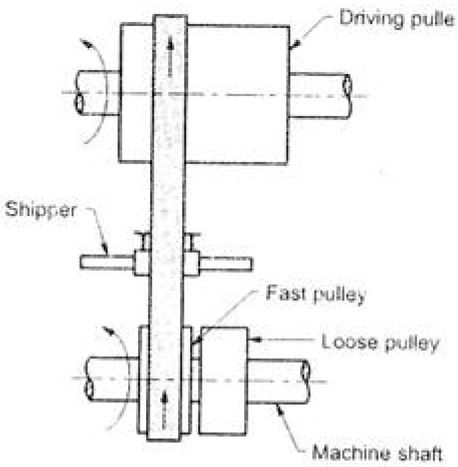


Figure 12.8 Fast and loose pulley drive

➢ **Construction**

In this drive, one-pulley is keyed with machine shaft called fast pulley and one pulley is kept free to rotate on machine shaft called loose pulley.

When machine is required to stop, the belt is pushed on the loose pulley by means of bar having fork called shipper.

12.5 Rope Drive

Rope drives are widely used where a large amount of power is to be transmitted from one shaft to another shaft over a considerable distance. The frictional grip in case of rope drive is more than flat belt drive or V-belt drive.

12.5.1 Types of Rope Drives

Depending upon the type of material used for the rope, the rope drives are classified as follows,

(a) Fiber ropes

The fiber ropes are made from fibrous material such as hemp, manila and cotton. Fiber ropes are used when shafts are about 60 meters apart.

(b) Wire ropes

The wire ropes are made from metallic wires. Wire ropes are used when shaft are about 150 meters apart. The wire ropes are used in elevators, mine hoists, cranes, conveyors etc.

12.6 Chain drive

Slipping occurs in belt and rope drives. In order to avoid this slipping phenomenon chain drives are used.

- **Construction**

A chain drive consists of three elements driving sprocket, driven sprocket and an endless chain which is wrapped around two sprockets.

A chain consists of a number of links connected by pin joints, while the sprockets are toothed wheels and fit into the corresponding recesses in the links of the chain.

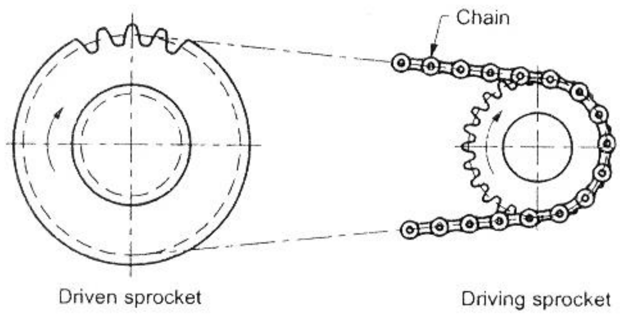


Figure 12.9 Chain drive

- **Advantages**
    1. It provides a positive transmission and slip is not present.
    2. It gives a constant velocity ratio.
- **Applications**

Bicycles, motor cycles, agricultural machinery, textile machinery and material handling equipments.

12.6.1 Types of Chains

The chains are classified into following three groups

1. Hoisting and Hauling chains
2. Conveyor chains
3. Power transmission chains

(1) Hoisting and hauling chains

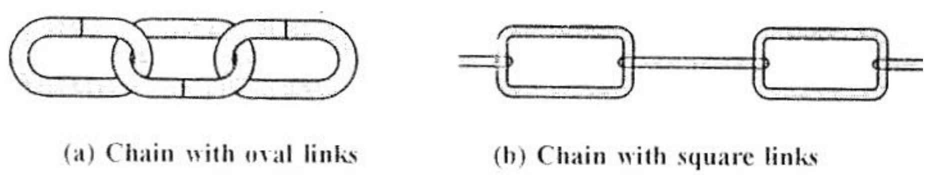


Figure 12.10 Hoisting and Hauling chains

- **Use**

It used for hoisting and hauling purposes.

These are further classified as,

- Chain with oval links
- Chain with square links

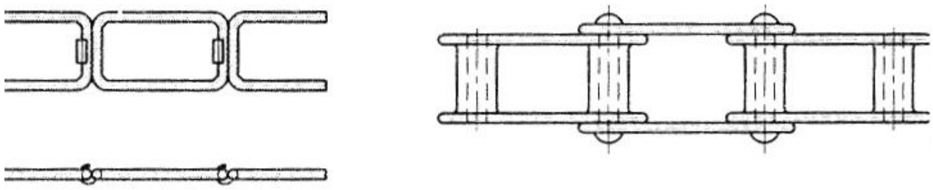
(2) Conveyor chains

➢ **Use**

Elevating and conveying the material continuously and they run at low speeds.

The conveyor chains are of the following two types.

- Detachable or hook joint type chain
- Closed joint type chain



(a) Hooke joint (b) Closed joint chain

Figure 12.11 Conveyor chains

The conveyor chains are usually made of malleable cast iron. These chains do not have smooth running operation.

(3) Power transmission chain

➢ **Use**

Transmitting motion from one shaft to another shaft. These chains operate at maximum speed of 15 m/sec.

Types of power transmission chains are as follows,

(a) Roller chains

It has rollers around the bushes and held between roller link plates. The roller chain consists of two rows of outer and inner plates. The pins are fitted to the outer plate and passed through the bushings which are pressed into the inner plate.

(b) Bush chain

The bushed chains are similar in design of roller chain except that they have no rollers in it.

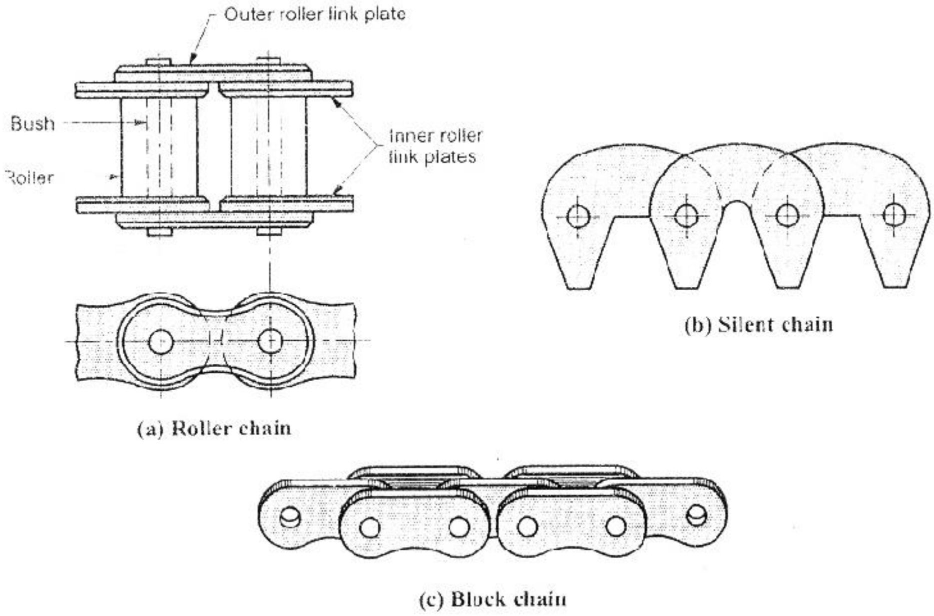


Figure 12.12 Power transmission chain

(c) Silent chain (Inverted tooth chain)

- **Use**

  To achieve an almost silent performance in power transmission.

It consists of special links which directly get engaged with the sprocket teeth.

(d) Block chain

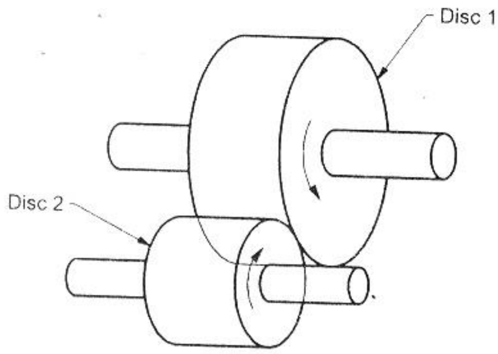
- **Use**

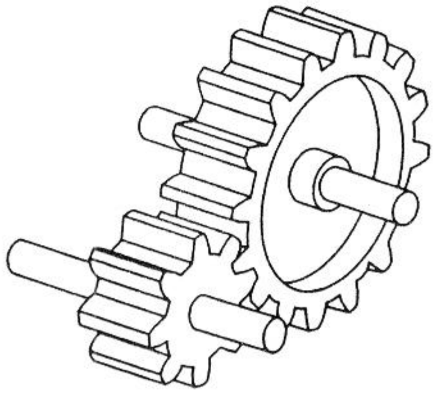
  Transmitting the power at low speed. In this chains rubbing takes place between teeth and the links.

12.7 Gear drive and friction drive

In case of rope and belt drives we have seen that the velocity ratio transmitted cannot be exact due to the slip of rope or belt on the pulley. Also due to frictional losses the efficiency of power transmission in such drives is less. The power may be transmitted from one shaft to another by means of mating gears with high transmission efficiency.

In early days, friction discs as shown in figure were used for transmitting the power from one shaft to another shaft. In such a case, the power transmission capacity depends on friction between surfaces of two discs. Therefore, this method is not suitable for transmitting higher power as slip occurs between the discs.





(a) Frictional disc *(b) Gear drive*

Figure 12.13 Power transmisssion by gear drive and friction drive

In order to transmit a definite power from one shaft to another shaft to the projection on one disc and recesses on another disc can be made which can mesh with each other. This leads to the formation of teeth on both discs and the discs with teeth on their periphery are known as "Gears".

- **Advantages**

1. It is a positive drive (no slip) i.e. it transmits exact velocity ratio from one shaft to another shaft.
2. It can transmit very large power.
3. High transmission efficiency.
4. Requires less space.
5. Reliable.

- **Disadvantages**

1. Manufacturing cost of gear is high, since special tools and machinery is required for gear manufacturing.
2. Maintenance cost of gear drive is also high due to lubrication requirements.
3. The error in cutting teeth may cause vibrations and noise during operation.
4. It requires precise alignment of shafts.

12.7.1 Terms related to gears

(1) Pitch circle

It is an imaginary circle by which pure rolling action would give the same motion as the actual gear.

(2) Pitch circle diameter (d)

It is the diameter of the pitch circle. The size of gear is usually specified by the pitch circle diameter.

(3) Pressure angle or angle of obliquity

It is an angle between the common normal to two gear teeth at the point of contact and the common tangent at common point between two pitch circles.

(4) Circular pitch (P_c)

It is the distance measured on the circumference of the pitch circle from a point of one tooth to the corresponding point on the next tooth.

$P_c = \pi D/T$ Where, T = number of teeth

(5) Module (m)

It is ratio of the pitch circle diameter in millimeters to number of teeth.

$m = d/T$

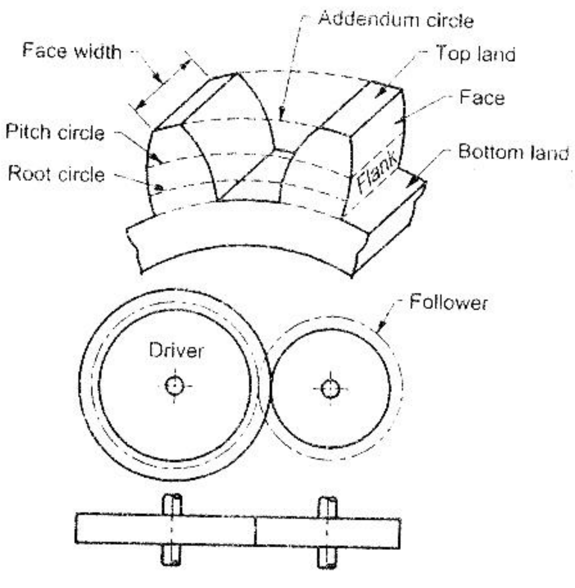
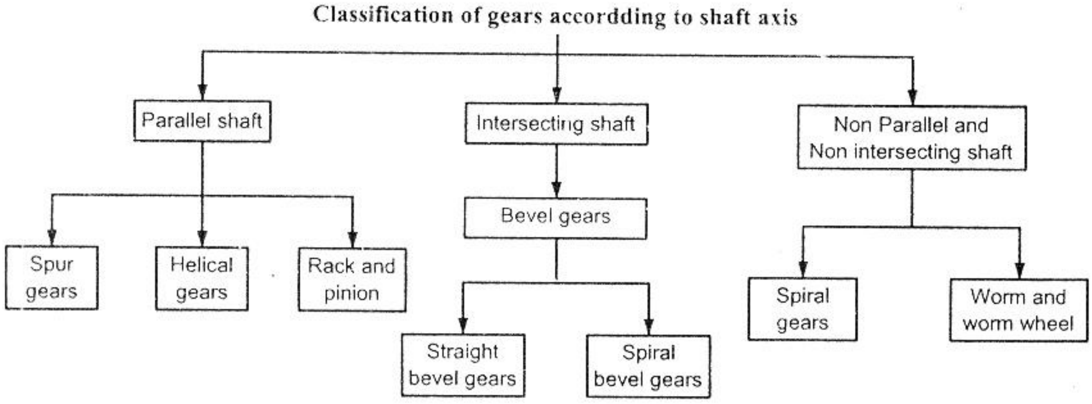


Figure12.14 Gear terminology

12.7.2 Classification of gears

1. According to position of shaft axes
2. According to peripheral velocity of gears
3. According to type of meshing
4. According to type of teeth profile



12.15 Classification of gears

(a) Spur gear

- **Use**

When the axis of two shafts are parallel to each other. These gears have teeth parallel to the axis of the shaft.

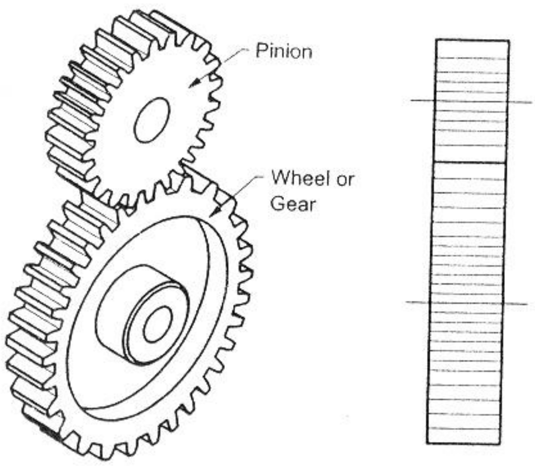


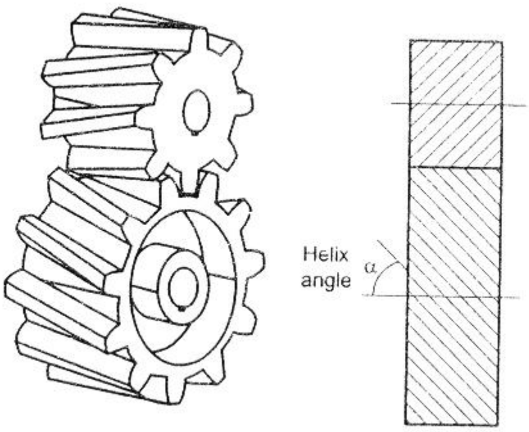
Figure 12.16 Spur gear

(b) Helical gear

In helical gears the teeth are at some angle called helix angle with respect to axis of the shaft.

➢ **Advantages**

1. It runs quieter as compared to spur gears since the contact between teeth is gradual.
2. Transmission of load is gradual which results in low impact stresses and reduction in noise. Thus they are used for high speed transmission.



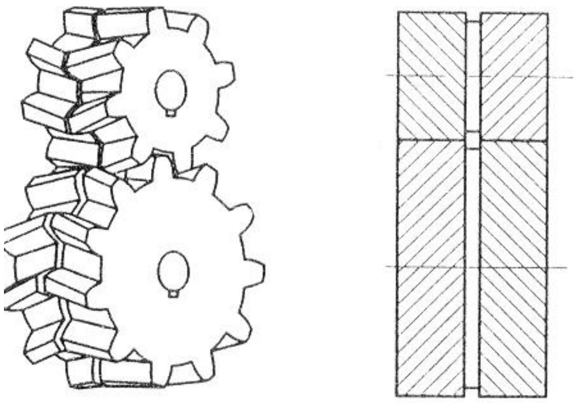


Figure 12.17 (a) Single Helical Gear *Figure 12.17 (b) Double Helical Gear*

➢ **Disadvantage**

They induce axial thrust in one direction on the bearings.

(c) Rack and pinion

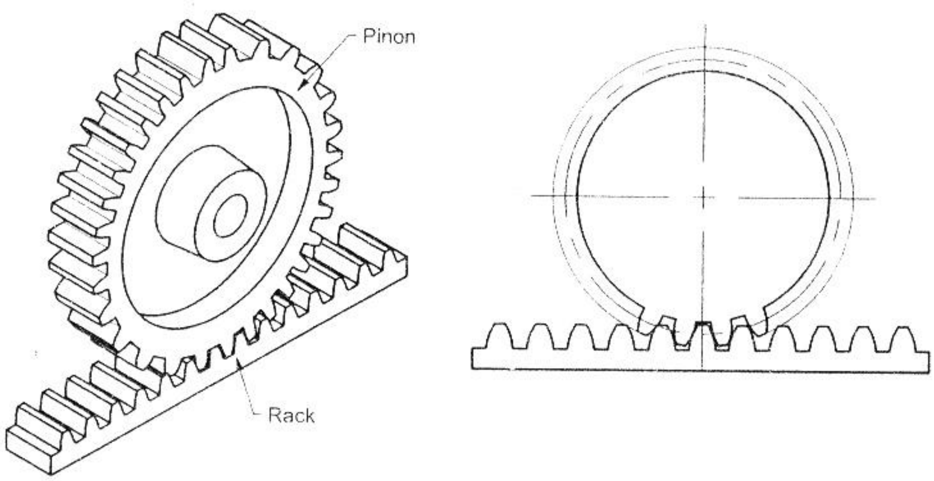


Figure 12.18 Rack and Pinion gear

It is a special case of spur gear in which one gear is having infinite diameter called "Rack".

- **Use**

  To transmit the rotary motion into reciprocating motion or vice-versa.

- **Application**

  Lathe machine, drilling machine and measuring instrument.

(d) Bevel gear

- **Use**

When power is required to be transmitted from one shaft to another shaft which are intersecting to each other then bevel gears are used. Generally, the angle between two shafts is 90^o.

The bevel gears are of two types,

1. Straight bevel gear
2. Spiral bevel gear

(1) Straight bevel gears

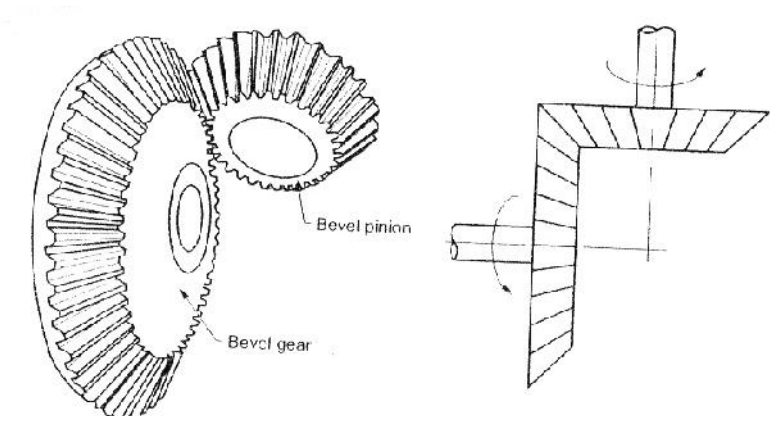


Figure 12.19 (a) Straight bevel gears

In straight bevel gears the teeth are formed straight on the cones, and they are parallel to the axis of the gear.

(2) Spiral bevel gears

In a spiral bevel gear, the teeth are formed at an angle with respect to its axis. The contact between two meshing teeth is gradual and smooth from start to end, as in case of helical gears.

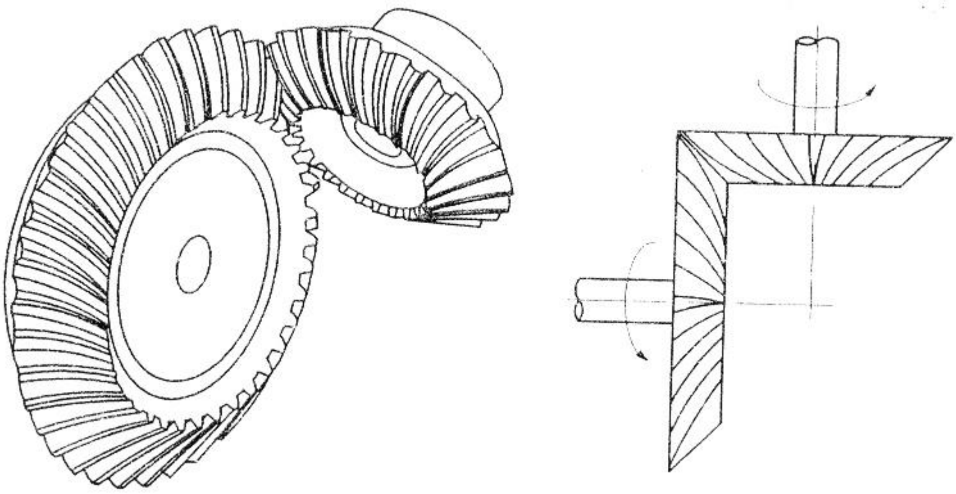


Figure 12.19 (b) Spiral bevel gears

- **Application**

  Automobile differential

(e) Spiral Gears (Skew gears or Crossed helical gears)

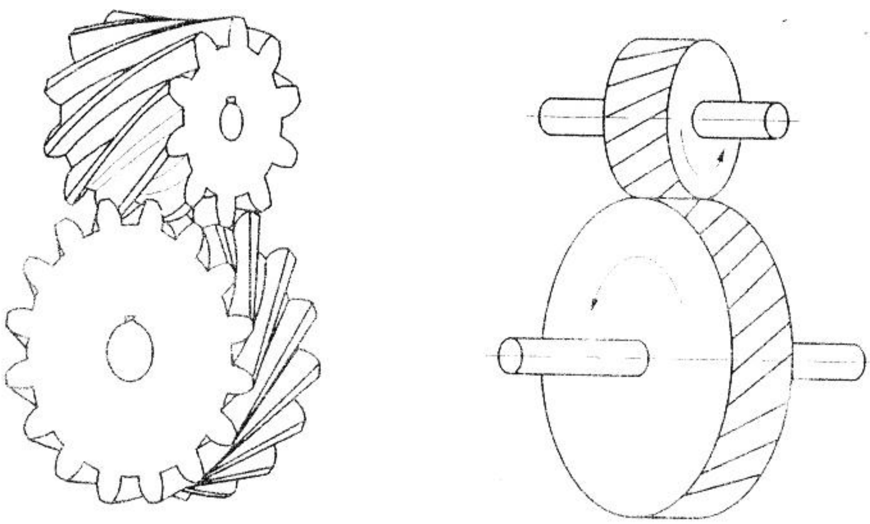


Figure 12.20 Spiral gears

- **Use**

  1. To transmit power from one shaft to another shaft which are non parallel and non intersecting.
  2. For low load transmission only since they have point contact between mating teeth.

(f) Worm and worm wheel

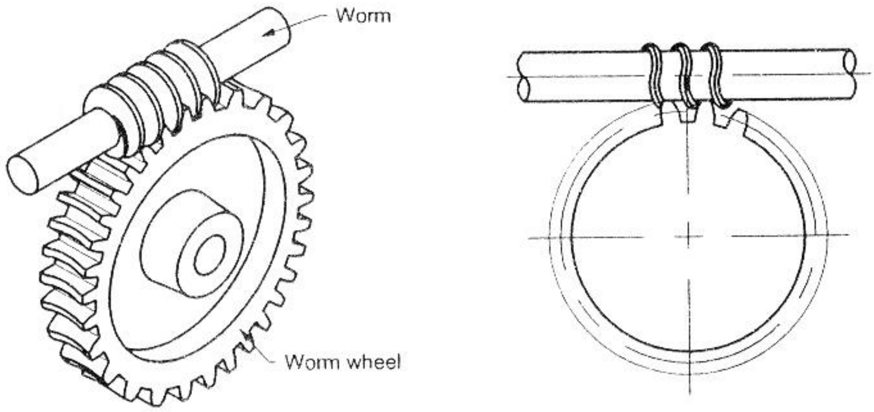


Figure 12.21 Worm and worm wheel

- **Use**

  To transmit power from one shaft to another shaft which are non intersecting and their axes are normally at right angles to each other.

- **Application**

  Lathe machine to get large speed reduction.

12.8 Comparison between belt drive, chain drive and gear drive

Sr. No.	Particulars	Belt drive	Chain drive	Gear drive
1	Main elements	Pulleys, belt	Sprockets, chain	Gears
2	Slip	Slip may occurs	No slip (Positive drive)	No slip (Positive drive)
3	Suitability	For large centre distance	For moderate centre distance	For short centre distance
4	Space requires	Large	Moderate	less (compact)
5	Design, manufacturing, complexity	Simplest	Simplest	Complicated

6	Failure	Failure of belt does not cause the further damage of machine.	Failure of chain may not seriously damage the machine.	Failure of gear may cause serious break down in the machine.
7	Life	Less	Moderate	Long
8	Lubrication	Not required	Require	Require proper lubrication
9	Installation cost	Less	Moderate	More
10	Use	For low velocity	For moderate velocity ratio	For high velocity ratio
11	Examples	Use as a first drive in transmission	Bicycle, Automobile	Machine tools, Automobile, gear boxes

CHAPTER-13 ENGINEERING MATERIALS

13.1 Introduction to Engineering Materials:

Since the earliest days of the evolution of mankind, the main distinguishing features between human begins and other mammals has been the ability to use and develop materials to satisfy our human requirements. Nowadays we use many types of materials, fashioned in many different ways, to satisfy our requirements for housing, heating, furniture, clothes, transportation, entertainment, medical care, defense and all the other trappings of a modern, civilized society.

Most materials doesn't exist in its pure shape, it is always exist as a ores. During the present century the scope of metallurgical science has expanded enormously, so that the subject can now be studied under the following headings:

a) Physical metallurgy
b) Extraction metallurgy
c) Process metallurgy

In the recent years studying the metallurgy science gave to humanity an ever growing range of useful alloys. Whilst many of these alloys are put to purposes of destruction, we must not forget that others have contributed to the material progress of mankind and to his domestic comfort.

This understanding of the materials resources and nature enable the engineers to select the most appropriate materials and to use them with greatest efficiency in minimum quantities whilst causing minimum pollution in their extraction, refinement and manufacture.

13.2 Selection of materials:

Let's now start by looking at the basic requirements for selecting materials that are suitable for a particular application. For example figure 2 shows the connecting rod of a motor car engine. This is made from a special steel alloy. This alloy has been chosen because it combines the properties of strength and toughness with the ability to be readily forged to shape and finished by machining.

Figure 13.1. The connecting rod of motor car engine.

Thus the reasons for selecting the materials in the above examples can be summarized as:
Commercial factors such as: Cost, availability, ease of manufacture, Appearance of material

<u>Engineering properties</u> of materials such as: Electrical conductivity, strength, toughness, ease of forming by extrusion, forging and casting, machinability and corrosion resistance.

13.3 Classification of engineering materials

The most convenient way to study the properties and uses of engineering materials is to classify them into 'families' as shown in figure below:

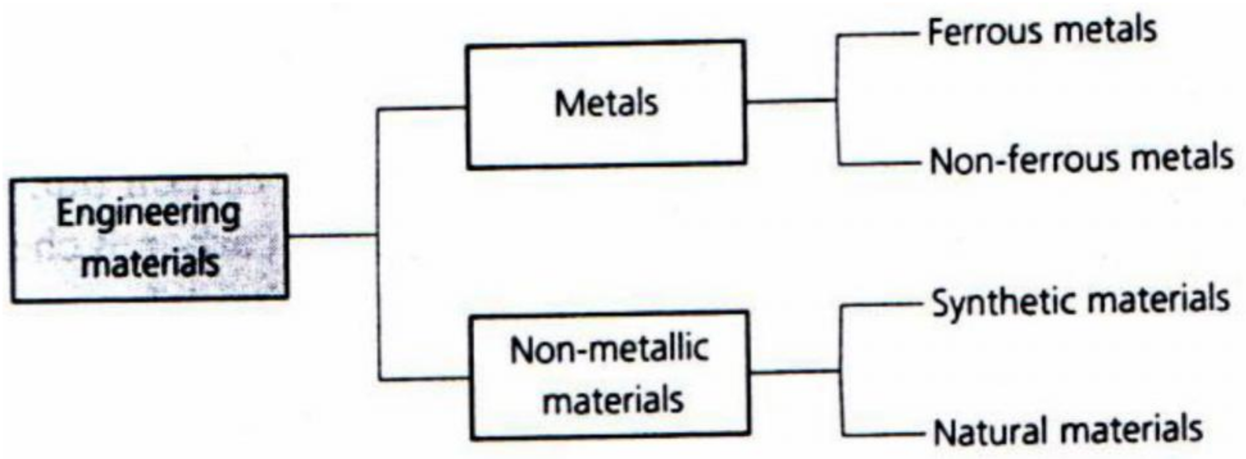


Figure 13.2 classifications of engineering materials.

13.4. Metals

13.4.1 Ferrous metals

- These are metals and alloys containing a high proportion of the element iron.
- They are the strongest materials available and are used for applications where high strength is required at relatively low cost and where weight is not of primary importance.
- As an example of ferrous metals such as: bridge building, the structure of large buildings, railway lines, locomotives and rolling stock and the bodies and highly stressed engine parts of road vehicles.
- The ferrous metals themselves can also be classified into "families',

13.4.2 Non – ferrous metals

- These materials refer to the remaining metals known to mankind.
- The pure metals are rarely used as structural materials as they lack mechanical strength.
- They are used where their special properties such as corrosion resistance, electrical conductivity and thermal conductivity are required. Copper and aluminum are used as electrical conductors and, together with sheet zinc and sheet lead, are use as roofing materials.
- They are mainly used with other metals to improve their strength.

13.5 Non – metallic materials

13.5.1 Non – metallic (synthetic materials)

These are non – metallic materials that do not exist in nature, although they are manufactured from natural substances such as oil, coal and clay.

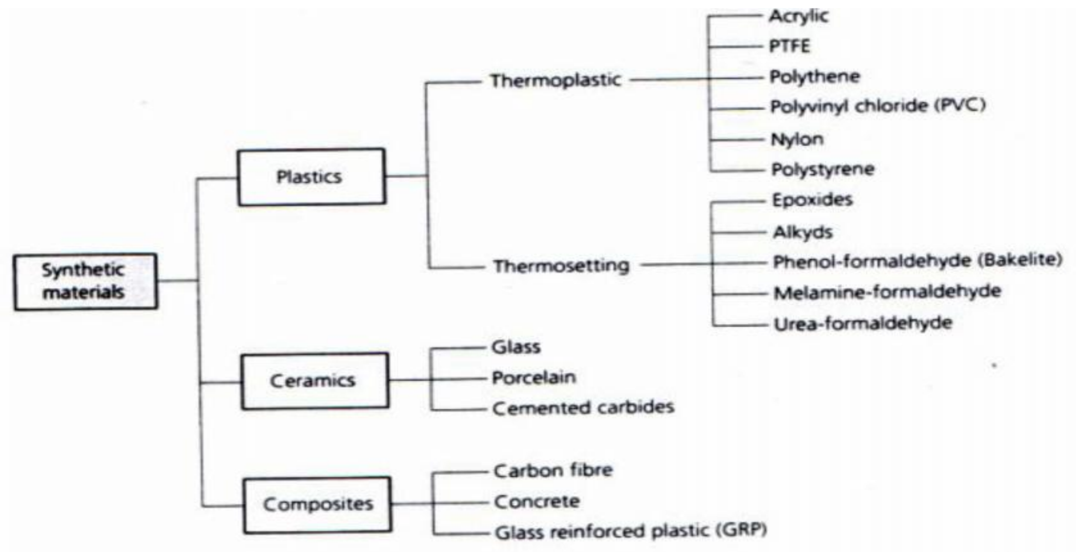


Figure 13.3 classifications of synthetic materials.

- They combine good corrosion resistance with ease of manufacture by moulding to shape and relatively low cost.
- Synthetic adhesives are also being used for the joining of metallic components even in highly stressed applications.

13.5.2 Non – metallic (Natural materials)

Such materials are so diverse that only a few can be listed here to give a basic introduction to some typical applications.

Wood: This is naturally occurring fibrous composite material used for the manufacture of casting patterns.

Rubber: This is used for hydraulic and compressed air hoses and oil seals. Naturally occurring latex is too soft for most engineering uses but it is used widely for vehicle tyres when it is compounded with carbon black.

Glass: This is a hardwearing, abrasion-resistant material with excellent weathering properties. It is used for electrical insulators, laboratory equipment, optical components in measuring instruments and, in the form of fibers, is used to reinforce plastics. It is made by melting together the naturally occurring materials : silica (sand), limestone (calcium carbonate) and soda (sodium carbonate).

Emery: This is a widely used abrasive and is a naturally occurring aluminum oxide. Nowadays it is produced synthetically to maintain uniform quality and performance.

Ceramic: These are produced by baking naturally occurring clays at high temperatures after moulding to shape. They are used for high – voltage insulators and high – temperature – resistant cutting tool tips.

Diamonds: These can be used for cutting tools for operation at high speeds for metal finishing where surface finish is greater importance. For example, internal combustion engine pistons and bearings. They are also used for dressing grinding wheels.

Oils: Are used as bearing lubricants, cutting fluids and fuels.

Silicon: This is used as an alloying element and also for the manufacture of semiconductor devices.

13.6 Composite materials (composites)

- These are materials made up from, or composed of, a combination of different materials to take overall advantage of their different properties.
- In man-made composites, the advantages of deliberately combining materials in order to obtain improved or modified properties were understood by ancient civilizations. An example of this was the reinforcement of air-dried bricks by mixing the clay with straw. This helped to reduce cracking caused by shrinkage stresses as the clay dried out. In more recent times, horse hair was used to reinforce the plaster used on the walls and ceiling of buildings. Again this was to reduce the onset of drying cracks.

Nowadays, especially with the growth of the plastics industry and the development of high-strength fibers, a vast range combination of materials is available for use in composites.

For example, carbon fiber reinforced frames for tennis rackets and shafts for golf clubs have revolutionized these sports.

13.6.1 Common Composite materials

Laminar or layer composites:

- Plywood, coated tools, insulated wires

Particulate composite:

- Concrete (cement sand and gravel)
- Abrasive particles and matrix in grinding wheels
- Cemented carbides- particle of WC uniformly distributed used as a cutting tool
- Properties are uniform in all direction

Fiber reinforced composite:

- Thin fibers of one material are embedded (fixed) in matrix of another material

- Glass is most widely used fiber with polymer as matrix. Other fibers are carbon, boron etc.
- Properties depend upon the fibred material volume fraction of fiber, orientation of fiber, properties of matrix, degree of bonding between fiber & matrix etc.

13.7 General Properties of Engineering Materials

1. Tensile strength

It is the ability of a material to withstand tensile (stretching) loads without breaking. For example, figure 13.4 shows a heavy load being held up by a rod fastened to beam. As the force of gravity acting on the load is trying to stretch the rod, the rod is said to be in tension. Therefore, the material from which the rod is made needs to have sufficient tensile strength to resist the pull of the load.

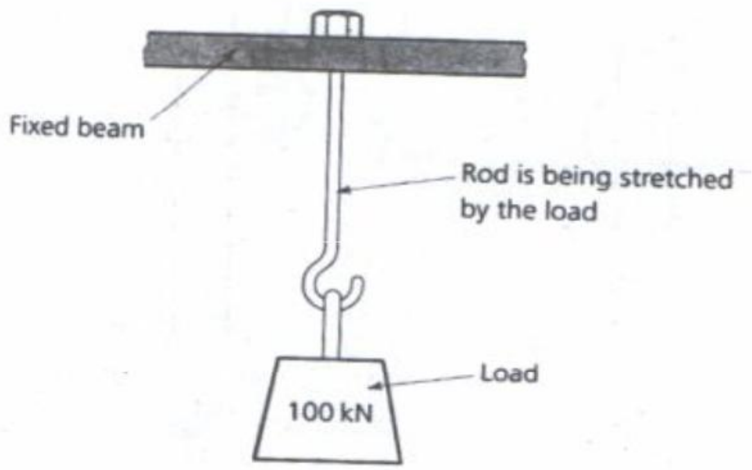


Figure 13.4 Tensile Strength

Strength: is the ability of a material to resist applied forces without fracturing.

2. Toughness

Toughness is the ability of a material to absorb energy without rupturing. The rubbers and most plastic materials do not shatter (break), therefore they are tough. For example, if a rod is made of high-carbon steel then it will be bend without breaking under the impact of the hammer, while if a rod is made of glass then it will broken by impact loading as shown in figure

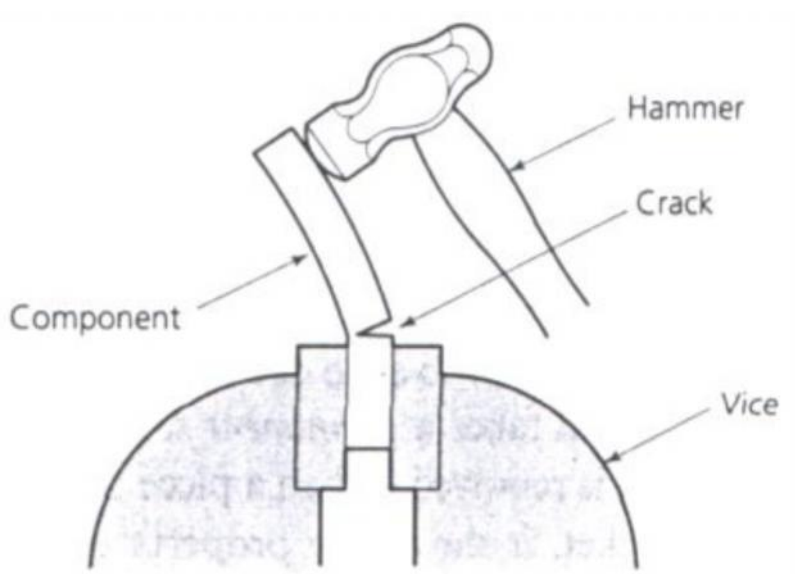


Figure 13.5 Toughness

3. Malleability

It is the capacity of substance to withstand deformation under compression without rupture or the malleable material allows a useful amount of plastic deformation to occur under compressive loading before fracture occurs. Such a material is required for handling by such processes as forging, rolling and rivet heading as shown in figure 13.6

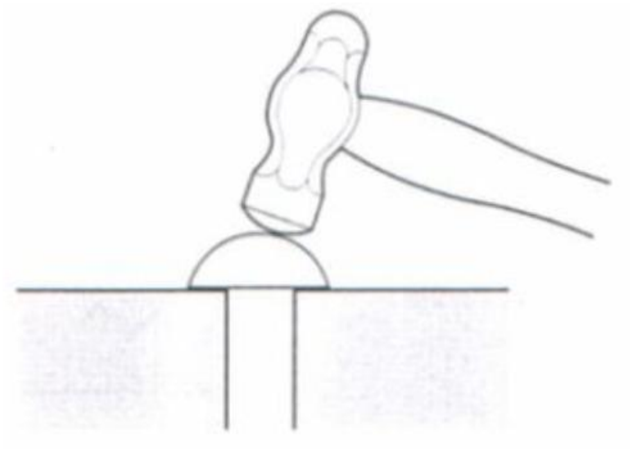


Figure 13.6. Malleability

4. Hardness

It is the ability of a material to withstand scratching (abrasion) or indentation by another hard body, it is an indication of the wear resistance of the material.

For example, figure 13.7 shows a hardened steel ball being pressed first into a hard material and then into a soft material by the same load. As seen that the ball only makes a small indentation in the hard material but it makes a very much deeper impression in the softer material.

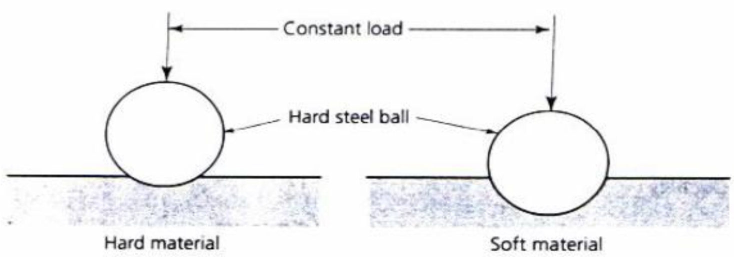


Figure 13.7. Hardness.

5. Ductility

It refer to the capacity of substance to undergo deformation under tension without rupture as in wire drawing (as shown in figure 13.8), tube drawing operation.

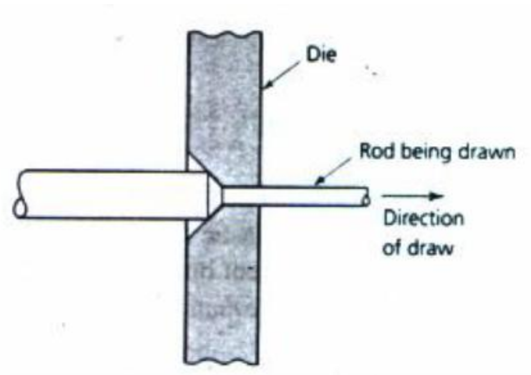


Figure 13.8 Ductility

6. Stiffness

Stiffness is the resistance of a material to elastic deformation or deflection. A material which suffers only a slight deformation under load has a high degree of stiffness.

7. Brittleness

It is the property of a material that shows little or no plastic deformation before fracture when a force is applied. Also it is usually said as the opposite of ductility and malleability.

8. Elasticity

It is the ability of a material to deform under load and return to its original size and shape when the load is removed. If it is made from an elastic material it will be the same length before and after the load is applied, despite the fact that it will be longer whilst the load is being applied.

All materials possess elasticity to some degree and each has its own ***elastic limits***. As in figure

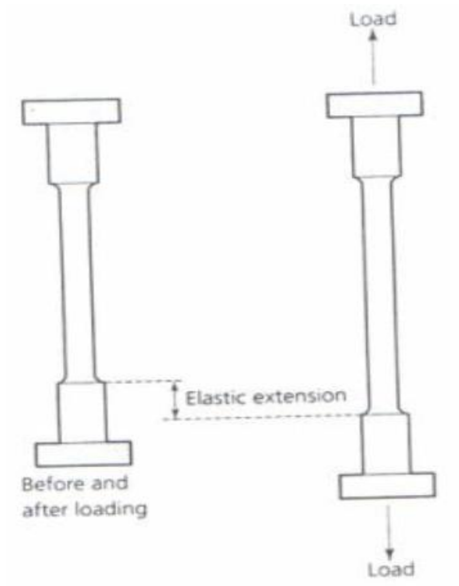


Figure 13.9. Elasticity.

9. Plasticity

This property is the exact opposite to elasticity. It is the state of a material which has been loaded beyond its elastic limit so as to cause the material to deform permanently. Under such conditions the material takes a permanent set and will not return to its original size and shape when the load is removed. When a piece of mild steel is bent at right angles into the shape of a bracket, it shows the property of plasticity since it does not spring back strength again, this is shown in figure

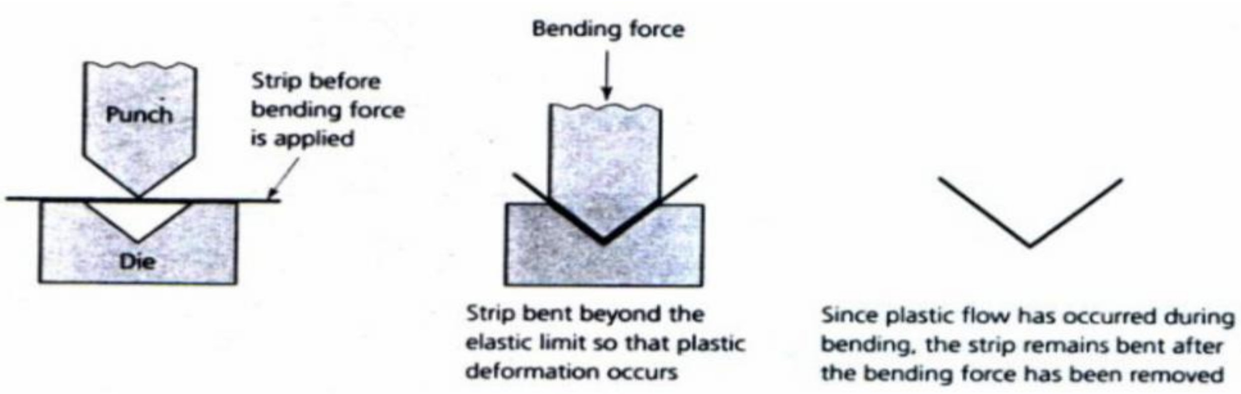


Figure 13.10. Plasticity

Some metals such as lead have a good plastic range at room temperature and can be extensively worked (where working of metal means squeezing, stretching or beating it to shape).

10. Creep

When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called *creep.* This property is considered in designing internal combustion engines, boilers and turbines.

11. Resilience

It is the property of a material to absorb energy and to resist shock and impact loads. It is measure by amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

12. Fatigue

A material fails at stresses below the yield point stresses when it is subjected to repeated tensile and compressive stresses. This type of failure of material is known as fatigue. This property is considered in designing shafts, connecting rods, gears, springs etc.

13. Thermal conductivity

This is the ability of the material to transmit heat energy by conduction. Figure shows a soldering iron. The bit is made from copper which is a good conductor of heat and so will allow the heat energy stored in it to travel easily down to the tip and into the work being soldered. The wooden handle remains cool as it has a low thermal conductivity and resists the flow of heat energy.

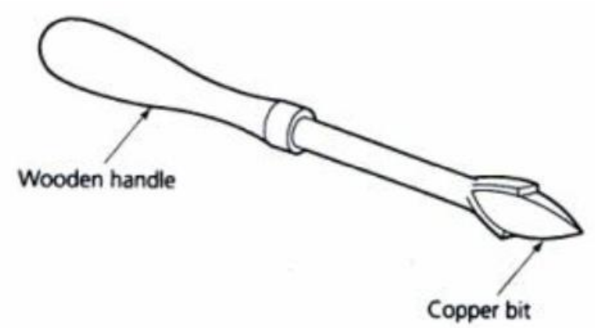


Figure 13.11. Thermal conductivity.

14. Electrical resistivity

It is the property of a material due to which it resists the flow of electricity through it.

15. Electrical conductivity

It is the property of a material due to which it allows the flow of electricity through it.