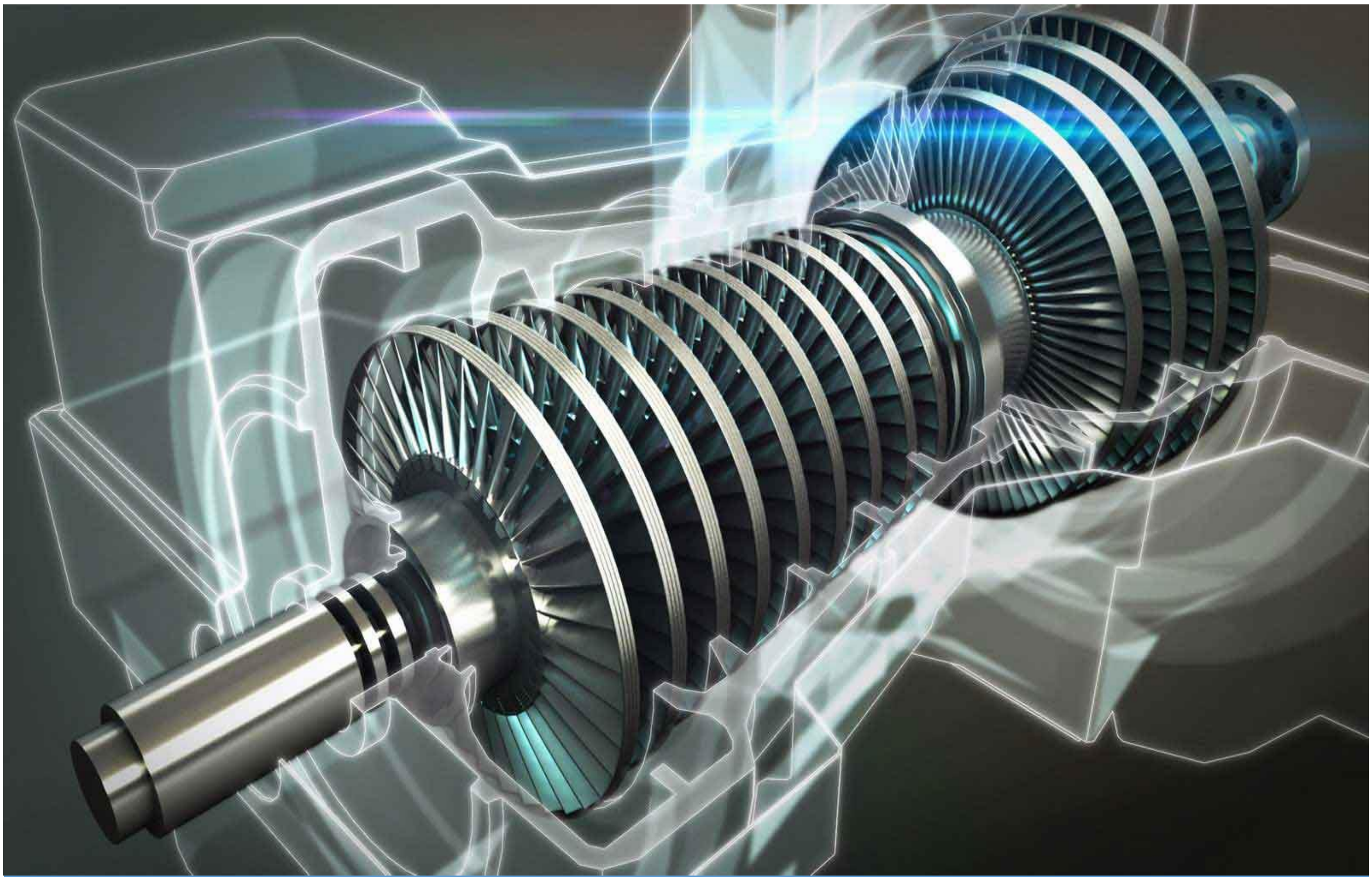
BASIC MECHANICAL ENGINEERING (3110006) E-NOTE

BE 1ST YEAR



Department of Mechanical Engineering

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Prime mover

A prime mover is defined as a device which converts energy from natural sources into mechanical energy or useful work (shaft power). Examples of prime movers are: Wind turbine, steam turbine, water turbine, I.C. Engine, etc.

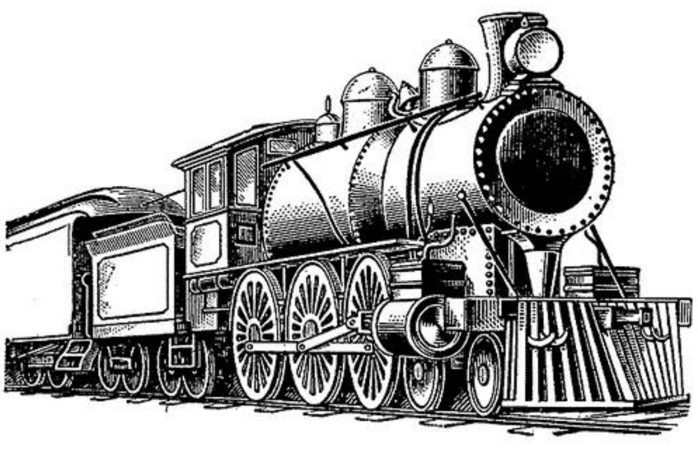
Sources of energy

Prime movers use various natural sources of energy like fuel, water energy, atom, biomass, wind etc.

1. **Fuel:** When fuel is burnt, heat energy is generated. Amount of heat generated 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). Various types of fuels are coal, petrol, diesel, gas etc.
2. **Water 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. For example water stored in dam contains potential energy.
3. **Atoms (Nuclear Energy):** Heat energy produced by the fission (nucleus is divided into two or more fragments) or fusion (two lighter atomic nuclei fuse to form a heavier nucleus) of atoms may be used to produce heat. This heat is used to produce shaft power by heat engines.
4. **Non-conventional Energy Sources:** These energy resources replace themselves naturally in a relatively short time and therefore will always be available. Examples of these resources are solar energy, wind energy, tidal energy, bio energy, solid wastes etc. Almost all non-conventional energy resources offer pollution free environment.

Types of prime movers

The prime mover can be classified according to the sources of energy utilized. The classification of prime movers is shown in fig. 1.2.



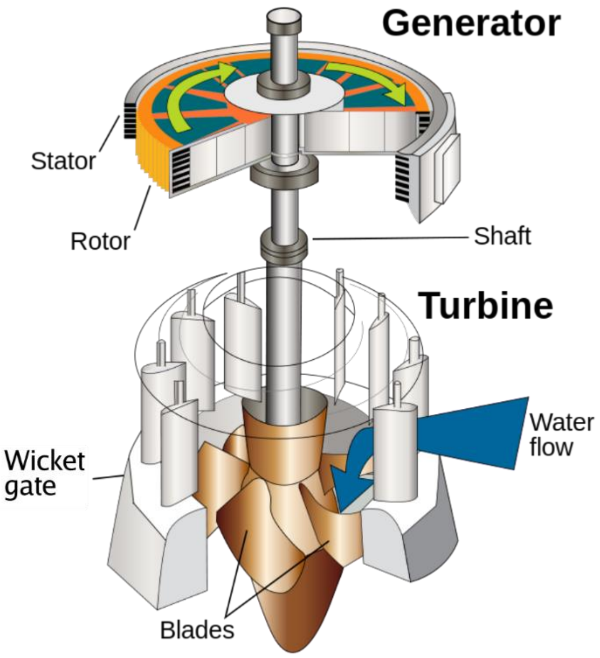


Fig 1.1 Examples of Prime mover (Steam engine and water turbine)

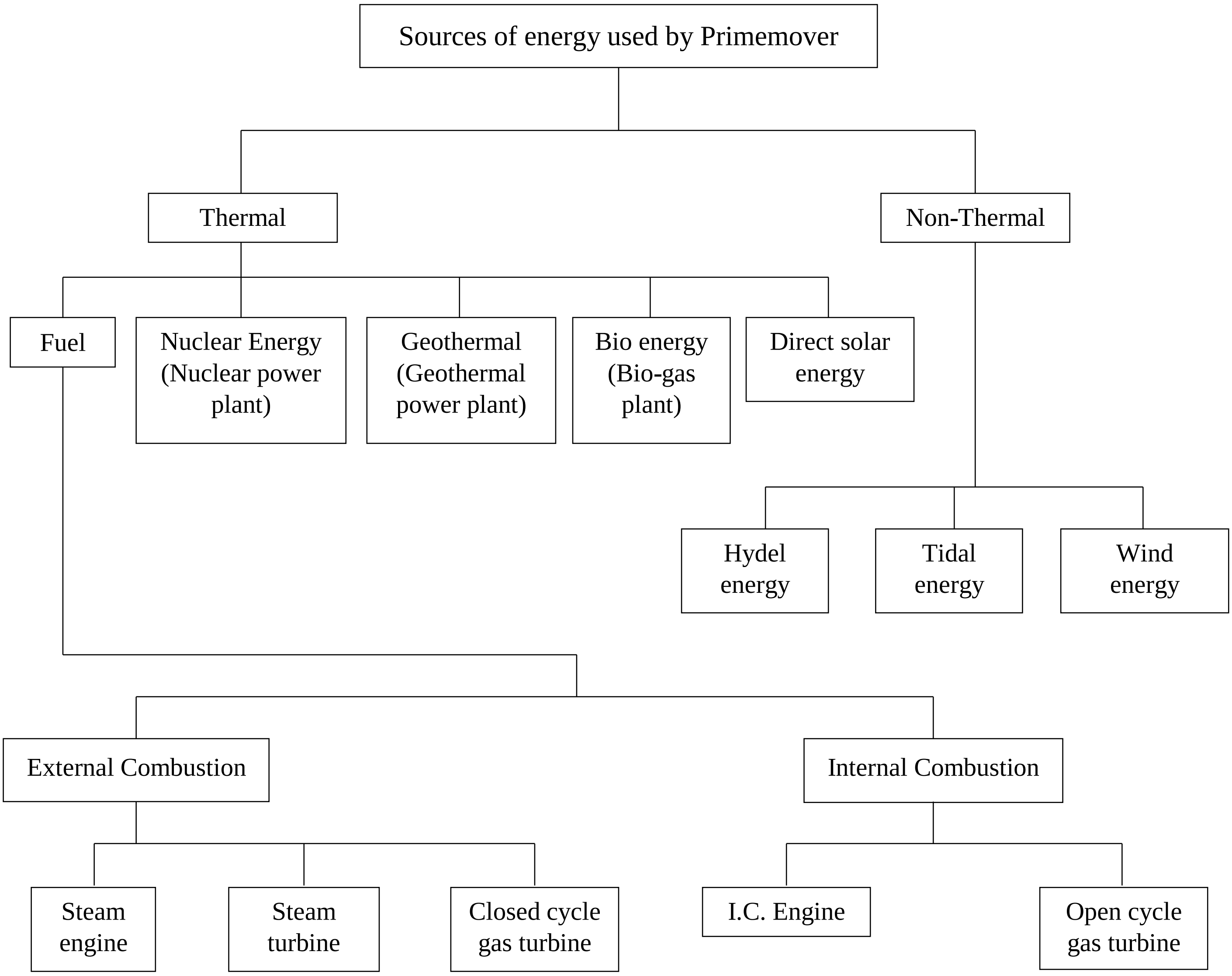


Fig. 1.2 Classification of prime movers

Basic Definitions

Mass

It is quantity of matter contained in a body. It does not depend upon gravitational force. The fundamental unit of mass is the Kilogram (kg).

Weight

Weight is the force exerted by gravity. Weight of body is dependent upon gravitational force, so it is not constant.

Weight = Mass x Gravitational acceleration

$$W = m \times g$$

Force

It is push or pull acting on a body which changes or tends to change the state of rest or uniform motion of the body.

As per Newton's second law of motion

$$\text{Force} \propto \text{acceleration}$$

$$F = m \times a$$

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

When m = 1 kg, and a = 1 m/s^2 then F = 1 N.

1 N: When unit mass is given unit acceleration then the force produced is 1 N.

Pressure

It is the force exerted by fluid (liquid or gas) on unit area. It is a property of fluid.

$$Pressure = \frac{Force}{Area} = \frac{N}{m^2}$$

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

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

Other commonly used units of pressure are:

1 kPa (Kilo Pascal) = 10^3 Pa

1 Mpa (Mega Pascal) = 10^6 Pa

1 bar = 10^5 Pa

Measurement of pressure:

Pressure is measured by Barometer, Pressure gauges and manometers.

Atmospheric pressure:

It is the pressure exerted by atmosphere. The atmospheric pressure varies from place to place. At sea level the pressure is,

1 standard atmosphere (atm) = 101325 Pa = 1.01325 bar

Barometer is used to measure atmospheric pressure.

Standard atmospheric pressure:
It is a pressure of atmospheric air at mean sea level. It is defined as "The pressure produced by a mercury column of 760 mm high having a density of 13595.09 kg/m^3 and acceleration due to gravity being 9.80665 m/s^2."

Now, $pressure = \rho \times g \times h$

$$= 13595.09 \times 9.80665 \times 760 \times 10^{-3}$$

$$= 1.01325 \times 10^{5} \text{ N/m}^2 = 1.01325 \text{ bar}$$

Gauge pressure:
The pressure relative to the atmosphere is called gauge pressure. This pressure is measured by pressure gauge.

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

Mathematically, **Absolute pressure = Atmospheric pressure + Gauge pressure**

Vacuum:
The pressure below atmospheric pressure is called vacuum. 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. 2.

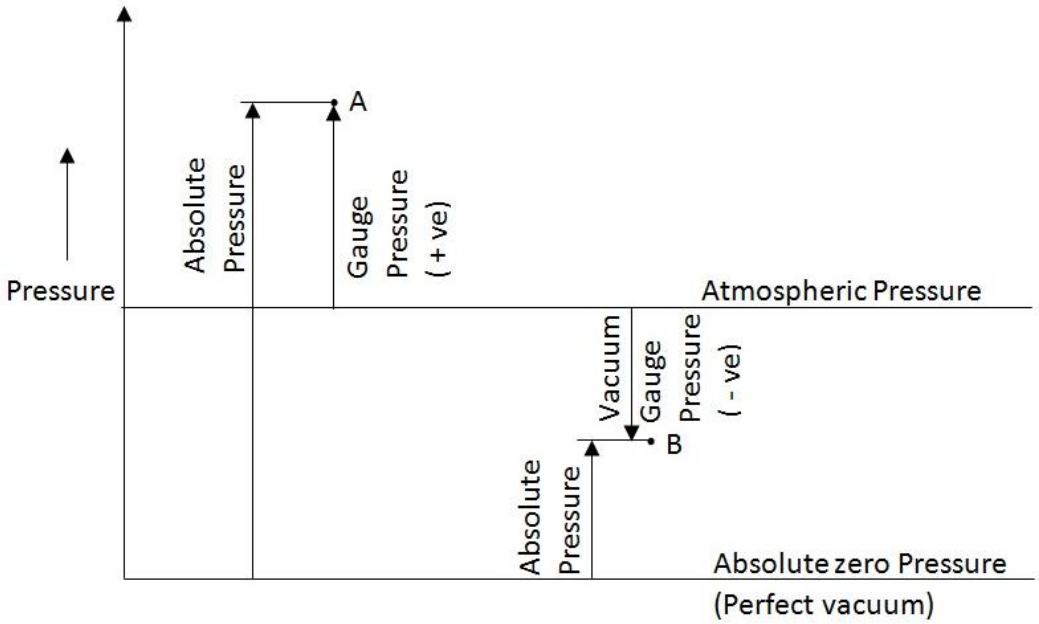


Fig. 1.3 Relation between different pressures

Work
Work is said to be done when a force moves the object through a distance in direction of force.

Hence, Work = Force x Distance moved into direction of force.

$$W = F \times d$$
$$W = \frac{F}{A} \times (A \times d)$$
$$W = P \times V$$

Unit of work is N·m or Joule (J).

Power

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

Mathematically, $Power = \frac{Workdone}{time}$ and unit of power is Joule/second.

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

Watt is very small unit, so another larger units are megawatt (MW), Kilowatt (kW).

Energy

Energy means capacity for doing work.

The unit of energy is the unit of work i.e. Joule. In our daily life unit of energy use is Kilowatt hour (kWh).

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

"Energy can neither be created nor be destroyed but the total amount of energy remains constant. It is possible to convert one form of energy into another form of energy." This is called the law of conservation of energy.

Quality of Energy

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.

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

(1) Stored energy:

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

(2) Energy in transition:

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

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

Types of Mechanical Energy:

There are two types of mechanical energy

(1) Potential energy (2) Kinetic energy

1. **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, $$\text{P.E.} = m \times g \times h$$

   Where

   m = mass of body in kg,

   g = gravitational acceleration = 9.81 m/s^2

   h = height in meter,

2. **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.

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

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

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.

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, °C.

Absolute zero temperature:

It is the temperature at which the volume occupied by the gas becomes zero. 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.

Table 1.1 Comparison of Scales

Sr No.	State	Temperature °C	Temperature 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

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 between two bodies which causes change in temperatures. This form of energy interaction is called heat.

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

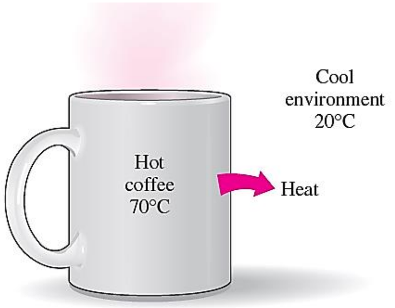


Fig. 1.4 Heat flows in the direction of decreasing temperature

Interchange of heat

Let us consider two bodies, hot body and cold body. When hot body comes in contact with cold body, the heat will flow from hot body to cold body. This interchange of heat is due to temperature difference. See fig. 1.5.

$T_1 > T_2$

Hot Body (T_1)	Cold Body (T_2)

Heat flow $\longrightarrow$

Fig. 1.5 Interchange of heat

There will be no heat flow if both the bodies in contact have equal temperature.

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 kilo joules

Specific heat

It is defines 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 kJ/kg K or J/kg K depending on the unit of Q.

From the definition of specific heat, the heat transfer Q is written as

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

$$\therefore C = \frac{Q}{m \times \Delta T}$$

$$= \frac{Q(kJ)}{m(kg) \times \Delta T(K)}$$

Heat capacity: 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, C_V

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

The specific heat at constant volume C_V: It is defined as the heat required to increase the temperature of the unit mass of a gas by one degree as the volume is maintained constant.

The specific heat at constant volume C_P: It is defined as the heat required to increase the temperature of the unit mass of a gas by one degree as the pressure is maintained constant.

Change of state

The various states of substance (Phases) are Solid, Liquid and Vapour/Gas. When heat is supplied to a substance at the solid phase, its temperature rises until it starts converting into liquid.

Table 1.2 Phase change terminology

Sr.	Phase change	Name	Process
1	Solid to liquid	Fusion	Melting
2	Solid to vapour	Sublimation	Defrosting
3	Liquid to vapour	Evaporation	Evaporating
4	Liquid to solid	Fusion	Freezing
5	Vapour to solid	Sublimation	Frosting
6	Vapour to liquid	Condensation	Condensing

Melting point: It is the temperature at which the solid is converted into liquid when heat is supplied.

Boiling point: It is the temperature at which the liquid is converted into vapour when heat is supplied.

Critical point: It is the temperature and pressure above which only one phase is existing i.e. vapour.

Triple point: Triple point of a substance refers to the state at which substance can coexist in solid, liquid and gaseous phase in equilibrium. For water triple point is 0.010 °C i.e. at this temperature ice, water and steam can coexist in equilibrium.

Thermodynamic systems

A system is defined as a quantity of matter or a region in space chosen for study. Examples: quantity of steam, turbine etc.

The mass or region outside the system is called the **surroundings.**

The real or imaginary surface that separates the system from its surroundings is called the **boundary.** These terms are illustrated in fig. 1.6.

The boundary of a system can be *fixed* or *movable. Note that the boundary is the contact surface shared by both the system and the surroundings.*

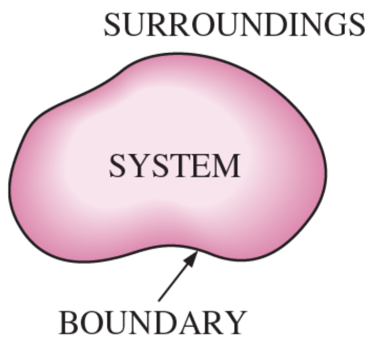


Fig. 1.6 System, surrounding and boundary

The system is identified by a boundary around the system. A system and its surroundings together are called the universe.

<u>*Universe = system + surroundings*</u>

Types of system

There are three types of system

(1) Open system, (2) Closed system and (3) Isolated system

1. Open system

In an open system mass and energy (in form of heat and work) both can transfer across the boundary (fig. 1.7).

Most of the engineering devices are open system. Examples: Boiler, turbine, compressor, pump, I.C. engine etc.

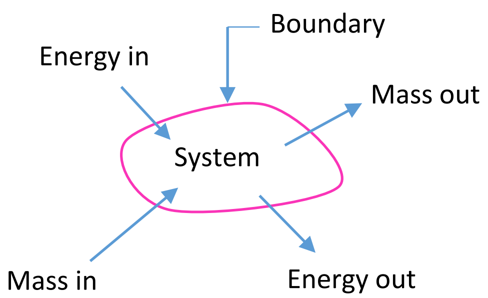


Fig. 1.7 An open system

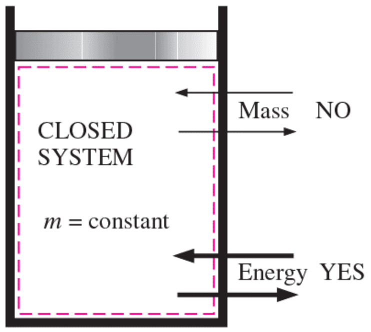


Fig. 1.8 A closed system

2. Closed system

A closed system exchange energy in the form of heat and work with its surroundings but there is no mass transfer across the system boundary (fig. 1.8).

The mass within the system remains constant though its volume can change against a flexible boundary. Example: cylinder bounded by a piston with certain quantity of fluid, pressure cooker etc.

3. Isolated system

There is no interaction between system and surroundings.

It is of fixed mass and energy, and hence there is no mass and energy transfer across the system boundary (fig. 1.9).

Example: The universe and perfectly insulated closed vessel (Thermo flask)

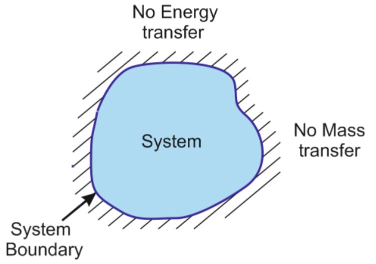


Fig. 1.9 An isolated system

Control Volume

For thermodynamic analysis of an open system, such as an air compressor, turbine, etc. attention is focused on a certain volume in space surrounding the system, known as control volume.

The control volume bounded by the surface is called **"Control Surface"**.

Both mass and energy can cross the control surface. It may be physical or imaginary. Example of control volume:

A diagram of an engine is shown in Fig. 1.10(*a*). The dashed line defines a control volume that surrounds the engine. Observe that air, fuel, and exhaust gases cross the boundary. A schematic such as in Fig. 1.10(*b*) often serves for engineering analysis.

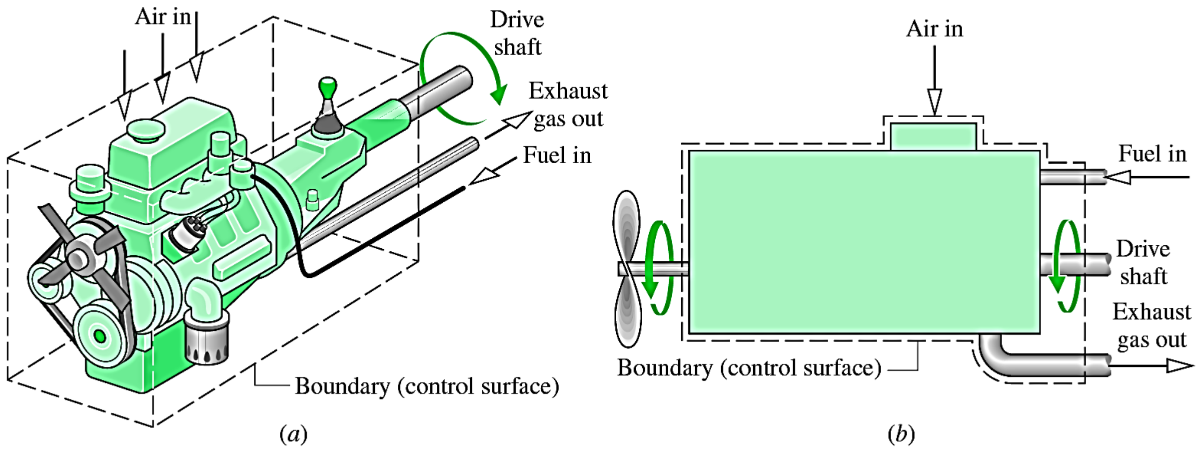


Fig. 1.10 Example of a control volume (open system) - An automobile engine

Sign convention for heat and work

Work

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

Heat

In general, the heat transferred to the system is considered as ***positive heat (+Q)*** while the heat transferred from the system is considered as ***negative heat (-Q)***.

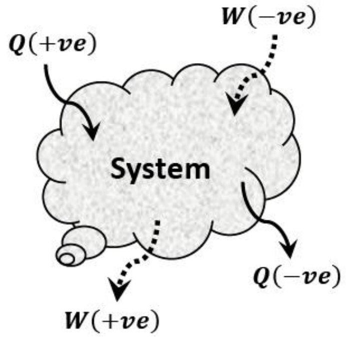


Fig. 1.11 Sign convention for heat and work

Comparison between heat and work

Similarities

1. Both are energy interactions.
2. Both are transient phenomena.
3. Both are boundary phenomena.
4. Both represents energy crossing the boundary of the system.
5. They are not the property of the system.
6. Both are path functions.

Dissimilarities

1. Heat transfer is the energy interaction due to temperature difference only while work is not.
2. Heat is low grade energy while work is high grade energy.
3. Heat is thermal energy transfer while work is mechanical energy transfer across the system boundary.

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.

When heat is supplied to a body the amount of heat transferred to a body is not fully converted to 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,

$$Q = W + U$$

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. Below equation is referred as non-flow energy equation. In other words, for non-flow process

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

Enthalpy

Enthalpy is a thermodynamic property of fluid, denoted by H. *It can be defined as the summation of internal energy and flow energy. Mathematically,*

$$H = \underset{\text{Internal energy}}{U} + \underset{\text{Flow work}}{PV}$$

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

$$h = u + pv$$

From expression of enthalpy it is clear 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.

Thermodynamic properties, Processes and Cycle

Thermodynamic property

"A thermodynamic property refers to the characteristics which can be used to describe the physical condition or state of a system."

Examples of thermodynamic properties are: Temperature, Pressure, Volume, Energy, Mass, Velocity, etc.

Types of thermodynamic property:

1. Intensive Property

Intensive property is **In**dependent of the mass of the system. Its value remains same whether one considers the whole system or only a part of it.

Examples: Pressure, Temperature, Density, etc.

2. Extensive Property

Extensive property depends on mass of the system.

Examples: Mass, Volume, Total energy, Enthalpy etc.

3. Specific Property

Extensive properties per unit mass are called specific properties.

Example: Specific volume $\left(v = \dfrac{V}{m}\right)$ and specific enthalpy $\left(h = \dfrac{H}{m}\right)$

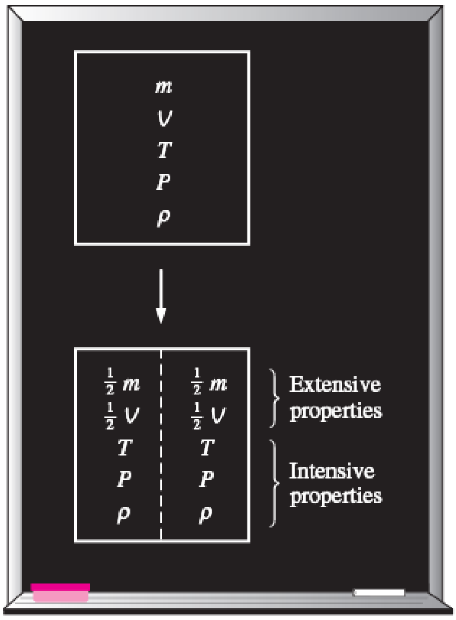


Fig. 1.12 Criterion to differentiate intensive and extensive properties

<u>State</u>

State refers to the condition of a system as described by its properties. It gives complete description of the system. At a given state, all the properties of a system have fixed values.

If the value of even one property changes, the state will change to a different one (fig. 1.13)

Equilibrium

The word **equilibrium** implies a state of balance. In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.

A system is in **thermal equilibrium** if the temperature is same throughout the entire system.

Mechanical equilibrium is related to pressure. If there is no change in pressure at any point in the system with time the system is in mechanical equilibrium.

Chemical equilibrium is that state when the chemical composition does not change with time and there is no chemical reaction.

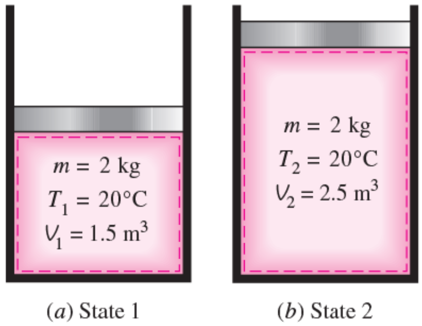


Figure 1.13 A system at two different states

A system will be in **thermodynamic equilibrium** only when it satisfies the conditions for all modes of equilibrium.

Process and path

Any change that a system undergoes from one equilibrium state to another is called a **process,** and the series of states through which a system passes during a process is called the **path** of the process (Figure 1.14).

To describe a process completely, one should specify the initial and final states of the process, as well as the path it follows, and the interactions with the surroundings.

There are infinite ways for a system to change from one state to another.

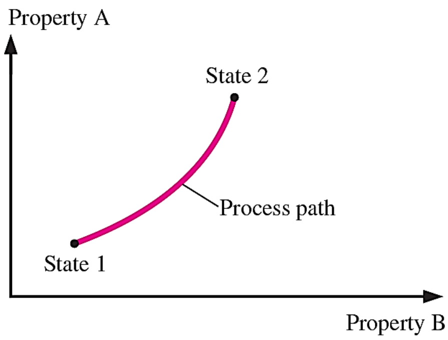


Fig. 1.14 A process between states 1 and 2 and the process path

Cycle

When a system in a given initial state goes through a number of different changes of state or processes and finally returns to its initial state, the system has undergone a **cycle.** Thus for a cycle the initial and final states -are identical.

Example: Steam that circulates through a steam power plant undergoes a cycle.

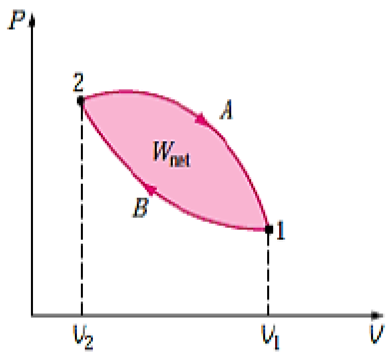


Fig. 1.15 Cyclic Process

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. 1.16 shows the Zeroth law of thermodynamics.

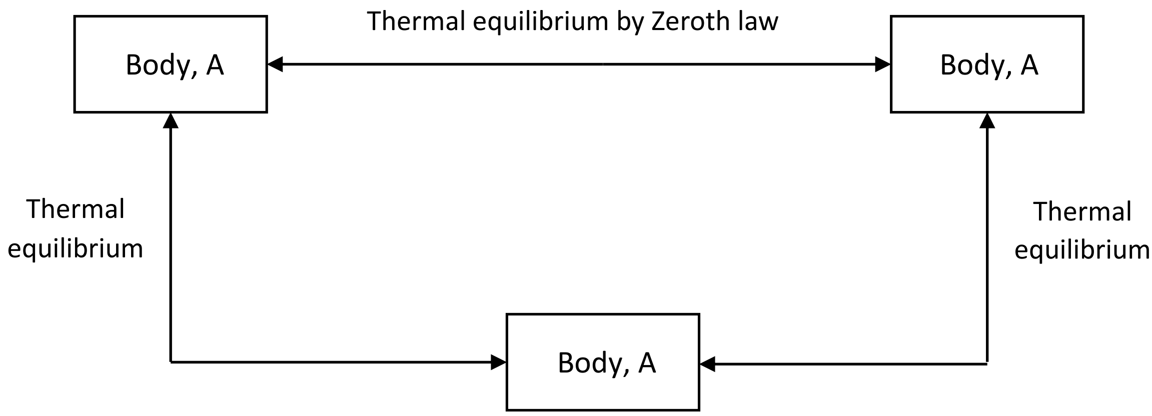


Fig. 1.16 Zeroth law of thermodynamics

First law of thermodynamics

The first law of thermodynamics is the law of conservation of energy and it states that "energy can neither be created nor destroyed, it can be converted from one form to another and total energy remains same".

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.

First law may be expressed as,

Change in total energy = net energy transferred as heat and work

$$\Delta E = Q - W$$

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

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

In closed system, mass is fixed and there is no elevation difference and movement. Hence, ΔKE = 0 and $\Delta PE = 0$.

$$\Delta U = Q - W$$

For cyclic process ΔE = 0

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

That is, the net heat transfer and net work done during a cyclic process are equal.

Energy

Energy is the capacity of a physical system to perform work. Energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, electrical, chemical or other forms.

According to the law of conservation of energy, the total energy of a system remains constant, though energy may transform into another form.

The SI unit of energy is the joule (J) or Newton-meter (N * m). The joule is also the SI unit of work.

Chemical energy is a form of potential energy related to the structural arrangement of atoms or molecules. This arrangement may be the result of chemical bonds within molecule or otherwise.

Chemical energy of a chemical substance can be transformed to other forms of energy by a chemical reaction. For example, when a fuel is burned the chemical energy converted to heat, same is the case with digestion of food metabolized in a biological organism.

Green plants transform solar energy to chemical energy through the process known photosynthesis, and electrical energy can be converted to chemical energy through electrochemical reactions.

Various Sources of Energy

There are two sources of energy

i. **Renewable sources of energy:** These are sources of energy which are gained from natural resources and replenished naturally. Energy produced by these sources are not harmful to environment. Example of sources of these energies is: sun, wind, rain, tides etc.
ii. **Non-renewable sources of energy**: This type of energy is gained from deposits found on earth. These are present in limited quantities. It took thousands of years for the resources to be formed on earth. When energy is produced using them, it causes harm nature. When we burn petrol, carbon dioxide along with soot is produced which is harmful to the environment.

Examples of non-renewable sources of energy: fossil fuels which include coals, natural gas, petroleum etc.

Nuclear energy

It is the part of the energy of an atomic nucleus, which can be released by fusion or fission or radioactive decay. The most common fissile nuclear fuels are uranium- 235 (235U) and plutonium-239 (239Pu). The actions of mining, refining, purifying, using, and ultimately disposing of nuclear fuel together make up the nuclear fuel cycle.
A nuclear power plant uses steam to generate electricity the same as fossil fuel power plant. The major difference between the fossil fuel power plant and nuclear power plant is the method used to heat the water and produce steam.

In nuclear power plant, uranium takes place of coal, oil or gas to be the fuel used to heat water and produce steam.

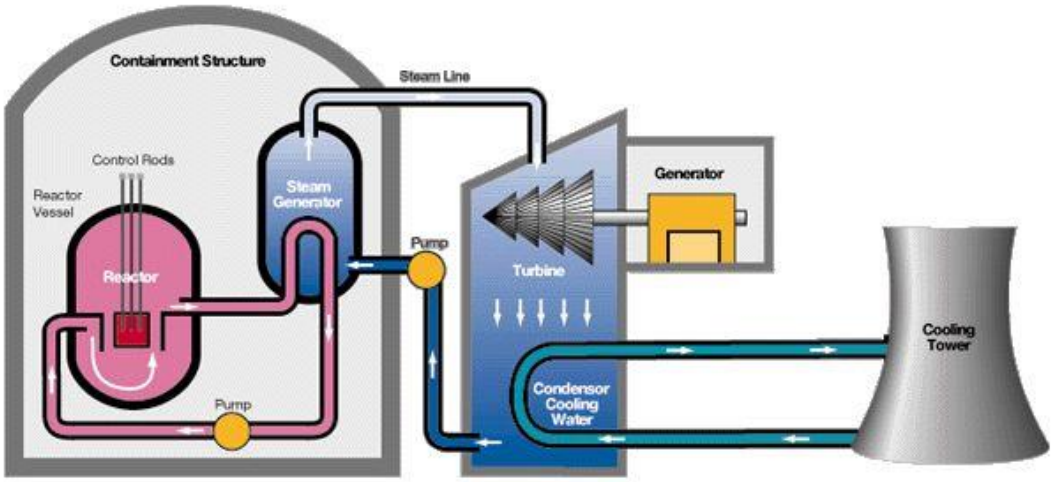


Fig. 2.1 Nuclear Power Plant

As the reserves of fossil fuel is depleting very fast, more number of nuclear power plants are coming up in most of the countries.

However main disadvantages of nuclear power plants are high investment and the byproducts of fission are radio-active which may cause a dangerous radio-active pollution.

Hydel/Hydraulic/Water Energy

Hydro power is the generation of electricity by using the natural force of water. It is generated in three different ways: hydroelectric power, tidal power, and wave power.

1) **Hydroelectric Power:** This is the most common form of hydro-power, making up the majority of all renewable energy produced. Electricity is produced in hydroelectric dams where the force of falling water drives massive turbines.

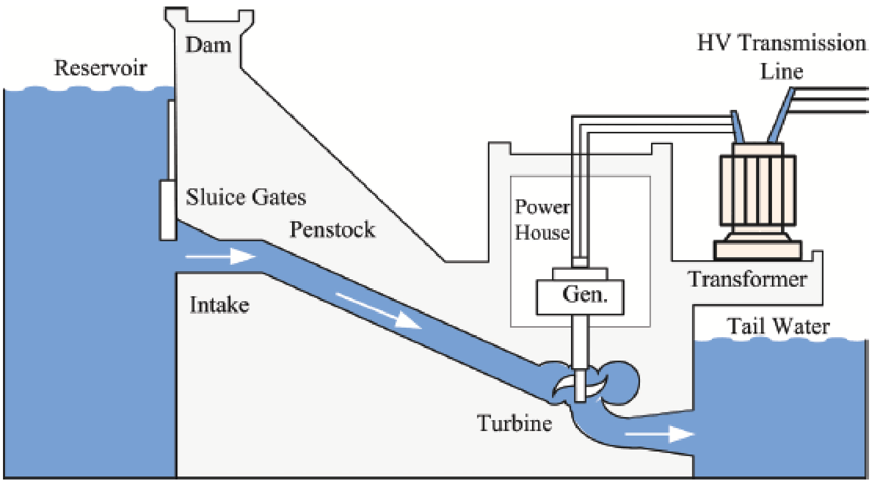


Fig. 2.2 Hydel power plant

It is relatively cheaper and better source of energy. Water stored at high level contains large potential energy. The water head is created by constructing dam across the river or lake at a higher level.

When water starts flowing from higher level, its potential energy gets converted into kinetic energy which is further converted into mechanical energy by running the hydraulic turbine and water wheels. Turbines and water wheels are coupled to electric generator -generating electric power.

Hydroelectric power generation is becoming more and more popular as it is reliable, require low maintenance cost, low operating cost and free from pollution. However it requires large initial investment cost for dam and reservoir.

Numbers of hydro power plants are constructed in India. Sardar sarovar hydro power project in Gujarat is one of the largest projects in India.

2) **Tidal Power:** The second most popular type of hydro power, tidal energy is produced by currents caused from the natural ebb and flow of the tide. The Rotec Tidal Turbine (RTT) is a unique solution to the problem of providing renewable energy. The RTT unit is completely submerged and is connected to an on-shore electrical substation via subsea

3) **Wave Power:** This is the latest of the three hydropower solutions. The system harnesses the power from ocean surface wave motion, where air displaced by waves is driven through a generator than spins a turbine. The end result is electricity.

These generators can either be coupled to floating devices on the sea, or fixed along the shore where seas are rough. Although this technology is relatively new, it has been estimated that there is enough energy in ocean waves to produce power.

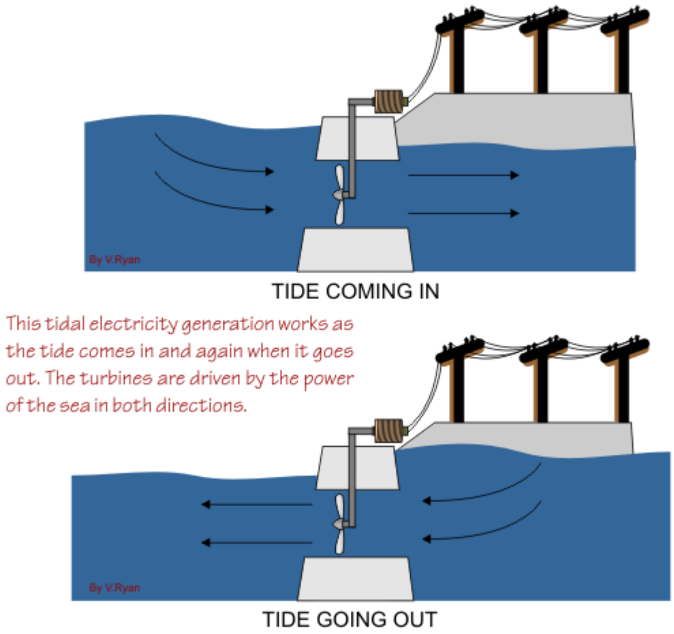


Fig. 2.3 Tidal power plant

Wind Energy

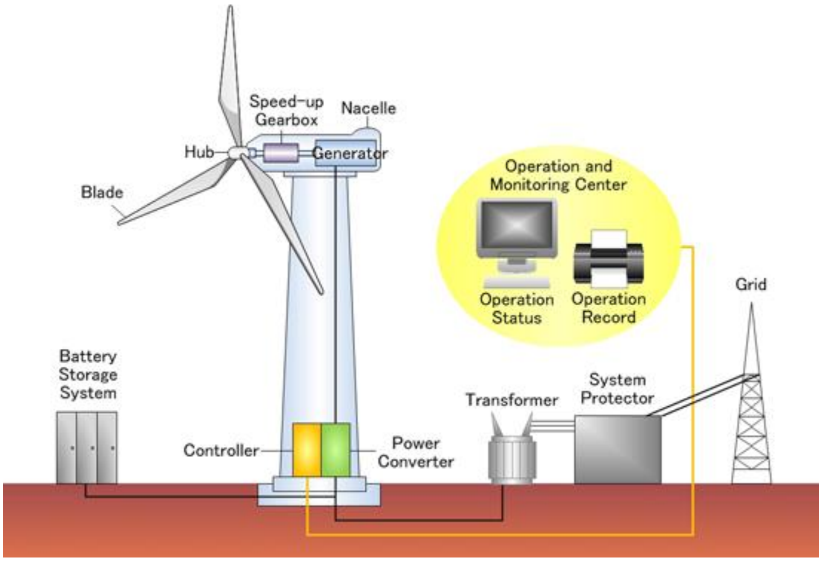


Fig. 2.4 Wind power plant

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to generate electric power, windmills for mechanical power, wind pumps for water pumping or drainage or sails to propel ships. Fig. 2.4 shows the outline of wind power generation.

Large wind farms consist of hundreds of individual wind turbines which are connected to the electric power transmission network. Offshore wind is steadier and stronger than on land and off-shore farms have less visual impact, but construction and maintenance costs are considerably higher.

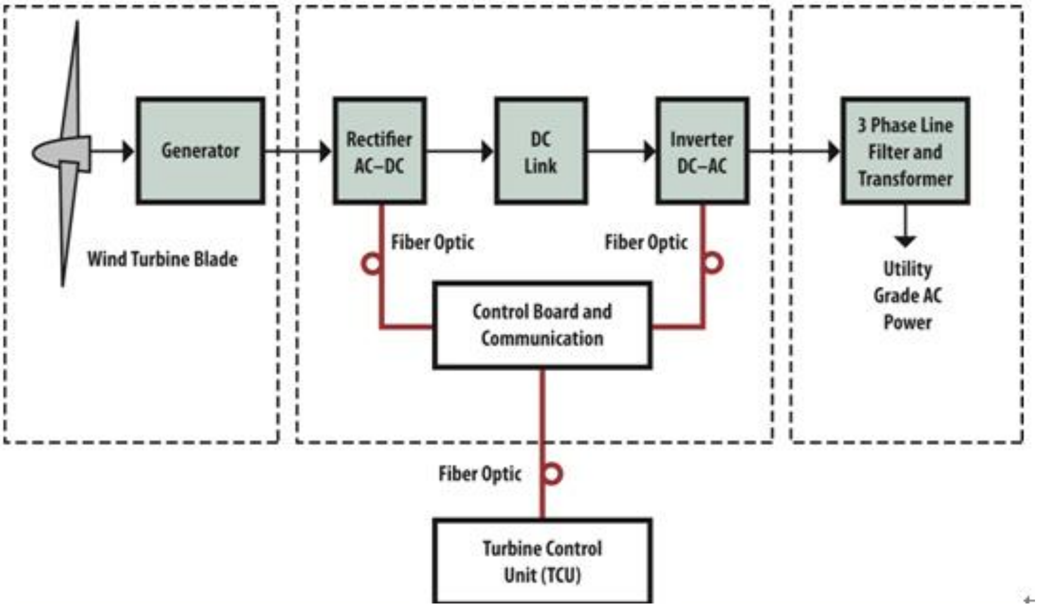


Fig. 2.5 Wind power plant line diagram

Small onshore wind farms provide electricity to isolated locations. Utility companies increasingly buy surplus electricity produced by small domestic wind turbines.

Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land.

The effects on the environment are generally less problematic than those from other power sources. Large wind farms are constructed at Kanyakumari in Chennai and at Bhuj in Gujarat.

Solar Energy:

Sun is the ultimate source of energy. The energy originates with the thermonuclear fusion reactions occurring in the sun. It Represents the entire electromagnetic radiation (visible light, infrared, ultraviolet, x-rays, and radio waves). Solar energy reaching the earth in tropical zones is about 1kW/meter square per day.

By one calculation, 30 days of sunshine striking the Earth have the energy equivalent of the total of all the planet's fossil fuels, both used and unused. In the Indian subcontinent, abundant solar energy is available for about ten months of the year for six to eight hours a day.

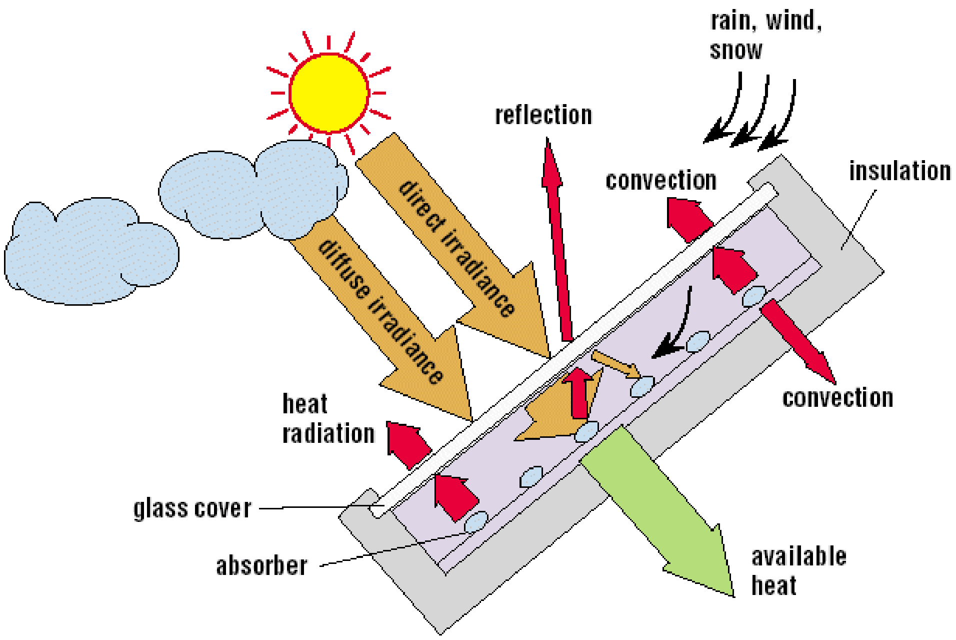


Fig. 2.6 Solar energy collector

Radiated heat energy from the sun can be utilized for both domestic and commercial purposes such as heating of water, distillation of water, refrigeration, drying, power generation, etc. For power generation there are mainly two technologies - (1) Solar Thermal and (2) Solar Photo Voltaic (PV).

Solar Thermal heat energy generate steam which runs turbine to generate power. Solar PV is more advanced technology which directly converts sunlight into electricity without using generators or any moving devices.. Solar PV power generation system is shown in fig 2.6.

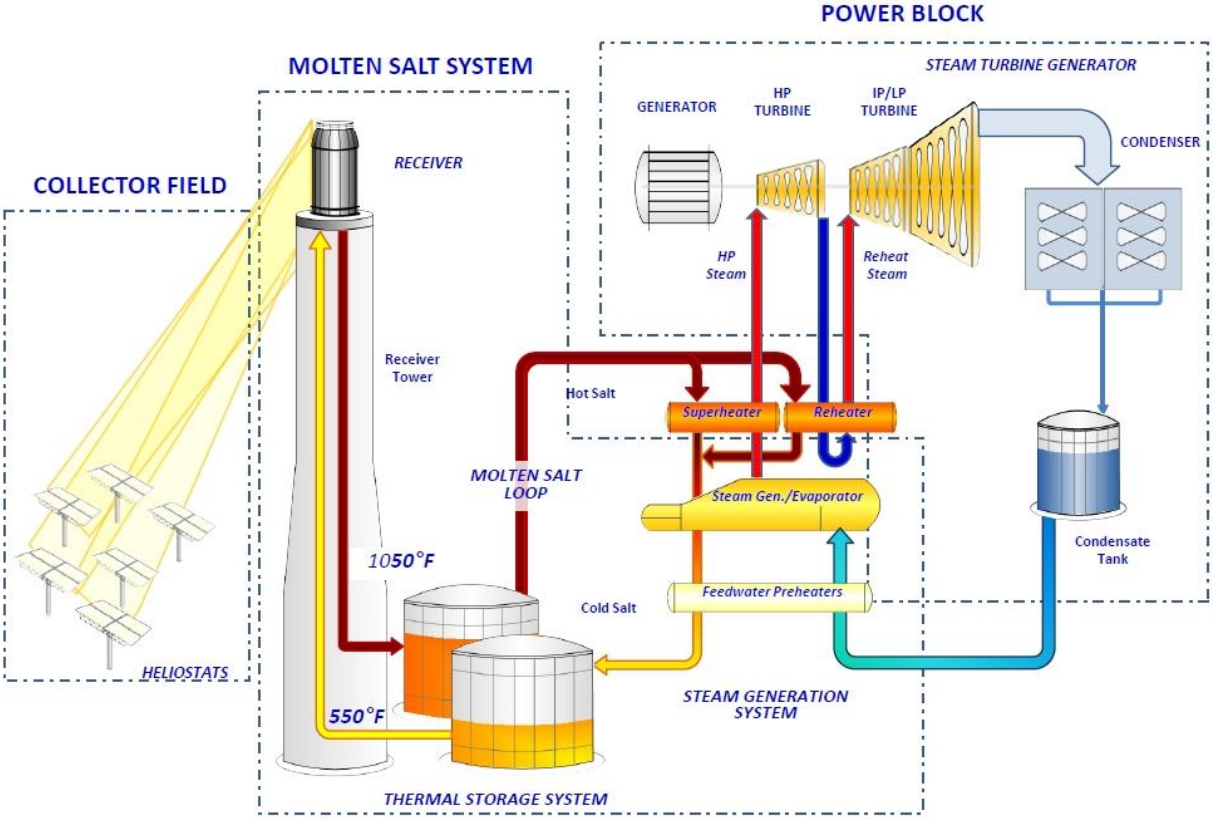


Fig. 2.7 Solar generation system

Energy from fossil Fuels:

There are three major forms of fossil fuels: coal, oil and natural gas. All three were formed many hundreds of millions of years ago before the time of the dinosaurs - hence the name fossil fuels.

Classification of Fuels:

There two ways the classify the fuels

(a) Natural and Artificial.
(b) Solid, liquid and gaseous.

(a) **Natural Fuel: -** Fuel that occur in nature. It is also known as primary fuel.
(b) **Artificial Fuel:** - They are prepared fuels. They are also known as secondary fuels.

Solid Fuels: -

Wood: - It is most commonly used and easily available natural fuel. In India, wood is used in almost all villages and towns as fuel. It ignites easily (approx. at 250°C) and so it is used for igniting other fuels.

Peat: - It is a mixture of water and decayed vegetable matter. It is the first stage in the formation of coal from wood. It contains large amount of moisture. It is dried for about 1 to 2 months before it is put to use. In Europe it is used as a domestic fuel. All other varieties of coal are derived from peat. It has the lowest calorific value.

Table 2.1 Types of Fuels

Type of Fuel	Natural (Primary)	Prepared (Secondary)
Solid	Wood	Coke
	Peat	Charcoal
	Lignite	Briquetted coal
		Pulverized coal
Liquid	Petroleum	Gasoline
		Kerosene
		Fuel oil
		Alcohol
		Benzol
		Shale oil
	Natural gas	Petroleum gas
Gaseous		Producer gas
		Coal gas
		Coke-oven gas
		Blast furnace gas
		Sewer gas

Lignite: - The formation of lignite is next to peat. Its color is brown. Hence it is also known as brown coal. The moisture content varies from 20 to 60%. It is low grade fuel. There are large deposits of lignite in Kashmir, Neyvelli and Rajasthan.

Bituminous Coal: It is the -next stage in development. It is shining black in appearance. It is easier to ignite. It burns with a long yellow and smoky flame. In India, coal reserves are located in Bihar, Bengal, M. P. and Orissa.

Anthracite Coal: - It is transformed from Bituminous coal. It is hard, brittle, and lustrous in appearance. It burns without flame or smoke. It is difficult to ignite. It burns without smell.

Amongst natural coal, this coal has minimum ash, Sulphur, volatile matter and moisture. It has the highest calorific value and hence very suitable for steam generation. In India, this coal reserves are found in Kashmir and Eastern Himalayas.

Artificial or Prepared Fuels

(a) Wood Charcoal: - It is obtained by destructive distillation of wood. During the process the volatile matter and water are expelled.

(b) Coke: - Coke is produced by removing the volatile matter from bituminous coal. It is hard, brittle and porous. It consist of carbon, mineral matter with 2% Sulphur and small quantities of hydrogen, nitrogen and phosphorus. It is smokeless and clear fuel. It can be produced by several processes. It is not used for steam raising but is used in gas producers.

(c) Briquetted Coal: - It consists of 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 of coal.

(d) Pulverized coal: - Coal when crushed to powder is called pulverized coal. The fineness is adjusted so that during combustion it floats. Thus there is better contact between air and fuel. Hence the combustion efficiency is very high. By this method, rough fuels can be used for steam raising in boilers. The advantages of this method are flexibility of control, complete combustion with less excess air and high flame temperature.

Liquid Fuels: -

The liquid fuels are classified according to mode of procurement as -

1) Natural or Crude oils
2) Artificial or manufactured oil.

Table 2.2 Liquid Fuel classification

Natural oils (Distilled)	Distilled artificial oils
Petrol	Coal-tar
Benzene	Tar-oil
Diesel	Shale-oil
Other light oils	Natural gas oil
Like kerosene	

Petroleum: - It is the lightest and most volatile liquid fuel. It is chiefly used for light petrol engine. Petrol comes out at 65°C to 220°C by distillation of crude oil. It is known as gasoline. In India the main sources of petroleum are Assam and Gujarat.

Kerosene: - It is also known as paraffin oil. Kerosene distills at 220°C to 345°C. Heavier and less volatile than petrol. It is used for heating and lighting purposes.

Diesel oil: - The liquid fuels distilled after petroleum and Kerosene is Diesel oil. Diesel oil may be obtained by straight distillation, by cracking or by blending several oils. Diesel Engines are the main users of this oil. It is also known as heavy fuel oils. It is also used in oil-fired boilers. They are distilled at temperature 345°C to 470°C

Tar: - It is an important by product obtained from the manufacture of coal gas. Redistilled, important fuel like benzene (C_6H_6) is produced. Benzene is less liable detonation than standard petrol.

Alcohol: - It is formed by fermentation of vegetable matter. It is an artificial liquid fuel. Its cost is higher than petrol. The energy content of Alcohol is lower than it is mainly industrial fuel and practically not used.

The advantages and disadvantages of liquid fuels over solid fuels:

Advantages:-

1) Require less space for storage.
2) Higher calorific value.
3) Easy handling and transportation.
4) Better control of consumption by using valves or a grates or less number of burners as required.
5) Better cleanliness and-freedom from dust.

6) Practically no ashes.
7) Non-corrosion of boiler plates.
8) Higher efficiency.

Disadvantages: -

1) Higher cost.
2) Greater risk of fire.
3) Costly containers are required for storage and transport

Gaseous Fuels: -

Most hydrocarbons in petroleum deposits occur naturally as a liquid but a few exist in gaseous state at atmospheric temperature. Methane is the most common natural gas. They can also be manufactured by heating coal. They are also obtained as a byproduct as in the case of blast furnace.

Coal Gas: - It mainly consists of hydrogen carbon monoxide and hydro-carbons. It is prepared by carbonization of coal. It is also known as town gas.

Coke-Oven gas: - It is obtained during the production of coke by heating the bituminous coal. The volatile content of coal is driven off by heating.

Blast furnace gas: - This is a by-product in the production of pig iron in the blast furnace. The gas leaving the blast furnace has a high dust content. The proportion of dust varies with the operation of blast furnace. Its heating value is comparatively law. Before using it as a fuel the dust be removed by dust catchers and washing operation. It is used as a fuel for metallurgical furnaces.

Producer gas: - When coal, coke or peat are burnt with insufficient quantity of air, producer gas is produced from partial oxidation. It is produced in specially designed retorts. It has got a very low calorific value because of nitrogen as its principle constituent and nitrogen is an inert gas. It is used in steel industry for firing open hearth furnace.

Water gas: - It is a mixture of hydrogen and carbon monoxide. It is made by passing steam over incandescent coke. As it burns with a blue flame, it is also known as blue water gas. It contains no unsaturated hydrocarbon. In order to use this gas for a domestic lighting, unsaturated hydrocarbons are added.

Sewer Gas: - It is obtained from Sewage disposal vats in which fermentation and decay occur. It mainly consists of CH_4. It is usually collected at large disposal plants. It works as a fuel for gas engines used for driving pumps of the plant and agitators.

Liquefied Petroleum Gas (LPG):

It is a product of petroleum gases. It consists principally of propane and butane. This must be stored under pressure to keep it in liquid state. At atmospheric pressure and above freezing temperature, these substances would be in a gas form. Large quantities of propane and butane are now available from gas and petroleum industries.

They are often used as fuel for tractors, trucks, buses and also as domestic fuel. Because of low boiling point (-44°C to 0°C) and high vapour pressure of these gases, their handling as liquid in pressurized cylinder is necessary Owing to demand from industry for butane derivatives, LPG sold now as fuel is made up largely of propane.

LPG leaves little or no engine deposit in cylinder when it bums and used in engines. LPG used in IC engines must have high compression ratio of above 10. This is necessary because of its high octane rating. The calorific value of LPG is about 45,360 kJ/kg.

Liquefied natural Gas (LNG):

It is a product of natural gas. This gas consists primarily of methane. Its properties are those of liquid methane slightly modified by minor constituents. The main source of natural gas is oil well and earth. This gas contains about 85% to 95% methane. One property which differentiates liquefied natural gas (LNG) from liquefied petroleum (LPG) is the low critical temperature of about - 73°C.

NG is contained in coal reserves in tight sands and is trapped in geopressured zones deep within the earth. LNG is obtained when natural gas (NG) is placed under very high pressure. When the high pressure is released, LNG converts to NG.

Because of low critical temperature of NG, it cannot be liquefied at ordinary temperature. NG must be cooled to cryogenic (ultra low) temperatures to be liquefied. It must be stored in well insulated container in order to hold it in liquid form. The pressure to be maintained is between 50 to 60 bars, for automobile, pressure of 220 - 250 bar is required.

For automobile, this NG is known CNG (compressed natural gas) and the one used for domestic purpose and industrial use is supplied in pipe and hence known as piped natural gas (PNG). The high pressure is suitably reduced in milibar based ort where NG is supplied for use. The calorific value of NG is 40.7 - 41.2 MJ/m^3. The main difference in CNG and LNG is in liquid form only. When it is burned there is no pollutants hence it is an ideal source of energy.

Compressed Natural Gas (CNG):

The main components of natural is methane (90%), ethane (4%), and propane (1.7%) with other contaminants with low concentrations. The compressed natural gas (CNG is made by compressing it to less than 1% of its volume at standard atmosphere pre' sure. It is stored and distributed in robust containers (usually cylindrical or spherical) at a normal pressure of 200 bar to 220 bar (20 MPa to 22 MPa). Due to its anti-knock property, CNG is safely used in I.C. Engines with higher compression ratio. CNG is nontoxic and lighter than air, so when leakage occurs it quickly disappears.

It has calorific value about 40700 kJ/cu.m to 41200 kJ/cu.m. As it has relatively high thermal efficiency and being less pollutant, it is now being used as a regular fuel for auto rickshaws, cars and busses as a substitute for petrol or diesel.

It is used as a dual fuel in automobile engines which work on both gas and diesel or petrol. Number of old cars and busses are conveniently converted from petrol/diesel to CNG with required modifications in the engine.

CNG is stored in a specially designed cylinders at a pressure of about 200 bars and 60 liters capacity which are suitable for cars.

Bio-Fuel:

The material of plants and animals is called biomass. It is organic, carbon based material that reacts with oxygen in combustion and natural metabolic process to release heat.

The material may be transformed by chemical and biological processes to produce intermediate biofuels, such as methane gas, ethanol liquid or charcoal solid.

The initial energy of the biomass - oxygen system is captured from solar radiation in photosynthesis. When released in combustion the biofuel energy is dissipated.

The industrial use of biomass energy may be large, say about 40% of national commercial supplies. In some sugarcane producing countries crop residues are burnt for process heat.

The domestic use of biofuel in wood, dung and plant residues for heating is of prime importance for about 50% of the world's population supplying total about 300 GW.

If biomass is to be considered renewable, growth must at least keep pace with use. It is disastrous that forest and fire wood consumption is significantly out pacing growth in ever increasing areas of the world.

The main dangers of extensive use of biomass fuel are deforestations, soil erosion and displacement of food crops by fuel crops.

Bio - gas described below is one of the method of producing Bio - fuel. This gas is produced by using sources like forest logging, Timber mill residues, Grain crops, sugarcane mill, crushed cane, residue, animal wastes, Municipal sewage etc. Soybean is used to produce bio-diesel.

Bio Gas:

A bio-fuel or gas unit is an asset to a farming family. It produces good manure (Fertilizer) and clean fuel. It also improves sanitation. The animal waste, vegetable waster for decomposition fermentation and from which a combustible by - product gas is produced known as bio-gas. For farmers, better quality of fertilizer is available.

Generally speeking cattle dung, when burnt as fuel, it is lost to the soil while a biogas plant doubles the availability of organic fertilizer, which is better in terms of both quantity and quality.

Presently agricultural residues and dung cakes are used as cooking fuel in rural areas. This will result in smoky kitchens which are harmful to the health of women and children. The collection and storage of these materials is problematic during rainy season.

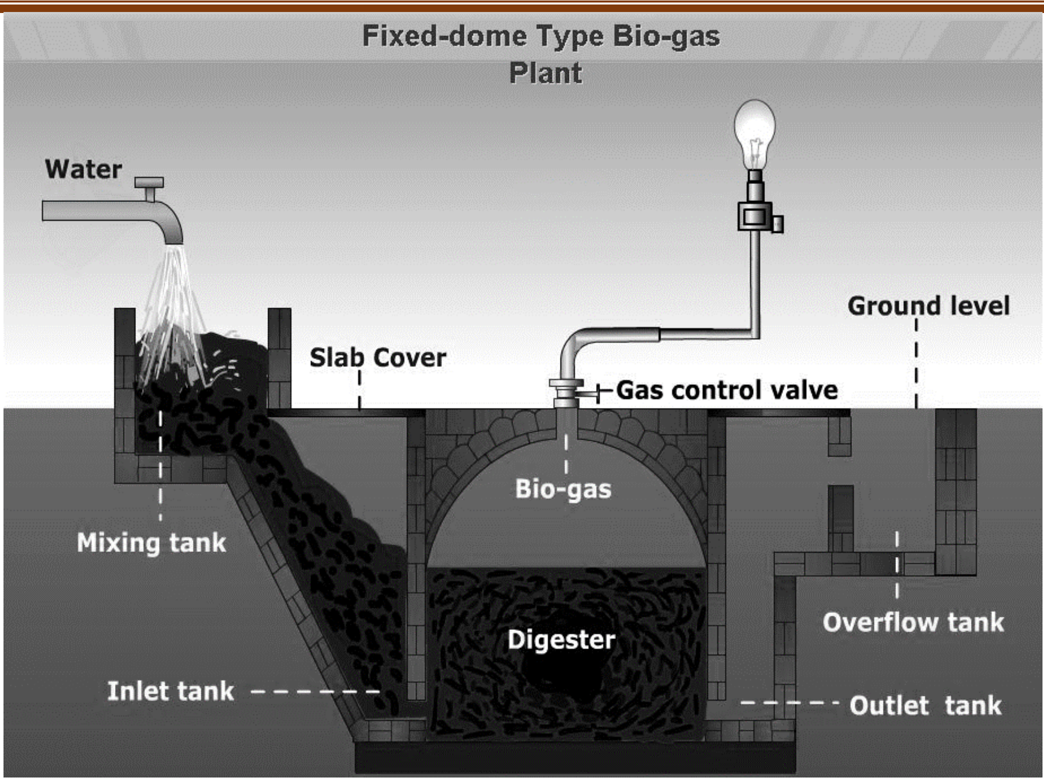


Fig. 2.8 Bio-gas plant

It is an efficient fuel for cooling purposes. Children can read under biogas illumination during erratic supply of electricity or shortage of kerosene.

Bio-gas units are effective means for the sanitary disposal of human excreta. If dry latrines, attached with a bio-gas units will eliminate the practice of carrying head loads of night-soil. By using Bio - gas plant for night-soil, most of the disease causing organisms are killed, and the digested slurry remains free from smell. This will also eliminate mosquitoes and flies. This will improve sanitation.

Bio-gas does not cause any smoke in the kitchen and also reduce eye diseases. Bio-gas being clean fuel does not cause air pollution. It is considered better fuel than CNG and LPG since it does not contain Sulphur. Sulphur when burnt with air produce SO_2 which is responsible for many lung diseases.

The danger of explosion of bio-gas is less as it contains CO_2 which acts as a fire extinguisher.

The fig shows a double chamber bio-gas plant. The low temperature in winter may reduce the production of gas. The calorific value of bio - gas is about 25 kJ/kg, the gases produced during digestion, bubble up through the slurry and get collected in the collecting tank provided at the top.

The collected gas can be taken out through a valve and pipe located on the top of the tank. The collecting tank can move up or down depending upon the gas pressure; the concentrated slurry thrown out from the bottom.

Hydrogen gas:

Hydrogen gas is a volatile gas at room temperature, but when chilled to - 253° C and compressed, it makes the perfect fuel. Hydrogen's greatest feature as a fuel is that it causes no pollution.

A hydrogen fuel cell works by combining hydrogen gas with atmospheric oxygen. The resulting chemical reaction generates electric power and the only by product it produces is clean water. At a time when there is real concern about global warming due to carbon emissions, this makes hydrogen fuel a desirable technology and perhaps the most feasible alternative to petrol and gasoline.

Hydrogen gas as a fuel is an important secondary fuel.

Advantages:

1) When it is combined with oxygen in air it produces water. While fossil fuels produce pollutants.
2) Its calorific value/unit mass is three times higher than gasoline.

Disadvantages:

1) It burns readily when come in contact with oxygen in air.
2) Its specific volume in gaseous form is very large.
3) If hydrogen is to be stored in liquid form it would need very low temperature and hence cryogenic storage vessel is needed.
4) This gas is produced by steam reforming of natural gas. This process is endothermic process.
5) At temperature between 700°C to 1100°C, steam reacts with methane in natural gas and product is carbon monoxide and hydrogen. The energy consumed in this cabon-monoxide and hydrogen. The energy consumed in this method is more. Tito other 1 methods are in progress to produce hydrogen gas.
6) This gas can be used in fuel cells and to run motor vehicles.

Advantages and disadvantages of Gaseous Fuels:
Advantages:

1) Better control of combustion.
2) Much less air is required for complete combustion.
3) They are directly used in I.C. Engines.
4) They are free from solid and liquid impurities.
5) They do not produce ash or smoke.
6) No problem of storage if the supply is available from public supply line.
7) Distribution is easy with the help of pipe lines.

Disadvantages:

1) They are readily inflammable
2) They require large storage capacity if public supply is not available.

Combustion

It is the process of chemical combination of Carbon, Hydrogen and Sulphur with Oxygen which is supplied by the air. The temperature at which the fuel is bur continuously without further supply of heat is known as ignition temperature.

Anybody can cause fuels to bum but it takes a good deal of skill to bum the fuel efficiently i.e. without waste. It is required to ensure that fuel is burnt efficiently because -

(a) Fuel is expensive and inefficient combustion means expensive wastage.

(b) Inefficient combustion results in pollution of the atmosphere with noxious gases.

Calorific Values

The calorific value or the heat value of a solid, liquid or gaseous fuel defined as the number of heat units developed by the complete combustion of unit normal volume of a given fuel.

It may be expressed as kJ/kg for solid and liquid and kJ/m^3 for gases.

Sometimes it also expressed by the name calorific power.

The following are the two types of the calorific values of fuels:

(a) Gross or Higher calorific value

(b) Net or Lower Calorific Value.

Fuels which contain hydrogen has two calorific values, the higher and the lower. It lower calorific value is the heat liberated per kg of fuel after deducting the heat necessary to vaporize the steam formed from hydrogen.

Gross or Higher Calorific Value (H.C.V.):

All fuels usually contain some percentage of hydrogen. Heat is produced when a given quantity of a fuel is burnt along with some hot flue gases. The water takes up some of the heat evolved and it is converted into steam.

When the heat taken away by the hot flue gases and the steam is taken into consideration that is, if the heat is recovered from the flue gases and steam is condensed back to water at room temperature usually taken at 15°C, then the total heat produced / kg is known as gross or higher calorific value of fuel.

Global Warming:

Global warming is the term used to describe a gradual increase in the average temperature of the Earth's atmosphere and its oceans, a change that is believed to be When the heat absorbed or carried away by the products of combustion is not recovered (which is the case in actual practice) and the steam formed during combustion is not condensed, then the amount of heat obtained / kg of fuel is lower calorific value.

If the higher calorific value is known, then the lower calorific value may be obtained by subtracting the amount of heat carried away by products of combustion (especially steam) from H.C.V.

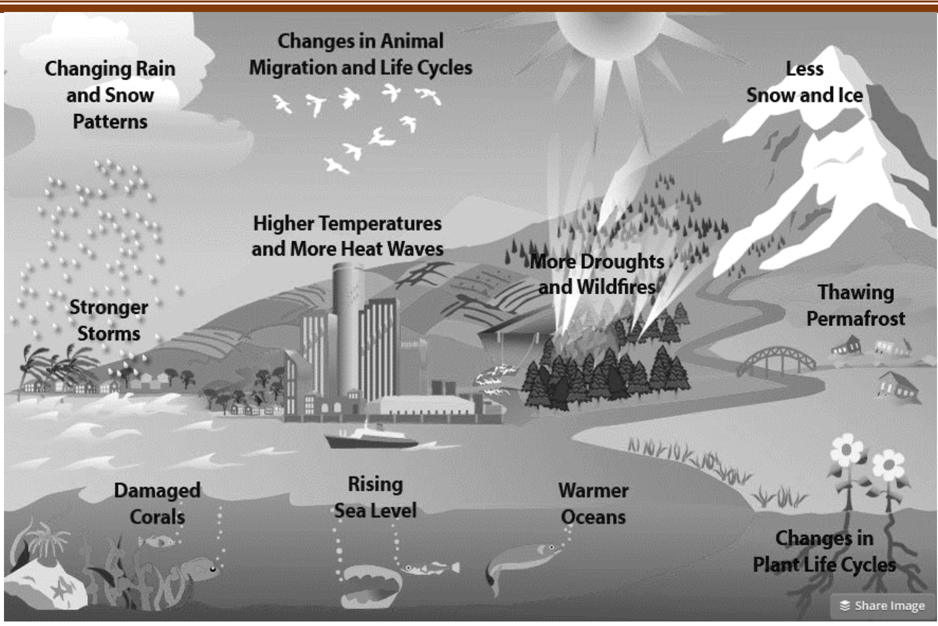


Fig. 2.9 Global warming

Permanently changing the Earth's climate. Since the early 20th century, Earth's mean surface temperature has increased by about 0.8 °C, with about two-thirds of the increase occurring since 1980.

Causes of Global Warming:

Most Greenhouse gases are generated by mankind, Vehicles burning Fossil fuels and Deforestation. Global warming is caused by excessive quantities of greenhouse gases emitted into Earth's near-surface atmosphere. Greenhouse gases are both man-mad and occur naturally, and include a number of gases, including: carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and water vapor.

Indicators of Global warming:

There are ten indicators which represent the global warming seven indicators are raising and three indicators are declining.

Rising Indicators:

1. Air temperature over land.
2. Sea-surface temperature.
3. Air temperature over oceans.
4. Sea level.
5. Ocean heat.
6. Humidity

Troposphere temperature in the "active-weather" layer of the atmosphere closest to the Earth's surface.

Declining Indicators:

1. Arctic sea
2. Ice glaciers
3. Spring snow cover.

Impacts of Global warming:

The impacts of global warming are dangerous weather patterns, unstable agriculture and economy and it encourages the spreading of diseases such as malaria which is transmitted by mosquitoes preferably. Other impacts are it changes ecosystems and it may cause frequent flooding and droughts due to changes of weather patterns.

Limiting the effects of Global Warming:

Mitigation of global warming generally involves reductions in human (anthropogenic emissions of greenhouse gases (GHGs). Mitigation may also be achieved by increaser the capacity of carbon sinks, e.g., through reforestation.

By building dikes in response to sea level rise. Examples of mitigation include switching to low-carbon energy sources, such as renewable and nuclear energy, and expanding forests and other “sinks” to remove greater amounts of carbon dioxide from the atmosphere.

Energy efficiency can also play a major for example, through improving the insulation of buildings. The main international treaty on climate change is the United Nations Framework Convention on Climate change (UNFCCC). In 2010, Parties to the UNFCCC agreed that future global warming should be limited to below 2.0 °C relative to the pre-industrial level.

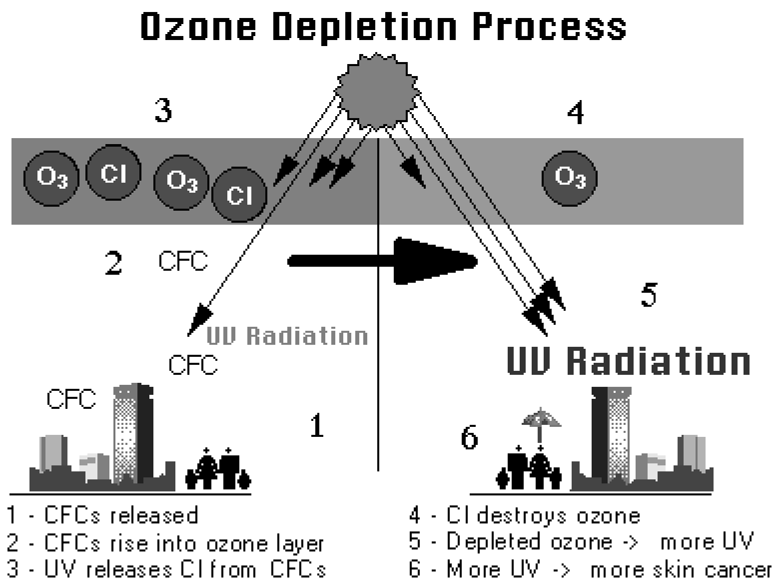


Fig. 2.10 Ozone depletion process

The Ozone layer is a belt of naturally occurring Ozone gas that sits 15 to 30 kilometers above Earth and serves as a shield from the harmful ultraviolet B radiation emitted by the sun. Ozone is a highly reactive molecule that contains three oxygen atoms.

It is constantly being formed and broken down in the high atmosphere, 10 to 50 kilometers above Earth, in the region called the stratosphere.

Today, there is widespread concern that the ozone layer is deteriorating due to the release of pollution containing the chemicals chlorine and bromine. Such deterioration allows large amounts of ultraviolet B rays to reach Earth.

Which can cause skin cancer and cataracts in humans and harm animals as well. Every chlorine atom can destroy up to 100000 ozone molecules.

The Main Ozone depleting substances are

1) Chlorofluorocarbon (CFC's): It is used as refrigerant in refrigerators, freezers and air conditioners in buildings and vehicles.
2) Bromofluorocarbons (Halons): It is used in some fire extinguishers where materials and equipment's would be destroyed by water or other fire extinguisher chemicals.
3) Chlorocarbons: Methyl chloroform, Carbon tetrachloride used in some aerosols, cold cleaning, solvents and some fire extinguishers.

Effects of Ozone Depletion on Humans and on the Earth

The health effect on humans from ozone depletion is widely varied. Since ozone is the earths, protection against ultraviolet (UV) radiation, a reduction in the ozone layer causes more UV-B wavelengths to reach the surface of the earth. UV-B wavelengths damage both proteins and DNA.

The UV-B wavelengths cause skin cancer, sunburn, aging and wrinkling of skin, cataracts, and blindness. The Environmental Protection Agency (EPA) estimates that each 1 percent drop in ozone levels will yield a 2 percent increase in UV-B wavelengths. This will result in a 3 to 6 percent rise in the incidence of skin cancer.

The EPA also estimates that there could be an additional 200000 deaths from skin cancer in the United States over the next 50 years due to the increase in ozone depletion.

Ozone Layer Protection:

Following precautionary actions can play the important role for protecting ozone layer.

1) Ending the production of ozone-depleting substances.
2) Ensuring that refrigerants and halon fire extinguishing agents are recycled properly.
3) Identifying safe and effective alternatives to ozone-depleting substances.
4) Banning the release of ozone-depleting refrigerants during the service, maintenance, and disposal of air conditioners and other refrigeration equipment.
5) Requiring that manufacturers label products either containing or made with the most harmful ozone depleting substances.

Definitions

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.

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."

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

$$\therefore pV = C \qquad (3.1)$$

Where,

p = Absolute pressure of gas in *Pa,*

V = Volume occupied by the gas in m^3

C = Constant of proportionality.

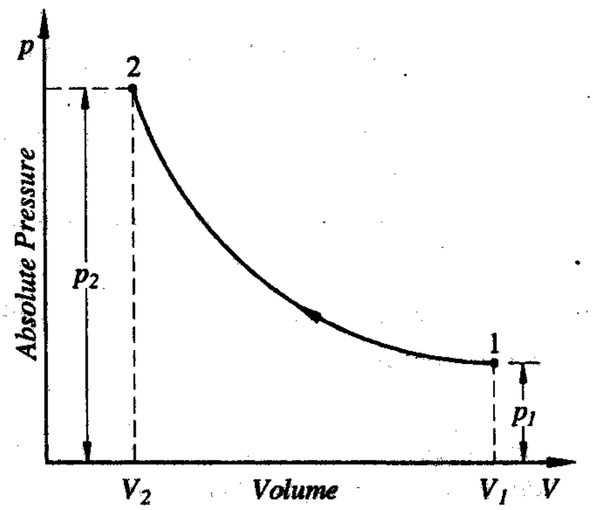


Fig. 3.1 Boyle's law

In fig. 3.1, 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,

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

$$\therefore p_1\,V_1 = p_2\,V_2 \tag{3.2}$$

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."

$$V \propto T$$

$$\therefore V = C\,T \quad \text{OR} \quad \frac{V}{T} = C \quad (3.3)$$

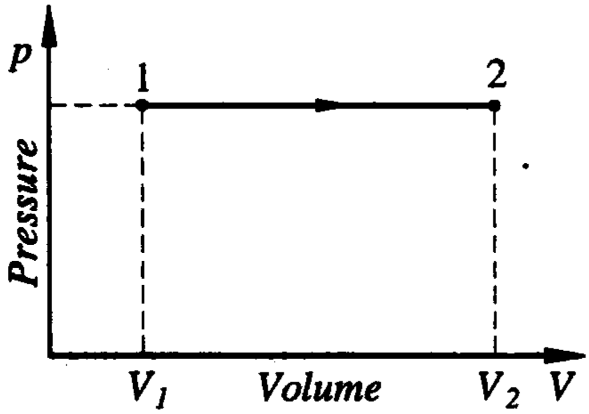


Fig 3.2 Charles law

where ,

V = Volume occupied by a given mass of gas in m^3

T = Absolute temperature of the gas in K.

C = Constant of proportionality

Referring to fig. 3.2,

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

∴ By using equation 3.3

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

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \tag{3.4}$$

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".

$$\therefore p \propto T$$

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

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

$$\therefore \frac{p_1}{p_2} = \frac{T_1}{T_2} \qquad (3.5)$$

3. Combined gas law:

In practice, pressure, volume and 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. 3.3) (i) Process 1-2 at constant pressure, and (ii) Process 2-3 at constant temperature.

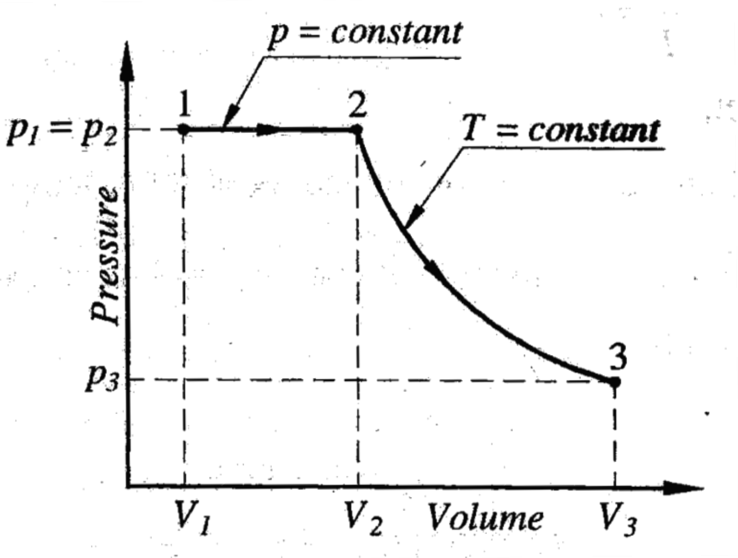


Fig. 3.3 Combined Gas law

For process 1-2,

Applying Charles law

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

And since $T_2 = T_3$, we may write

$$\frac{V_1}{T_1} = \frac{V_2}{T_3} \qquad (3.6)$$

For process 2-3,

Applying Boyle's law

$p_2V_2 = p_3V_3$ and since, $p_2 = p_1$

$$\therefore p_1 V_2 = p_3 V_3$$

$$\therefore V_2 = \frac{p_3 V_3}{p_1} \tag{3.7}$$

Substituting the value of V_2 from eq. (3.7) in eq. (3.6), we get

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

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

$$\therefore \frac{pV}{T} = \text{Constant} \tag{3.8}$$

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,

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

$$\therefore pV = mRT \tag{3.9}$$

Equation (3.9) is called equation of state for a perfect gas.

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

$$\therefore pv = RT$$

Where,

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

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,

1. Constant volume (Isochoric) process
2. Constant pressure (Isobaric) process

3. Constant Temperature (Isothermal) process
4. Adiabatic process
5. Polytropic 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.***

Fig. 3.4 shows the system and states before and after heat addition at constant volume.

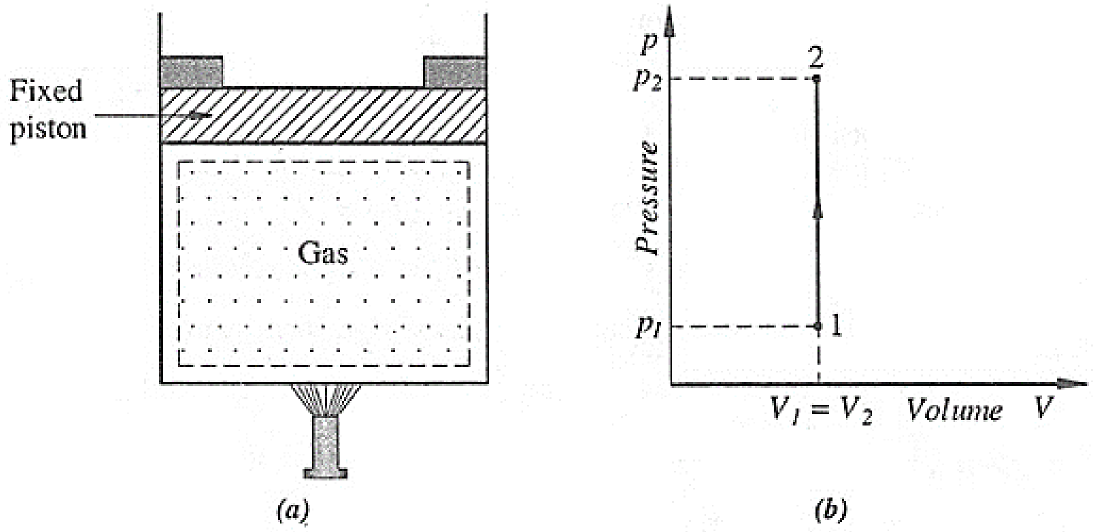


Fig. 3.4 Constant volume process

Work done during the process

We have,

Work done $= p\,dV$

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

Since the volume is constant, Change in volume $dV = 0$.

$\therefore$ workdone $\quad W = 0$

Relation between *p*, V and T:

We know that

$$\frac{pV}{T} = \text{Constant}$$

$$\therefore \frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

But $V_1 = V_2 = \text{constant}$

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

Change in internal energy:

We know that,

$$du = C_v(T_2 - T_1)$$

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

Thus, internal energy is a function of temperature alone.

Heat transferred:

According to first law of thermodynamics,

$$\delta Q = \delta W + dU$$

For constant volume process,

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

$$\therefore \delta \text{Q} = \text{dU} = mC_v(T_2 - T_1)$$

So, Heat transfer = Change in internal energy

Change in enthalpy:

As per definition of enthalpy, $H = U + pV$

For state 1 and 2,-

$$H_1 = U_1 + p_1V_1$$
$$H_2 = U_2 + p_2V_2$$

Change in enthalpy,

$$\begin{aligned} \Delta H &= H_2 - H_1 \\ &= \left(U_2 - U_1\right) + \left(p_2V_2 - p_1V_1\right) \qquad \left\{\because pV = mRT \ \& \ dU = mC_v(T_2 - T_1)\right\} \\ &= m\, C_v\left(T_2 - T_1\right) + mR\left(T_2 - T_1\right) \end{aligned}$$

But $R = C_p - C_v$

$$\therefore \Delta H = \text{m}\,\text{C}_\text{v}\left(\text{T}_2 - \text{T}_1\right) + \text{m}\,(\text{C}_\text{p} - \text{C}_\text{v})\,\left(\text{T}_2 - \text{T}_1\right)$$

$$\therefore \Delta H = \text{m}\,\text{C}_\text{p}\left(\text{T}_2 - \text{T}_1\right)$$

Constant Pressure Process (Isobaric Process)

In an isobaric process, the process of the gas remains constant.

Work done during the process

We have,

Work done = pdV . 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 as shown in fig. 3.5.

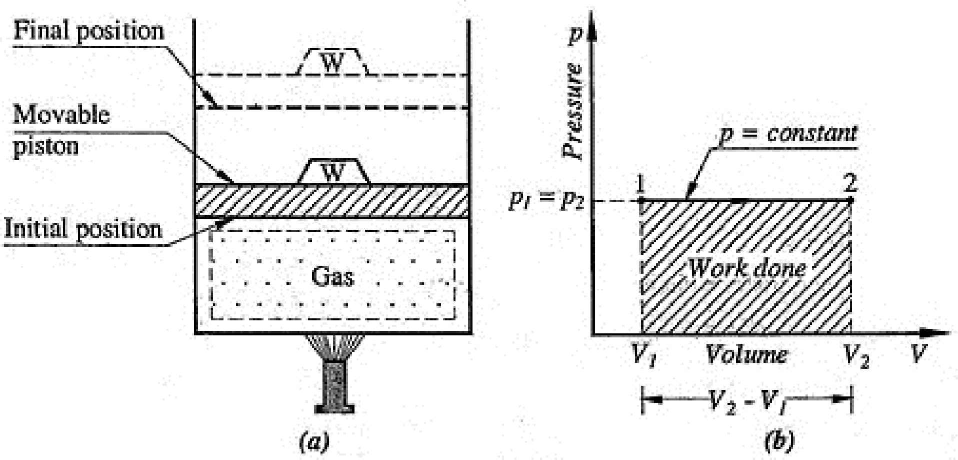


Figure 3.5 Constant pressure process

Relation between *p*, V and T:

We know that

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

But $p_1 = p_2 =$ Constant

$$\therefore \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

This is the equation of Charle's law.

Change in internal energy:

We know that,

$$du = m\,C_v\left(T_2 - T_1\right)$$

Heat transferred:

According to first law of thermodynamics,

$$\delta Q = \delta W + \mathrm{d}U$$

$$= p(V_2 - V_1) + mC_v(T_2 - T_1)$$

$$= m\,R\,(T_2 - T_1) + mC_v(T_2 - T_1) \quad (\because PV = mRT)$$

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

$$= m\,C_p(T_2 - T_1)$$

Change in enthalpy:

As per definition of enthalpy, $H = U + pV$

For state 1 and 2,

$$H_1 = U_1 + p_1V_1$$
$$H_2 = U_2 + p_2V_2$$

Change in enthalpy,

$$\Delta H = H_2 - H_1$$
$$= (U_2 - U_1) + (p_2V_2 - p_1V_1) \qquad \{\because pV = mRT \;\&\; dU = mC_v(T_2 - T_1)\}$$
$$= m\,C_v(T_2 - T_1) + mR(T_2 - T_1)$$

But $R = C_p - C_v$

$$\therefore \Delta H = \mathrm{m}\,\mathrm{C_v}(\mathrm{T_2} - \mathrm{T_1}) + \mathrm{m}\,(\mathrm{C_p} - \mathrm{C_v})\,(\mathrm{T_2} - \mathrm{T_1})$$

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

Constant Temperature Process (Isothermal Process)

In an 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.***

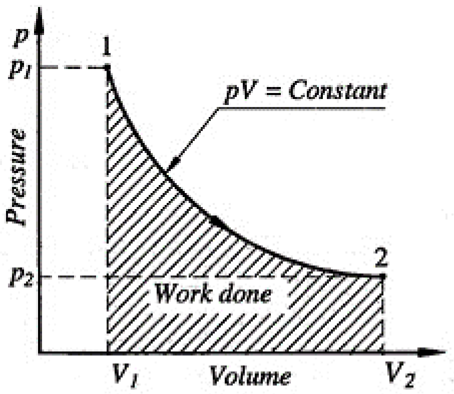


Figure 3.6 Isothermal Process

Work done during the process

Work done, W = Area below the curve

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

But $pV = p_1V_1 = C$

Hence, $p = \dfrac{C}{V}$

Substituting for p in the integral, we get,

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

Substituting for C, we get

Work done, $W = p_1V_1 \ln \dfrac{V_2}{V_1}$

$$= p_1V_1 \ln \mathrm{r}$$

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

But $p_1V_1 = mRT_1$ and $p_2V_2 = mRT_2$

Therefore,

Work done

$W = mRT_1 \log_e r = mRT_2 \log_e r$

Relation between *p*, V and T:

We know that

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

But $T_1 = T_2 = Constant$

$$\therefore p_1V_1 = p_2V_2$$

Change in internal energy:

We know that,

$$du \ = \ m \ C_v \left(T_2 - T_1\right)$$

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,

$$\delta Q = \delta W + \mathrm{d}U$$

But change in internal energy $dU = 0$.

So, $\delta Q \;=\; \delta W$

$$\therefore \text{Heat transfer, } \delta \mathrm{Q} \;= p_1 \mathrm{V}_1 \log_e \frac{V_2}{V_1} = p_1 \mathrm{V}_1 \log_e \frac{p_1}{p_2}$$

$$= mR\mathrm{T}_1 \log_e \frac{p_1}{p_2}$$

Change in enthalpy:

Change in enthalpy,

$$\Delta H = H_2 - H_1 = mC_p\left(T_2 - T_1\right)$$

But, $T_1 = T_2$.

So, $\Delta H \;=\; 0.$

Therefore in isothermal process there is no change in internal energy and enthalpy.

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***.

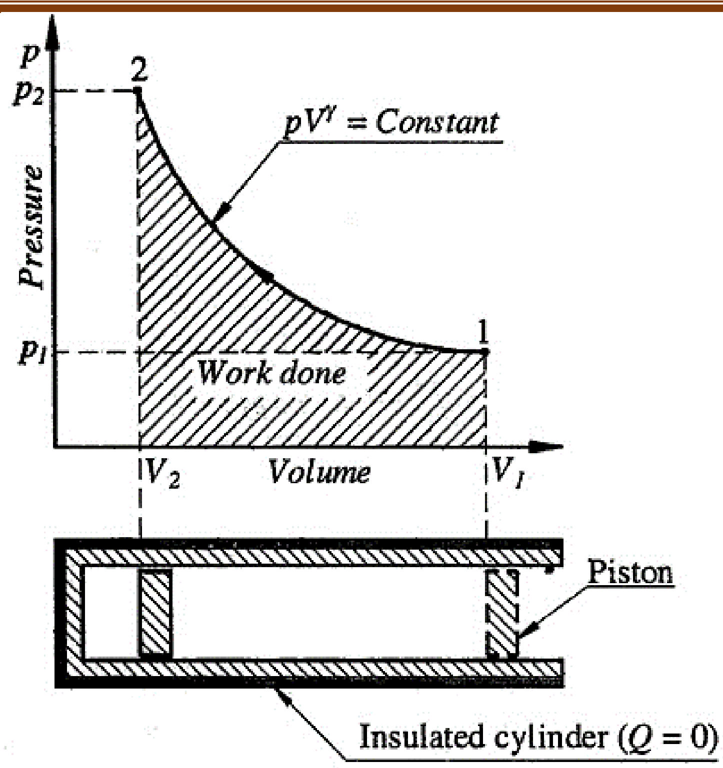


Fig. 3.7 Adiabatic Process

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, $\delta q = C_v dT + pdv$

For, adiabatic process $\delta q = 0$.

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

We have characteristic gas equation

$$pV = RT \qquad \text{(for unit mass)}$$

By differentiating this equation, we get

$$pdv + vdp = RdT \tag{3.10}$$

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

Substituting value of dT in equation 3.10,

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

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

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

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

Dividing above equation by $C_v \cdot p \cdot v$, 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

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

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

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

The above equation is known as **Poission's law.**

The adiabatic process on *p* – V diagram is represented in figure 3.7.

Work done during the process

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

For adiabatic process, $pV^{\gamma}=\text{constant}\ =C$

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

Substituting value of *p* in the integral, we get,

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

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

$$C=p_1\mathrm{V}_1^{\gamma}=p_2\mathrm{V}_2^{\gamma}$$

By substituting for C, we get

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

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

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

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

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

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

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

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

Relation between *p*, V and T:

We know that $pV^{\gamma} = \text{Constant}$ and $\dfrac{pV}{T} = Const$

So we have

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

$$\frac{p_2}{p_1} = \frac{V_1^{\gamma}}{V_2^{\gamma}} = \left(\frac{V_1}{V_2}\right)^{\gamma} \tag{3.11}$$

and $\dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2}$

$$\therefore \frac{T_2}{T_1} = \frac{p_2}{p_1} \times \frac{V_2}{V_1} \tag{3.12}$$

Put the value of eq. 3.11 in 3.12

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

$$\therefore \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \qquad (3.13)$$

From above equations, we get,

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

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

Change in internal energy:

$du = mC_v(T_2 - T_1)$

or

According to first law of thermodynamics,

$\delta Q = \delta W + dU$

But for adiabatic process $\delta Q = 0$. (No heat transfer)

Therefore, $dU = -\delta W$

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:

$dh = mC_p(T_2 - T_1)$

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 $pV^n = \text{Constant}$, where n is the index which can vary from $-\infty$ to $-\infty$. But generally index n lies within the range of 1 to 1.7. Thus the various thermodynamic processes discussed above are special cases of polytropic *process*.

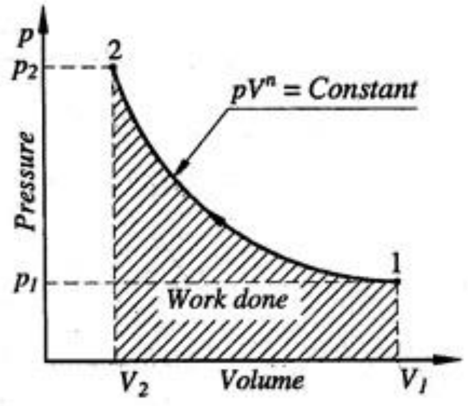


Fig. 3.8 Polytropic Process

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.

Relation between *p*, V and T:

$$\therefore p_1V_1^n = p_2V_2^n$$

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

Work done during the process

From adiabatic process,

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

So substituting γ = n in equation, we get

$$W = \frac{p_1V_1 - p_2V_2}{n-1} = \frac{mR(T_1 - T_2)}{n-1}$$

Change in internal energy:

$$dU = mC_v\left(T_2 - T_1\right)$$

Heat transferred:

By first law of thermodynamics

Heat supplied = Work done + Change in internal energy

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

Change in internal energy $= mC_v\left(T_2 - T_1\right)$

But, $C_v = \dfrac{R}{\gamma - 1}$,

So, heat transferred,

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

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

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

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

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

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

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

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

$$\therefore \text{Heat transferred}, \delta Q = \left(\frac{\gamma - n}{\gamma - 1}\right) \times \text{work done during polytropic process}$$

Change in enthalpy:

$$dh = mC_p\left(T_2 - T_1\right)$$

Special cases of Polytropic Process

(a) 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***.

(b) 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***.

(C) When *n = γ*

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

So, the process is an ***adiabatic process***.

(d) When n =∞,

$$p_1V_1^n = p_2V_2^n$$

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

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

When these values are plotted on *p* – V diagram as shown in fig. 3.9, it can be seen that they form a family of curves.

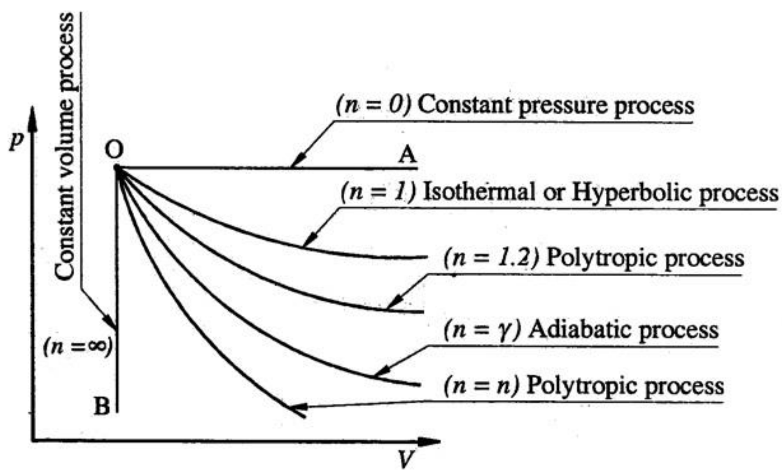


Fig. 3.9 Polytropic processes on p – V diagram

Properties of Steam

Difference between Steam and Gas:

Table 4.1 Comparison between Vapour and Gas

Sr. No.	Steam (Vapour)	Gas
1.	It is state of substance in which evaporation is not completed from its liquid state.	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.	It obeys all gas laws, hence it is perfect gas.
3.	When the steam is cooled it gets condensed.	It remains in gaseous state at moderate pressure and temperature.
4.	Specific volume of steam is less compared to gases.	Specific volume of gases is more compared to steam.

Steam Formation:

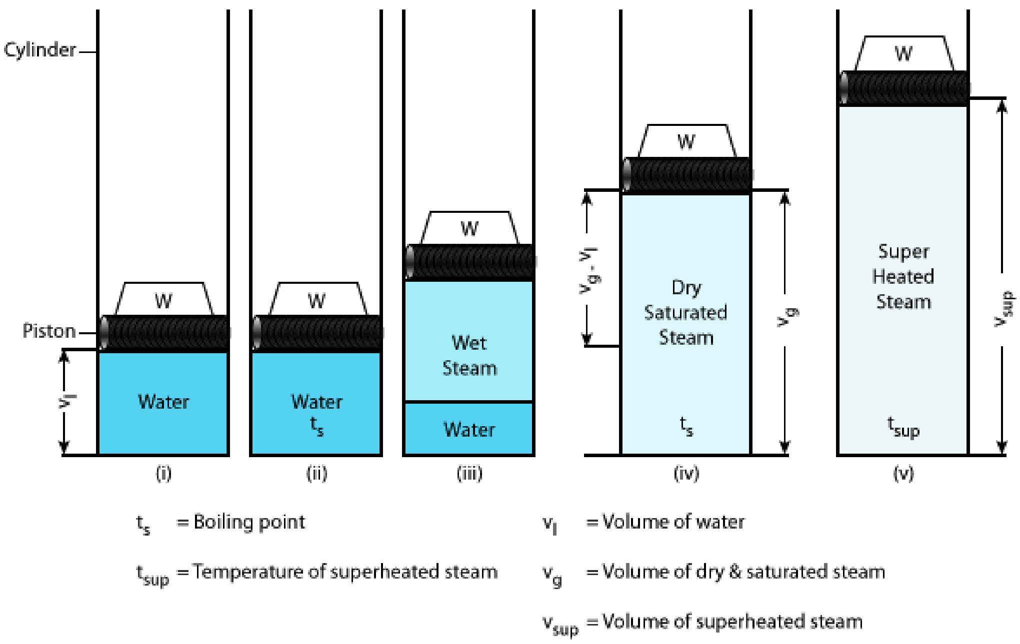


Fig. 4.1 Formation of steam

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).

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.

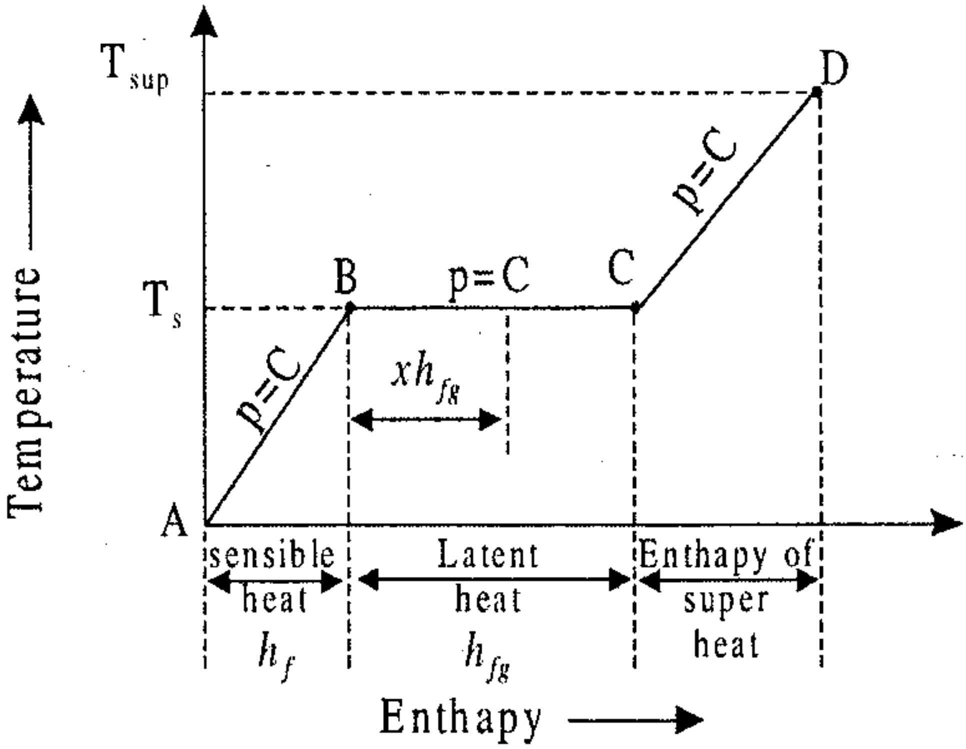


Fig. 4.1 Temperature – Enthalpy diagram

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**.

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.

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

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

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.

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.

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

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.

$$h = h_f + xh_{fg} \ kJ/kg$$

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($T_{\sup}$)

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

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 = $\left(T_{\sup} - T_{sat}\right)$

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 = $C_{ps}\left(T_{\sup} - T_{sat}\right)$

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.

$$v = xv_g + (1-x)v_f$$

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

$$\therefore v = xv_g \ \ \mathrm{m^3/kg}$$

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.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

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.

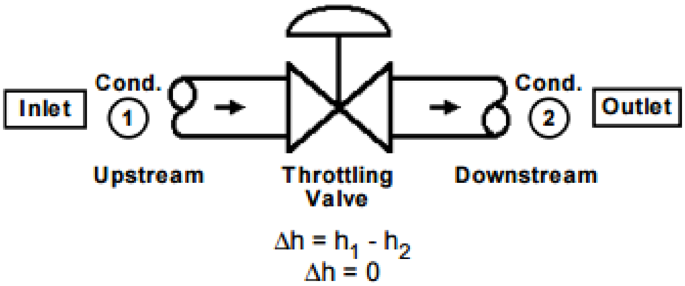


Fig. 4.3 Throttling Process

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, $\therefore w = 0$.

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

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 by calorimeter.

Various types of calorimeters used for measuring dryness fraction of steam are as follows:

1. Bucket or Barrel calorimeter
2. Separating calorimeter
3. Throttling calorimeter
4. Separating and throttling calorimeter

Bucket or Barrel Calorimeter

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.

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.

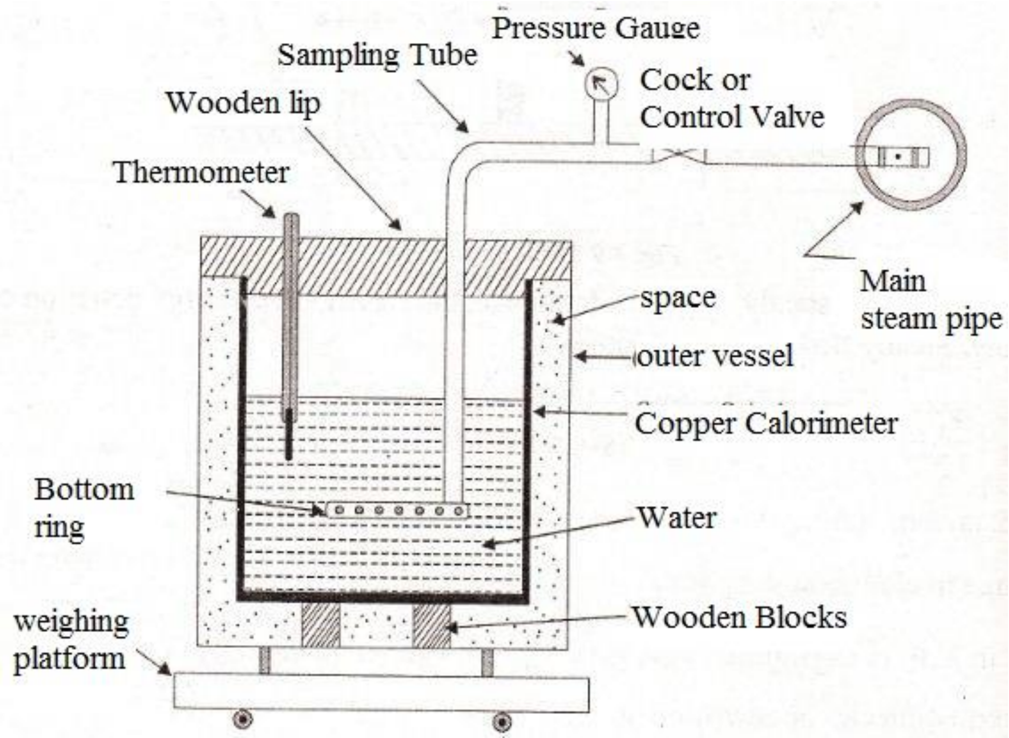


Fig. 4.4 Barrel or Bucket calorimeter

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.

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.

Separating Calorimeter

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.

Working

From main steam pipe certain quantity of steam is taken to the calorimeter through sampling tube.

This steam strike 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.

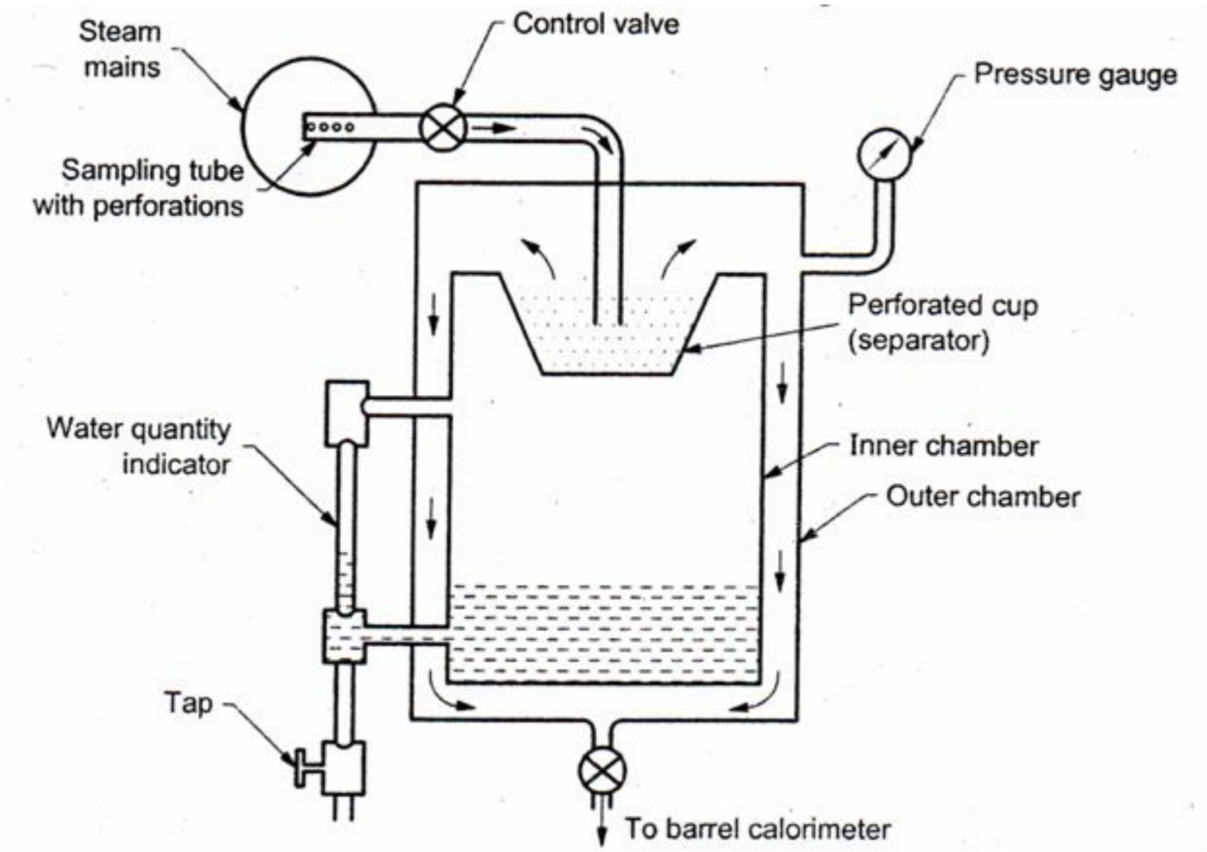


Fig. 4.5 Separating Calorimeter

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

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

Limitation

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

Throttling Calorimeter

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.

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 (p_1) and temperature after throttling is to be measured.

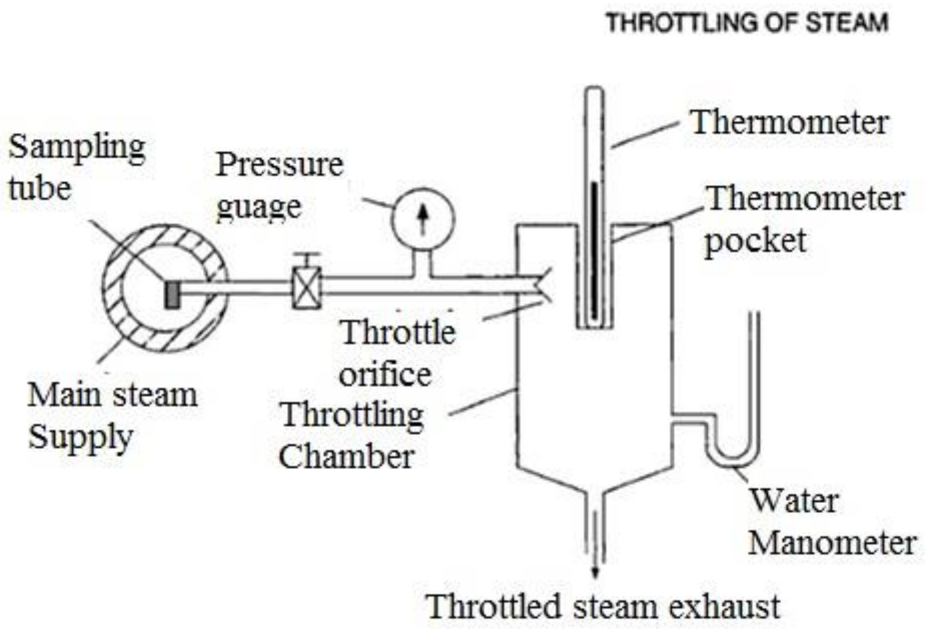


Fig. 4.6 Throttling Calorimeter

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

$$h_{f1} + X_1 h_{fg1} = h_{f2} + h_{fg2} + C_{ps}(T_{\sup_2} - T_{s_2})$$

$$= h_{g2} + C_{ps}(T_{\sup} - T_{s_2})$$

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

Let X_1 = unknown dryness fraction,

h_{f1} = enthalpy of saturated liquid at p_1, kJ/kg

h_{fg1} = latent heat of steam at p_1, kJ/kg

h_{f2} = sensible heat of water at p_2, kJ/kg

h_{fg2} = latent heat of steam at p_2, kJ/kg

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

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

T_{s2} = saturation temperature of steam at p_2

Limitation

This calorimeter is used when the dryness fraction is greater than 0.95.

To use this calorimeter condition of steam after throttling must be superheated.

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. Even load values of dryness fraction of steam can be easily determined.

Construction

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

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.

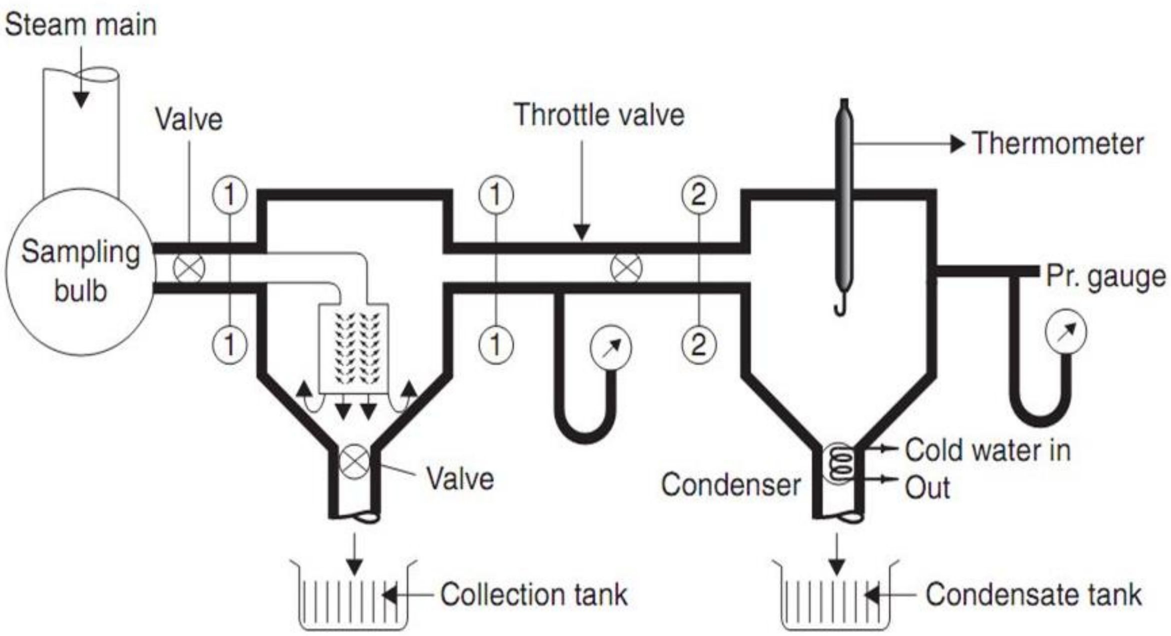


Fig. 4.7 Combined Separating and Throttling Calorimeter

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.

Equation for the mass of water can be written as,

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

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

Substituting the value of m / M+ m

$$\therefore (1-X)=(1-X_1)+(1-X_2)X_1$$
$$\therefore (1-X)=1-X_1+X_1-X_1X_2$$
$$\therefore X=X_1\cdot X_2$$

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.***

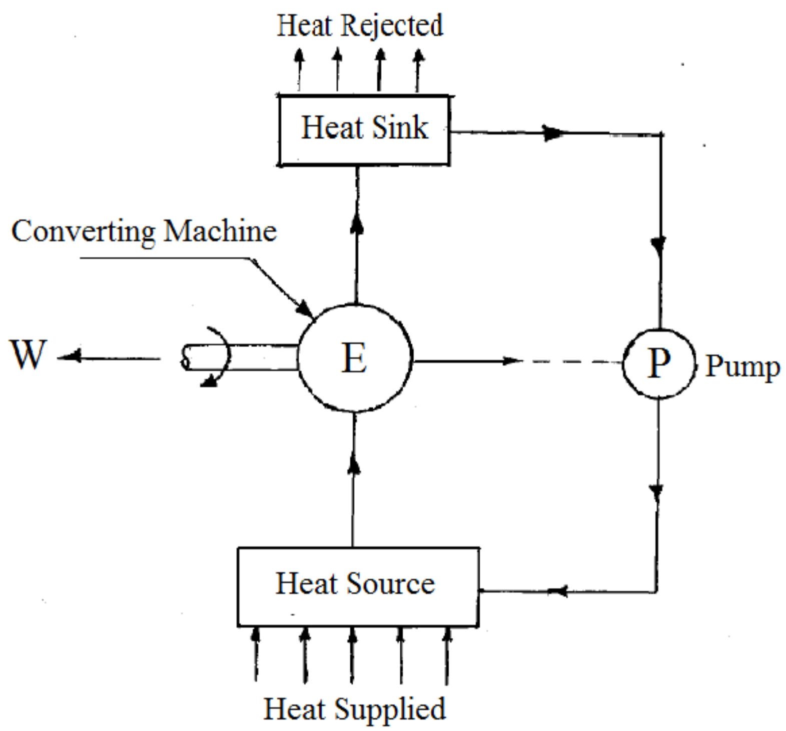


Fig. 5.1 Elementary Heat Engine

Fig. 5.1 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:

1) External combustion engine

2) 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.
6) The advantage of external combustion engines are:
7) Use of cheaper fuels.
8) High starting torque.
9) 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.

A Carnot cycle is a hypothetical cycle consisting four different processes: two reversible isothermal processes and two reversible adiabatic (isentropic) processes.

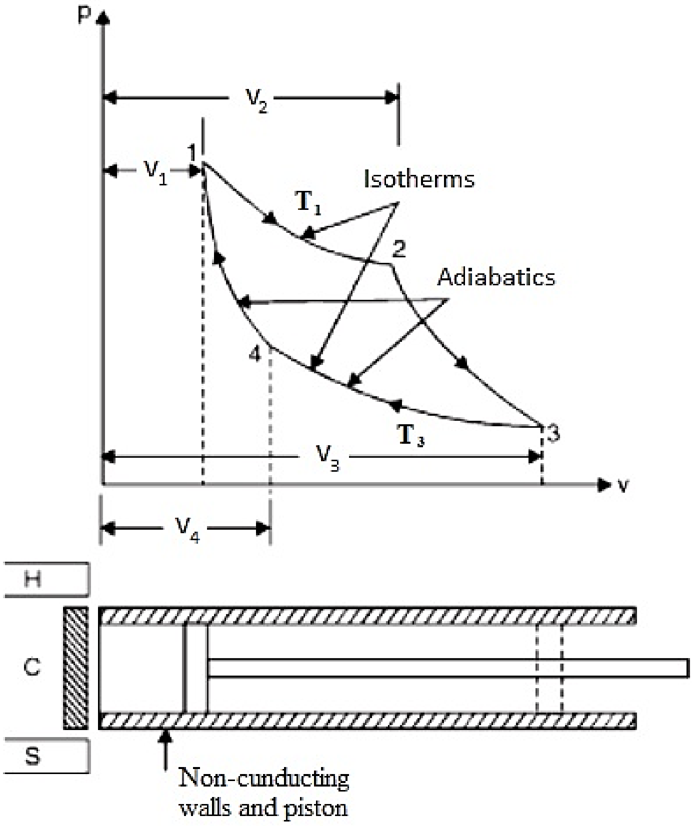
Assumptions made in the working of the Carnot cycle

a) Working fluid is a perfect gas.
b) Piston cylinder arrangement is weightless and does not produce friction during motion.
c) The walls of cylinder and piston are considered as perfectly insulated.
d) Compression and expansion are reversible.
e) The transfer of heat does not change the temperature of sources or sink.

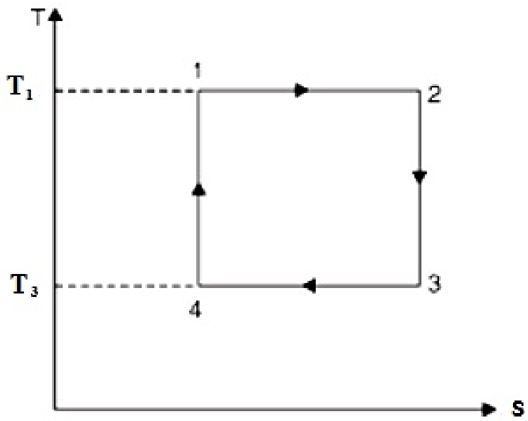
Fig. 5.2 shows essential elements for a Carnot cycle, P-v and T-S diagrams.

This cycle has the highest possible efficiency and it consists four simple operations as below:

1. Isothermal Expansion (1 – 2)
2. Isentropic Expansion (2 – 3)
3. Isothermal Compression (3 – 4)
4. Isentropic Compression (4 – 1)



(a) **Four stages of Carnot cycle**



(b) T-s **diagram**

Fig. 5.2 P-v, T-S and schematic diagram of Carnot gas power cycle

Isothermal expansion (1 – 2):-

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

Adiabatic expansion (2 – 3):-

Adiabatic cover (C) is brought in contact with the cylinder head. The cylinder becomes perfect insulator because of non-conducting walls and end. Hence no heat transfer takes place. The fluid expands adiabatically and reversibly. The temperature falls from T_1 to T_3.

Isothermal compression (3 – 4):-

Adiabatic cover is removed and sink (S) is applied to the end of the cylinder. The heat, Q_2 is transferred reversibly and isothermally at temperature T_3 from the system to the sink (S).

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_3 to T_1.

Efficiency of Carnot cycle:

Consider 1 kg of working substance

Heat supplied during isothermal process (1-2)

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

$$\therefore Q_1 = RT_1 \ln\frac{V_2}{V_1} \tag{5.1}$$

Heat rejected during isothermal compression (3-4);

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

$$Q_2 = RT_3 \ln\frac{V_4}{V_3} \tag{5.2}$$

During ***adiabatic expansion (2-3)*** and ***adiabatic compression (4-1)***, the heat transfer from or to the system is ***zero***.

Work done,

$$W = Q_1 - Q_2$$

$$\therefore W = RT_1 \ln\frac{V_2}{V_1} - RT_3 \ln\frac{V_4}{V_3} \tag{5.3}$$

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 equation 5.3, we get,

$$W = RT_1 \ln r - RT_3 \ln r$$

$$\therefore W = R\ln r(T_1 - T_3) \tag{5.4}$$

Thermal efficiency,

$$\eta = \frac{Work\ done}{Heat\ supplied} = \frac{Q_1 - Q_2}{Q_1}$$

$$\therefore \eta = \frac{R \ln r (T_1 - T_3)}{R T_1 \ln r}$$

$$\therefore \eta = \frac{T_1 - T_3}{T_1} = 1 - \frac{T_3}{T_1} \tag{5.5}$$

Where,

$T_1 =$ Maximum temperature of the cycle (K)

$T_3 =$ Minimum temperature of cycle (K)

In equation 5.5, if temperature T_3 decreases, efficiency increases and it becomes 100% if temperature T_3 becomes absolute zero; which is ***impossible*** to attain.

Limitations of Carnot Gas Cycle:

a) The Carnot cycle is hypothetical.
b) The thermal efficiency of Carnot cycle depends upon absolute temperature of heat source T_1 and heat sink T_3 only, and independent of the working substance.
c) Practically it is not possible to neglect friction between piston and cylinder. It can be minimized but cannot be eliminated.
d) 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.
e) 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.
f) The output obtained per cycle is very small. This work may not be able to overcome the friction of the reciprocating parts.

Rankine Cycle

The Rankine cycle is the ideal cycle for steam power plants. In a steam power plants, the heat energy of the fuel is converted into mechanical energy or power.

The ideal Rankine cycle is shown schematically and on P-V, T-s & h-s diagram in Fig. 5.3. The liquid, vapour and wet regions are also indicated with the help of saturation curve.

Process 4 – 1: Constant pressure heat addition in the boiler

The water is heated at constant pressure p_1 in the boiler until the saturation temperature is reached, Saturated water is converted into saturated steam at constant pressure. During 1-1' process steam is superheated in super heater.

Heat supplied is given by

$$Q_s = h_1 - h_4$$

Process 1 – 2: Isentropic expansion in the turbine

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.

Turbine work is given by,

$$W_T = h_1 - h_2$$

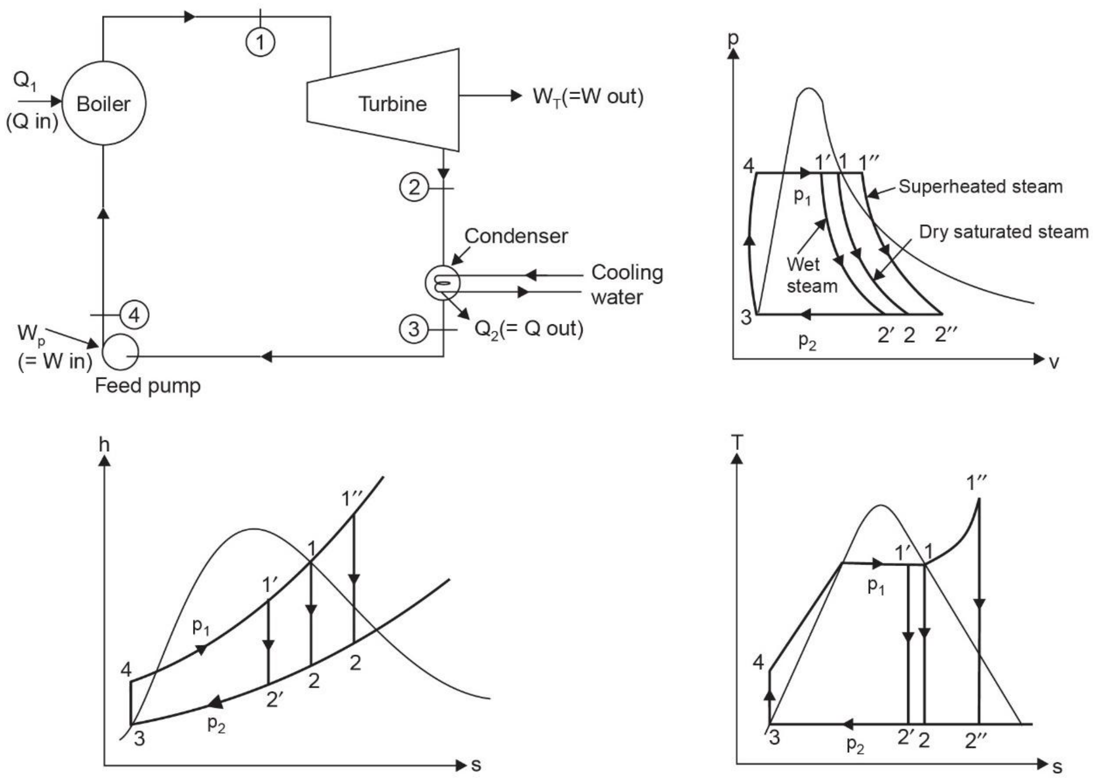


Fig. 5.3 p-V, T-s, h-s and schematic diagram of Rankine cycle

Process 2 – 3: Constant pressure heat rejection in the condenser

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.

Heat rejected is given by,

$$Q_R = h_2 - h_3$$

Process 3 – 4: Isentropic compression in the pump (Pumping Process)

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.

Pump work is given by,

$$W_P = h_4 - h_3$$

Efficiency of Rankine Cycle

Thermal efficiency is given by,

$$\text{Efficiency} = \eta_R = \frac{\text{Net work output}}{\text{Heat supplied in boiler}}$$

$$\therefore \eta_R = \frac{W_{net}}{Q_s} \tag{5.6}$$

Heat supplied to the working fluid in a boiler during process 4 – 1,

$$Q_s = h_1 - h_4 \tag{5.7}$$

Turbine work during process 1 – 2,

$$W_T = h_1 - h_2 \tag{5.8}$$

Heat rejected during condensation process 2 – 3,

$$Q_R = h_2 - h_3 \tag{5.9}$$

Pump work during process 3 – 4,

$$W_P = h_4 - h_3 \tag{5.10}$$

Net work output

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

$$W_{net} = (h_1 - h_2) - (h_4 - h_3) \tag{5.11}$$

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

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

$$\therefore \eta_R = 1 - \frac{h_2 - h_3}{h_1 - h_4} \tag{5.12}$$

Usually pump work is very small, hence it is neglected

$$\therefore \eta_R = \frac{h_1 - h_2}{h_1 - h_4} \tag{5.13}$$

Air Standard Cycles

In most of the power developing systems, such as petrol engine, diesel engine and gas turbine, the common working fluid used is air. These devices take in either a mixture of fuel and air as in petrol engine or air and fuel separately and mix them in the combustion chamber as in diesel engine

The mass of fuel used compared with the mass of air is rather small. Therefore the properties of mixture can be approximated to the properties of air.

Exact condition existing within the actual engine cylinder are very difficult to determine, but by making certain simplifying assumptions, it is possible to approximate these conditions more or less closely. The approximate engine cycles thus analysed are known as theoretical cycles.

The simplest theoretical cycle is called the air-cycle approximation. The air-cycle approximation used for calculating conditions in internal combustion engine is called the air-standard cycle.

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.

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.
   $C_P = 1.005\,kJ/kg\;K,\; C_V = 0.718\,kJ/kg\;K,\quad \gamma = 1.4$
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.

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.

Fig. 5.4 shows the Otto cycle plotted on p – V diagram.

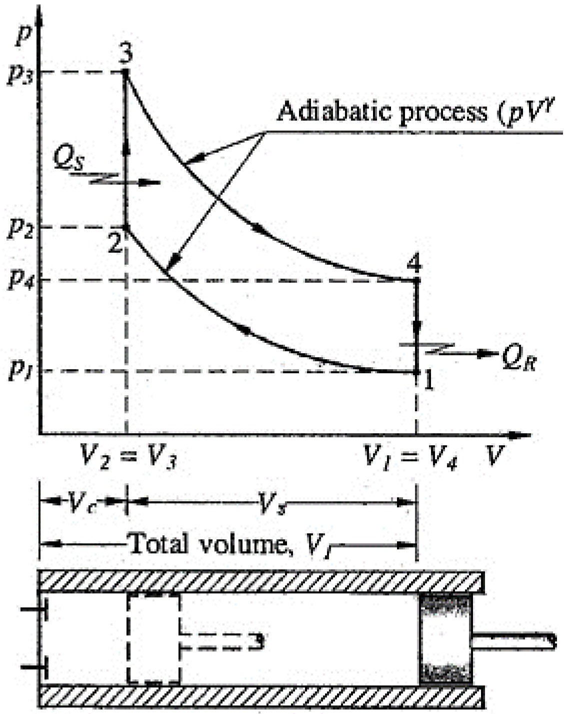


Fig. 5.4 P-V diagram for petrol cycle.

<u>**Adiabatic Compression Process (1 – 2):**</u>

At pt. 1 cylinder is full of air with volume V_1, pressure P_1 and temp. T_1.

Piston moves from BDC to TDC and an ideal gas (air) is compressed isentropically to state point 2 through compression ratio,

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

<u>**Constant Volume Heat Addition Process (2 – 3):**</u>

Heat is added at constant volume from an external heat source.

The pressure rises and the ratio $r_p \ or \ \alpha = \frac{p_3}{p_2}$ is called expansion ratio or pressure ratio.

Adiabatic Expansion Process (3 – 4):

The increased high pressure exerts a greater amount of force on the piston and pushes it towards the BDC.

Expansion of working fluid takes place isentropically and work done by the system.

The volume ratio $\frac{V_4}{V_3}$ is called isentropic expansion ratio.

Constant Volume Heat Rejection Process (4 – 1):

Heat is rejected to the external sink at constant volume. This process is so controlled that ultimately the working fluid comes to its initial state 1 and the cycle is repeated.

Many petrol and gas engines work on a cycle which is a slight modification of the Otto cycle.

This cycle is called *constant volume cycle* because the heat is supplied to air at constant volume.

Air Standard Efficiency of an Otto Cycle:

Consider a unit mass of air undergoing a cyclic change.

Heat supplied during the process 2 – 3,

$$q_1 = C_V \left(T_3 - T_2\right)$$

Heat rejected during process 4 – 1,

$$q_2 = C_V \left(T_4 - T_1\right)$$

Work done,

$$\therefore W = q_1 - q_2$$

$$\therefore W = C_V \left(T_3 - T_2\right) - C_V \left(T_4 - T_1\right)$$

Thermal efficiency,

$$\eta = \frac{Work\ done}{Heat\ supplied} = \frac{W}{q_1}$$

$$= \frac{C_V \left(T_3 - T_2\right) - C_V \left(T_4 - T_1\right)}{C_V \left(T_3 - T_2\right)}$$

$$= 1 - \frac{\left(T_4 - T_1\right)}{\left(T_3 - T_2\right)} \qquad (5.14)$$

For Adiabatic compression process (1 – 2),

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

$$\therefore T_2 = T_1 r^{\gamma-1} \tag{5.15}$$

For Isentropic expansion process (3 – 4),

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$$

$$\therefore T_3 = T_4\left(\frac{V_4}{V_3}\right)^{\gamma-1}$$

$$\therefore T_3 = T_4\left(\frac{V_1}{V_2}\right)^{\gamma-1} \qquad (\because V_1 = V_4, V_2 = V_3)$$

$$\therefore T_3 = T_4 (r)^{\gamma-1} \tag{5.16}$$

From equation 5.14, 5.15 & 5.16, we get,

$$\eta_{otto} = 1 - \frac{(T_4 - T_1)}{T_4 r^{\gamma-1} - T_1 r^{\gamma-1}}$$

$$\therefore \eta_{otto} = 1 - \frac{(T_4 - T_1)}{r^{\gamma-1}(T_4 - T_1)}$$

$$\therefore \eta_{otto} = 1 - \frac{1}{r^{\gamma-1}} \tag{5.17}$$

Expression 5.17 is known as the air standard efficiency of the Otto cycle.

It is clear from the above expression that efficiency increases with the increase in the value of r (as γ is constant).

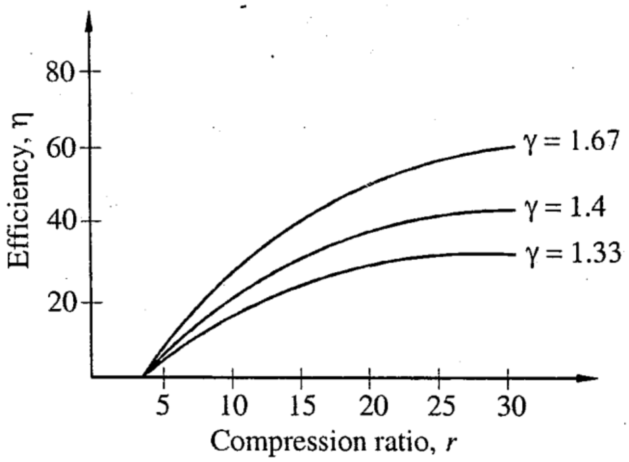


Fig. 5.5 Effect of compression ratio on η

Fig. 5.5 shows the variation of air standard efficiency of Otto cycle with 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. 5.6.

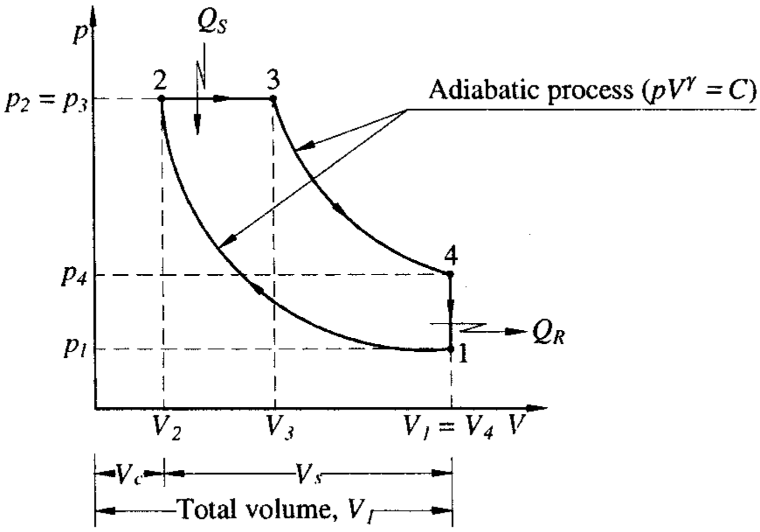


Fig. 5.6 p-V diagram for diesel cycle

Reversible adiabatic Compression Process (1 – 2):

Isentropic (Reversible adiabatic) compression with $r = \dfrac{V_1}{V_2}$.

Constant Pressure Heat Addition 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.

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

Reversible adiabatic Expansion Process (3 – 4):

Isentropic expansion of air $\frac{\mathrm{V}_4}{\mathrm{V}_3}$ = isentropic expansion ratio.

Work is developed during this process.

Constant Volume Heat Rejection Process (4 – 1):

In this process heat is rejected at constant volume. Hence pressure and temperature of air decreases to initial value. This way cycle is complete.

This thermodynamics cycle is called constant pressure cycle because heat is supplied to the air at constant pressure.

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

Fig. 9 p-V diagram for diesel cycle

Efficiency of Diesel cycle:

Net work done,
$$W_{net} = \text{Heat supplied} - \text{ Heat rejected}$$
$$= mC_p(T_3 - T_2) - mC_v(T_4 - T_1)$$

Air standard efficiency,
$$\eta = \frac{\text{Net work done}}{\text{Heat supplied}}$$
$$= \frac{mC_p(T_3 - T_2) - mC_v(T_4 - T_1)}{mC_p(T_3 - T_2)}$$
$$= 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)} \tag{5.18}$$

Let,

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

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

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

For process (1-2):

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

$$\therefore T_2 = T_1 \cdot r^{\gamma-1} \tag{5.19}$$

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. 6)

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

By substituting the value of T_2 from eq. (5.19)

$$\therefore T_3 = \left[T_1 \cdot r^{\gamma-1}\right] \cdot \rho \tag{5.20}$$

For process (3-4):

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$$

$$\frac{V_4}{V_3} = \frac{V_4 / V_2}{V_3 / V_2} = \frac{r}{\rho} \qquad (\because V_1 = V_4)$$

$$\therefore \frac{T_3}{T_4} = \left(\frac{r}{\rho}\right)^{\gamma-1}$$

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

By substituting the value of T_3 from eq. (5.20), we get

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

$$\therefore T_4 = \rho^{\gamma} \cdot T_1 \tag{5.21}$$

By substituting the values of T_2, T_3 and T_4 in eq. (5.18) we get,

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

$$\therefore \eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right] \qquad (5.22)$$

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. (5.22) it is clear that the efficiency of Diesel cycle increases with the increase of compression ratio and with the decreases of cut-off ratio.

Introduction

Steam boiler is a closed vessel in which heat produced by the combustion of fuel is utilized to generate steam from water, at desired temperature and pressure.

According to IBR (Indian Boiler Regulation) boiler is defined as ***"Boiler is a closed pressure vessel with capacity exceeding 22.75 liters used for generating steam under pressure."***

The steam produced may be supplied:

a. For generating power in steam Engine or steam turbines.
b. At low pressures for industrial process work in cotton mills, sugar factories, etc., and
c. For producing hot water for supply of hot water and for heating the buildings in cold weather.

Classification of Steam Boilers

1. **According to relative position of water and hot gases**
   a. Fire Tube boiler - hot gases pass through fire tubes which are surrounded by water.
   b. Water tube - water flows inside the tubes and the hot flue gases flow outside the tubes.
2. **According to the axis of the shell**
   a. Vertical boiler – the axis of the shell is vertical.
   b. Horizontal boiler – the axis of the shell is horizontal.
   c. Inclined boiler – the axis of the boilers is inclined.
3. **According to the method of firing**
   a. Externally fired boilers – furnace is located outside the shell.
   b. Internally fired boilers – furnace is located inside the shell, means combustion takes place inside the boiler shell.
4. **According to the method of water circulation**
   a. Forced Circulation boilers - water is circulated by pumps which is driven by motor.
   b. 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.
5. **According to the pressure of steam**
   a. High pressure – boilers working pressure is less than 10 bars. Example: Babcock and Wilcox boiler
   b. Medium pressure boilers – working pressure is 10 to 70 bars. Example: Lancashire and locomotive boiler
   c. Low pressure boilers – working pressure is above 70 bars. Example: Cochran and Cornish boiler.
6. **According to the mobility of boiler**
   a. Stationary boilers – it is used for stationary plants.
   b. Mobile boilers – it can move from one place to another.
7. **According to the number of tubes in the boiler**
   a. Single tube boilers – they have only one fire or water tube.
   b. Multi tube boilers – they have more than one fire or water tubes.

Comparison between Fire tube and Water tube boiler

Sr. No.	Particular	Fire Tube boiler	Water tube boiler
1	Position of water and hot gases	Hot gases inside the tubes and water outside the tubes	Water inside the tubes and hot gases outside the tubes
2	Operating pressure	Limited to 25 bar	More than 125 bars
3	Rate of steam generation	Lower	Higher
4	Suitability	Not suitable for large power plant	Suitable for large power plant
5	Chance of explosion	Less due to low pressure	More due to low 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 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 & bursting	Small deposition of scale will cause overheating and bursting of the tubes.

Cochran Boiler (Vertical multi-tubes boiler)

It is one of the best type of vertical multi-tubular boiler. It is fire tube boiler and used for steam generation at lower rate.

Specification

Shell diameter = 2.75 m

Height = 5.75 m

Working pressure = 6.5 bar

Heating surface area 120 m^2

Steam capacity = 3500 kg/hr (Max. = 4000 kg/hr)

Efficiency = 70 to 75 %

Characteristics of boiler

It is a vertical, multi tubes, fire tube, internally fired, natural circulation boiler.

Construction

The boiler consists of a cylindrical shell, hemispherical fire box, fire tubes and chimney. The top of the shell having hemispherical shaped crown as shown in fig 6.1.

The hemispherical crown of boiler gives good strength to withstand pressure of steam inside the boiler. The hemispherical shape of furnace can withstand high heat and it is also useful to increase radiant heat transfer.

The grate is placed at the bottom of furnace and ash pit is located below the grate. The furnace and the combustion chamber are connected by short flue pipe. The wall of the combustion chamber is lined with the fire bricks.

Working

The water is supplied to the boiler through feed check valve. The level is adjusted with the help of water level indicator. Coal is added through the fire-hole or door to the grate and burnt. The hot gases produced are collected in the fir box.

These hot gases enter into horizontal fire tubes. Heat transfer takes place from flue gases passing inside the tubes to water surrounded the tubes. The flue gas coming from the fire tubes enter into smoke box. Finally they discharged to atmosphere through a chimney.

The ash formed is collected in ash pit. The steam is collected through anti priming pipe on the top of the shell.

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)

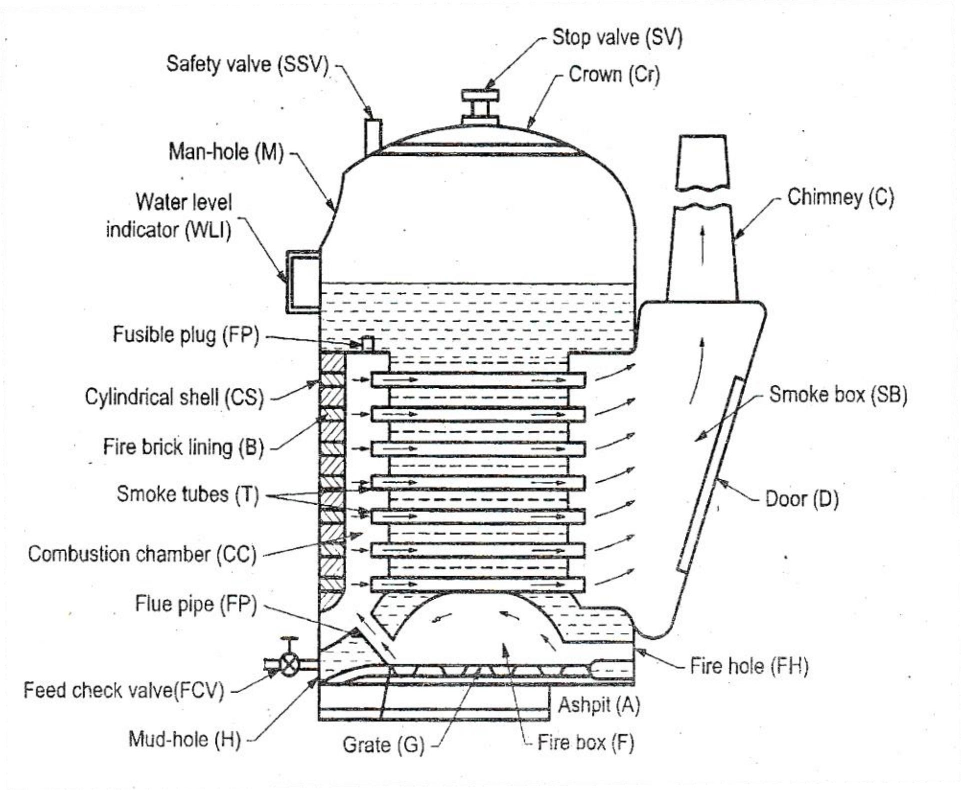


Fig. 6.1 Cochran Boiler

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.

Lancashire Boiler

It is simple in design, easy to operate and less operating and maintenance cost. It is one of the most commonly used stationary boilers. It is normally used in sugar mills, textile industries where power generation as well as process heating is required.

Specification

Shell diameter = 2 to 3 m

Length of the shell = 7 TO 9 m

Working pressure = 16 bar

Steam capacity = 8000-9000 kg/hr

Efficiency = 50 to 70 %

Characteristics

Horizontal, stationary, fire tube, internally fired multi-tube (two fire tube), natural circulation of hot gases, medium pressure boiler.

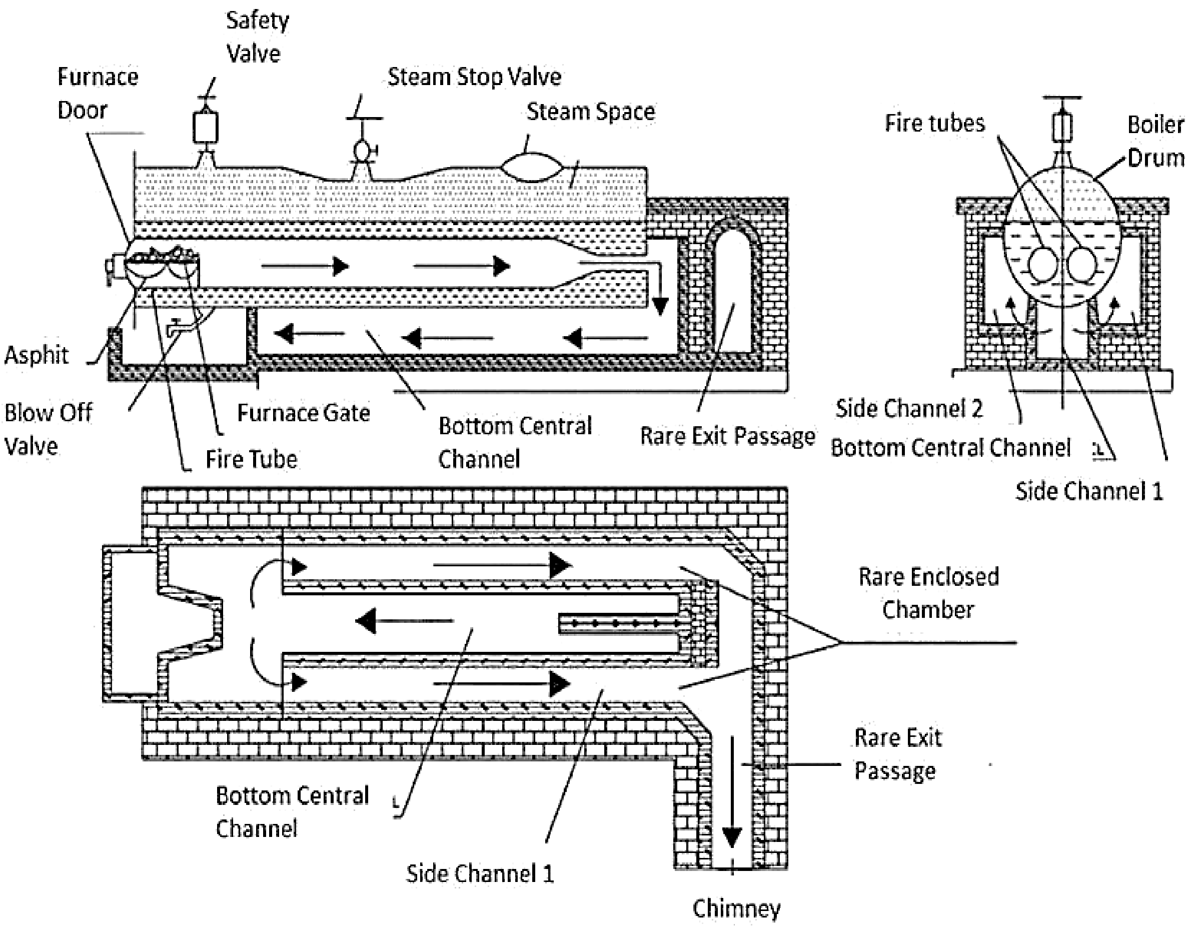


Figure 6.2 Lancashire Boiler

Construction

It consists of a cylindrical shell and two fire tubes as shown in fig. 6.2. The cylindrical shell is placed over the brick structure.

The boiler has three passes for flow of gases. One flue passes from inside of boiler and through fire tubes, is called main flue (MF). Second flue passes froth below the shell is called bottom flue (BF) and third from the side of boiler is called side flue (SF). The side flue and bottom flue passes are formed by brick work.

The fuel grates are provided at the front end and inside of two main fire tubes. A fire bridge is provided at the end of the grate to prevent coal and ash particles entering into the interior of the furnace tubes.

Superheater is provided at the end of the main flue tubes in passage of flue gases. While an economiser is at the end of the side flues, before exhausting the gases to chimney. Dampers (sliding doors) are placed at the end of the side flues to control the flow of gases.

The pressure gauge and water level indicator and feed check valve are provided at front of the boiler. On the front side, the blow off cock is provided at the bottom. The fusible plugs are mounted on the top of the main flues just over the grate. The antipriming pipe, safety valve, low water and high steam safety valve and manhole are provided on the top of boiler shell.

Working

The coal is introduced to the grate through fire holes. The combustion of coal takes place in presence of air which is regulated by damper. The combustion will produce hot gases.

Path of flue gases: The hot gases from the grate pass upto back end of the tubes and then in the downward direction (MF to BF). They move by the bottom flue to the front of the boiler where they are divided into two streams and pass into the side flues (BF to SF). They move along two side flues and enter the chimney and discharged to atmosphere.

Path of flue gases is as under

Grate ⟶ Fire tube (MF) ⟶ BF ⟶ SF ⟶ Chimney ⟶ Atm

Due to this flue gas path, the water in the shell is heated from bottom by the bottom flue, from sides by side flue and from center by fire tubes.

Damper regulates mass flow rate of flue gases. Ultimately it regulates fuel combustion rate as well as steam generation rate. Dampers are opened by chain passing over a pulley outside the boiler.

Advantages

Response of pressure build up is less.

1. The furnace is inside the tubes therefore the grate area is restricted.
2. Due to three passes of flue gases, the heating surface area per unit volume of boiler is large.
3. The fluctuations in load can be easily met by this boiler due to large reservoir.
4. Easy operation, low maintenance costs, easy to clean and inspect.
5. By use of economiser and superheater, maximum heat of flue gases is utilized, so efficiency of boiler can be increased.

Disadvantages

1. Maximum working pressure is limited to 16 bar.
2. Due to brick work, more floor area is required.

Babcock and Wilcox boiler

It is a water tube boiler and used in stationary and marine engine. The efficiency of this boiler is much greater than that of the fire tube boiler. This boiler is exclusively used when pressure is above 10 bar and steam generating capacity is required higher than 7000 kg/hr.

Specification

Diameter of the drum = 2000 to 4000.

Length = 6000 to 9000 mm.

Size of the water tube = 76.2 to 101.6 mm

Size of upper header tube = 38.4 to 57.1 mm

Maximum working pressure = 42 bar

Maximum steam capacity = 40,000 kg/hr

Efficiency = 60 to 80 %

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 can be fired.

Construction

Fig. 3 shows a Babcock and Wilcox boiler. It consists of inclined water tubes, a steam and water drum, a mud box and super heater.

The drum is connected with uptake and downtake header by short riser tubes. These headers are connected to series of inclined water tubes.

The water tubes are inclined to horizontal about 15° or above to bring natural circulation of water. The hand hole is provided in header in front of each tube for cleaning and inspection of tubes.

The baffles plates are provided in order to make the circulation of hot gases in sine wave form. A damper is fitted at back of the boiler to regulate the draught and chain grate stoker is used to feed the coal to furnace.

Soot doors are provided to clean the outside of water tubes and to remove the soot. Soot doors are also helpful to access the interior of the boiler.

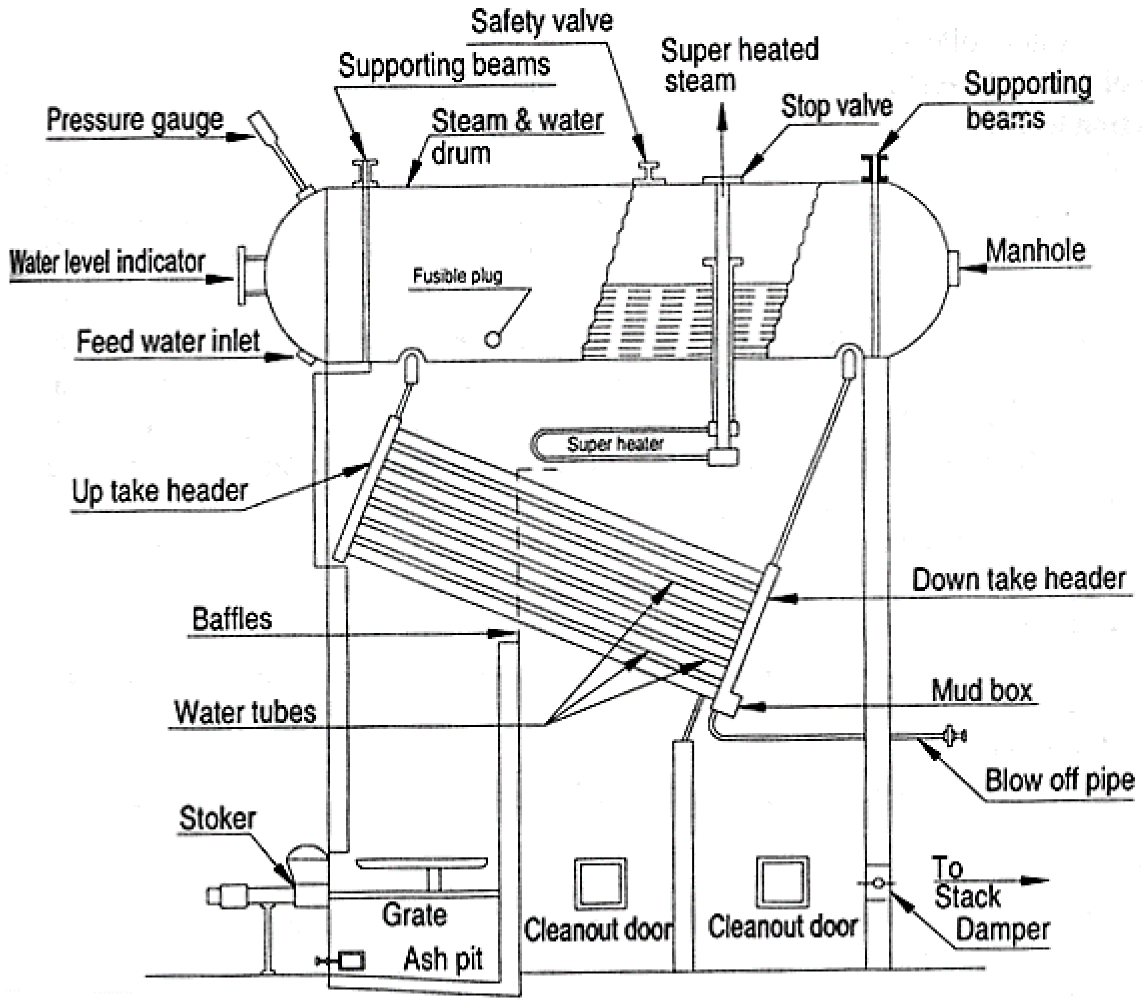


Fig. 6.3 Babcock Wilcox Boiler

Working

The water fed into the boiler shell through the feed check valve. Due to gravity water passes through the vertical tubes, headers and fills up the inclined tubes first. Then the water collects in the drum. Initially one half of drum is filled up with water.

The coal is introduced to furnace grate by help of stoker. The coal is fired, hot gases produced is first forced to move upward through passage between tubes. The baffles plates make flow of hot gases in sine wave, as move down and then move upward over the water tubes. The damper controls the flow of air into the furnace.

Water in the drum comes down through down take header and enter the tubes. They are heated by hot gases coming from furnace. Due to heating of the water, density of water decreases. Low density water moves upward in water tubes. The water tubes just above the furnace are heated comparatively at a higher temperature than the rest of it. Therefore low density water is gradually converted into steam in their path and rises into drum through up take header.

Thus a continuous circulation of water from drum to water tubes and water tubes to drum is maintained due to density difference of water and gravity, without any pump.

The steam then enters to the antipriming pipe and flows in the superheater tubes where it is further heated and is finally taken out thorough the main steam stop valve and supplied to the engine when needed.

At lowest point of the header, mud collector is provided to remove the mud particles through a blow down cock.

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.

Boiler Mountings and Accessories

Boiler Mountings

These are different fittings and devices which are necessary for the operation and safety of a boiler. Normally these devices are mounted on boiler shell.

According to IBR the following are the list of mountings should be fitted to the boilers.

1. Two water level indicators
2. A pressure gauge
3. Safety valves
4. A Steam stop valve
5. A feed check valve
6. A blow off cock
7. Fusible plug
8. A man hole, Mud holes or sight holes

Water level indicator

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.

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.

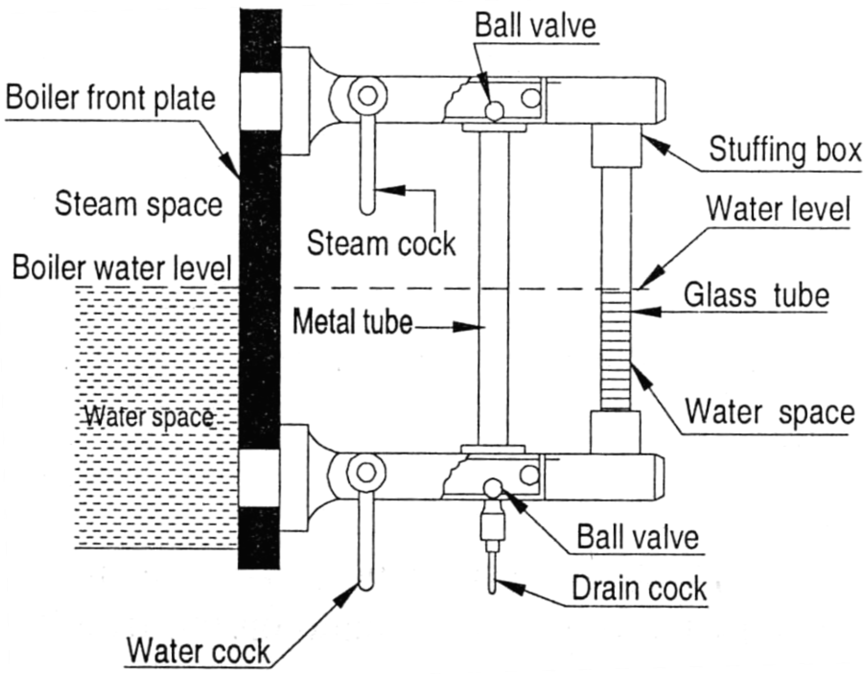


Fig. 6.4 Water Level Indicator

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.

Pressure Gauge

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.

Construction

It consists of an elliptical elastic tube XYZ bent into an arc of a circle, as shown in fig. 6.5. 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.

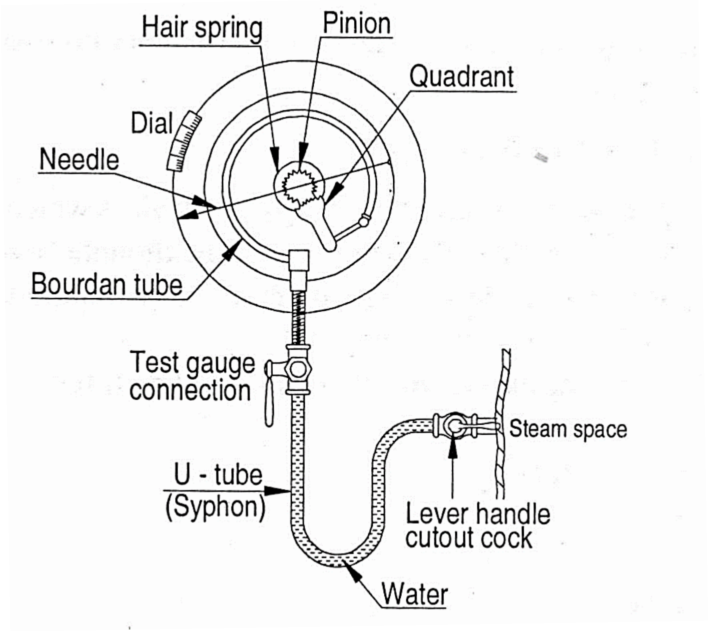


Fig. 6.5 Pressure Gauge

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 tube rotates the pointer. This pointer moves over a calibrated scale, which directly gives the gauge pressure.

Safety Valves

It is the device 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.

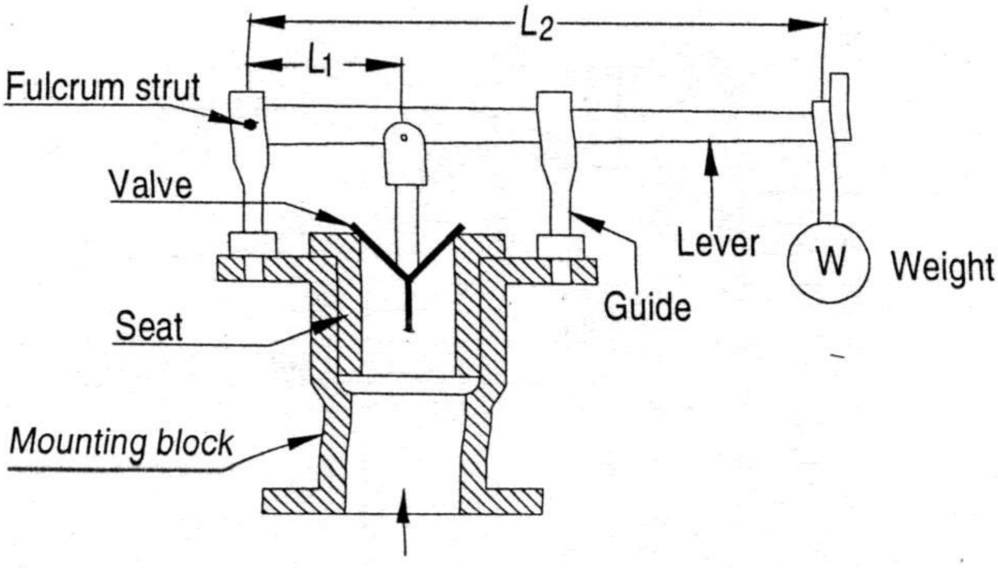


Fig. 6.6 Lever Safety Valve

Lever Safety Valve

A lever safety valve used on steam boilers is shown in fig. 6.6. 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.

Dead Weight Safety Valve

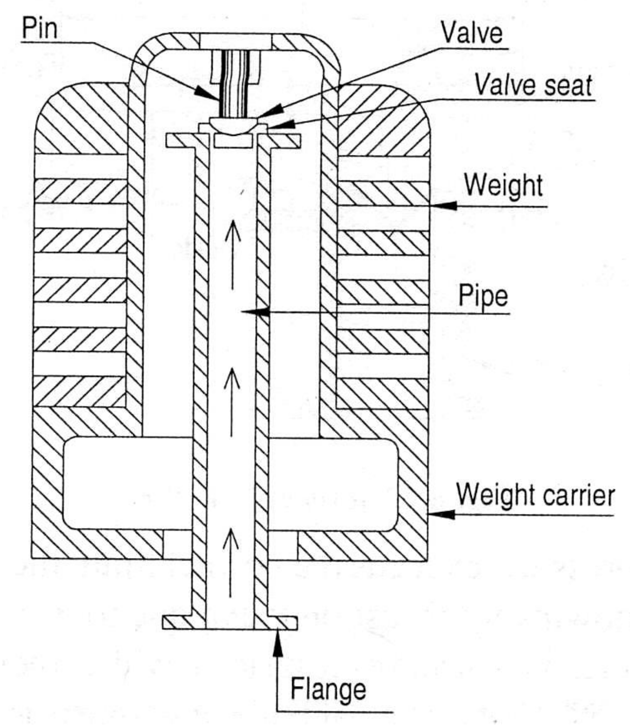


Fig. 6.7 Dead Weight Safety Valve

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.

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.

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.

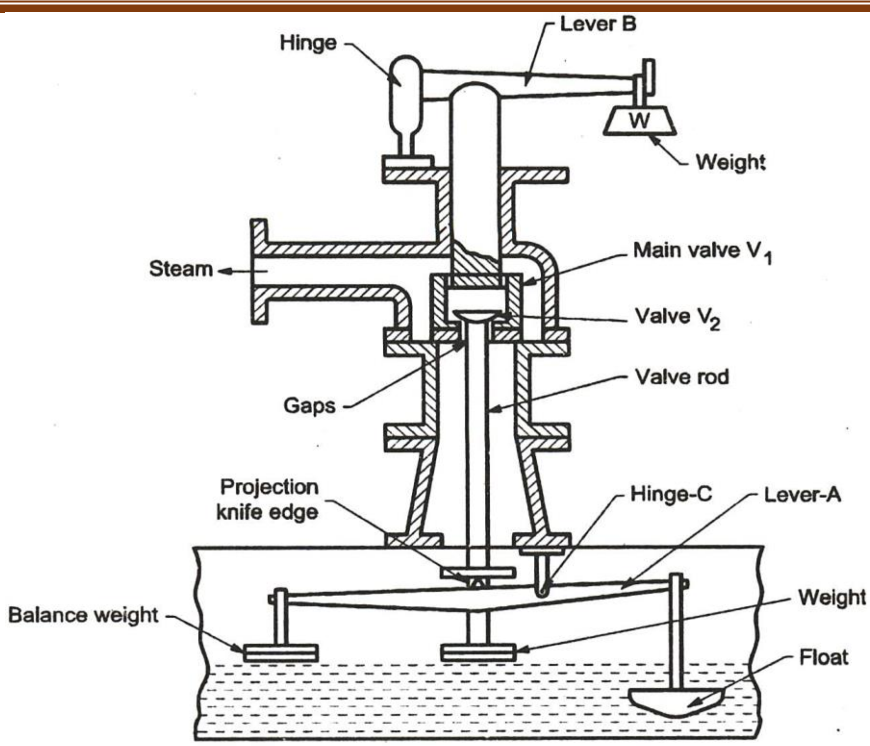


Fig. 6.8 High stem low water safety valve

When the water level falls and floats 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.

Spring Loaded Safety Valve

A Ramsbottom spring loaded safety valve is shown in Fig. 6.9. 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.

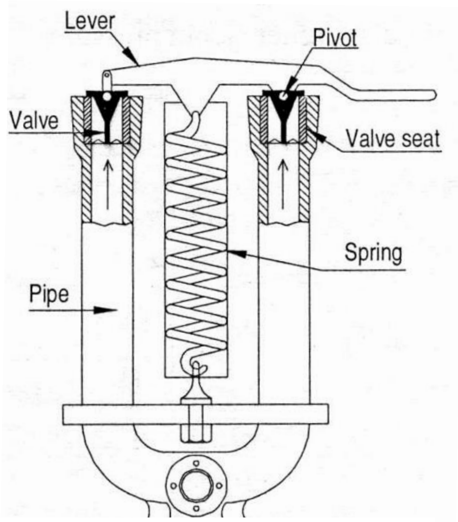


Fig. 6.9 Spring Loaded Safety Valve

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.

Steam Stop Valve

Function

To control the flow of steam from the boiler to the main steam pipe.

To shut off the steam completely when required.

Construction

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.

Working

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.

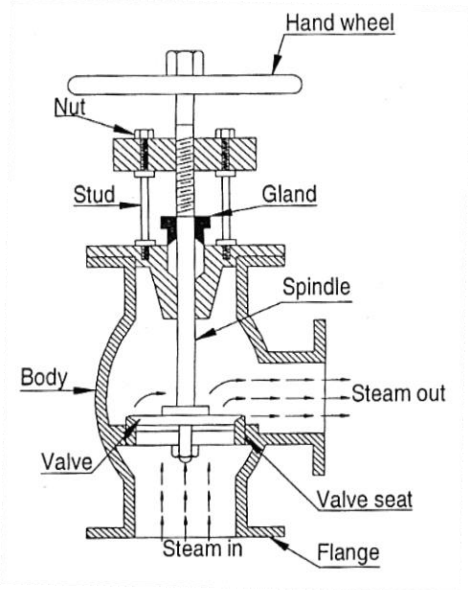


Fig. 6.10 Steam Stop Valve

Feed Check Valve

Function

Its function is to regulate the supply of water, which is pumped into the boiler, by the feed pump.

Construction

It is a non-return valve, fitted to a screwed spindle to regulate the lift. This valve must have its spindle lifted before the pump is started.

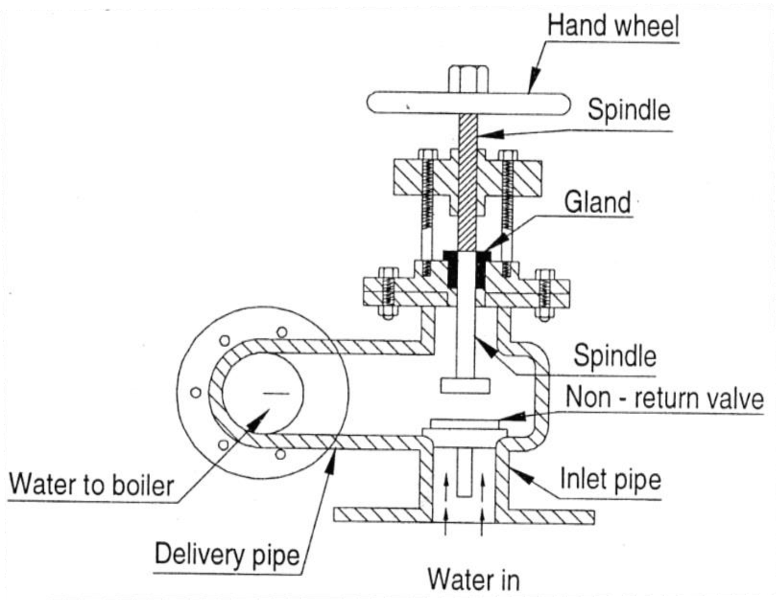


Figure 6.11 Feed Check Valve

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.

Working

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.

Blow Off Cock

Function

It may discharge a portion of water when the boiler is in operation to blow out mud, scale or sediments periodically.

It may empty the boiler when necessary for cleaning and repair.

Construction

A common type of blow-off cock is shown in fig. 6.12. A conical plug is fitted accurately into a similar casing. The plug has a rectangular opening. The plug slot is perpendicular to the flow passage.

Working

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.

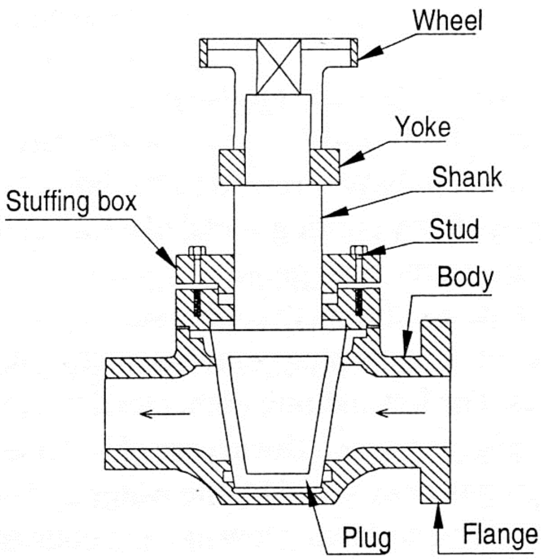


Fig. 6.12 Blow-off Cock

Fusible Plug

Function

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

Construction

The construction of the fusible plug is shown in fig. 6.13 which consists of three plugs. The hollow plug A having hexagonal flanges is screwed to the fire box crown plate. The plug B gunmetal plug is screwed to the body A. The third plug C is made up of copper is locked with metal like tin or lead which has a low melting point.

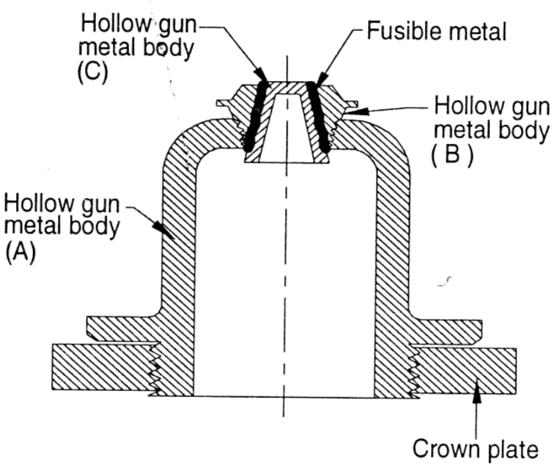


Fig. 6.13 Fusible Plug

Working

In normal working condition, water covers the fusible plug 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.

Boiler Accessories

These are auxiliary plants or parts required for steam boilers for their proper operation and to increase the efficiency of the boiler.

Commonly used boiler accessories are as:

1. Feed pumps
2. Injector
3. Economiser
4. Air preheater
5. Superheater
6. Steam separator
7. Steam trap

Economizer

Function

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

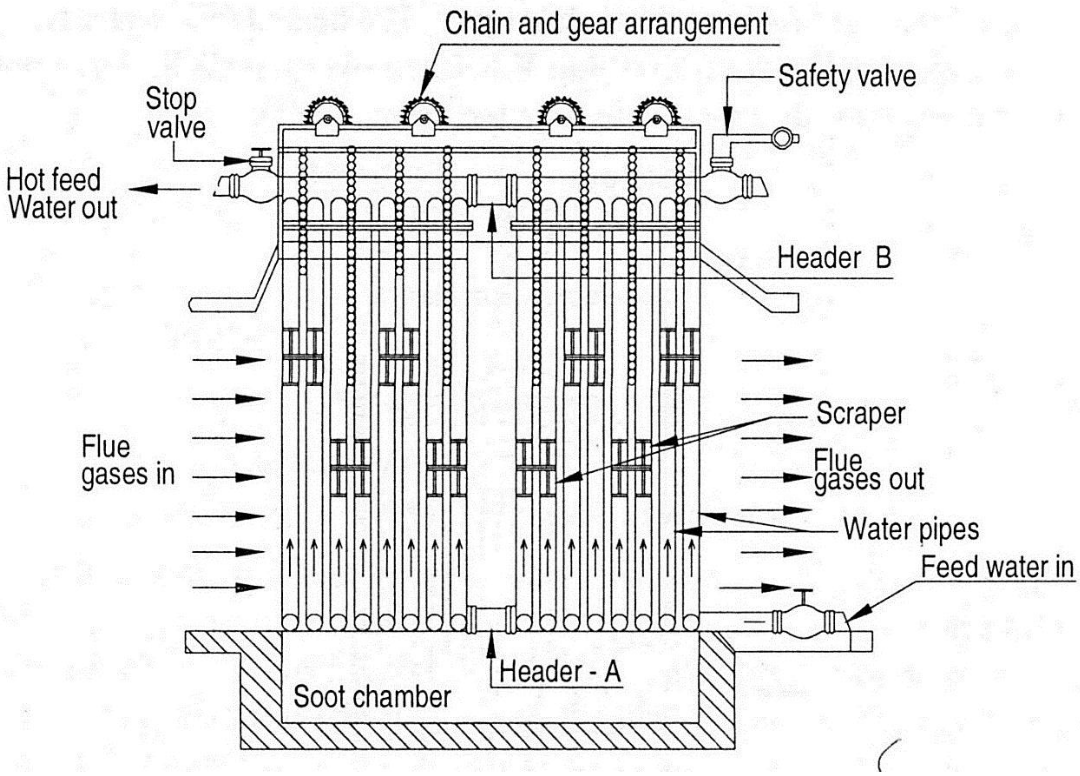


Fig. 6.14 Economizer

Construction and working

Fig. 14 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 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.

Super Heater

Function

Superheater increases the temperature of the steam above its saturation temperature by utilizing exhaust gases.

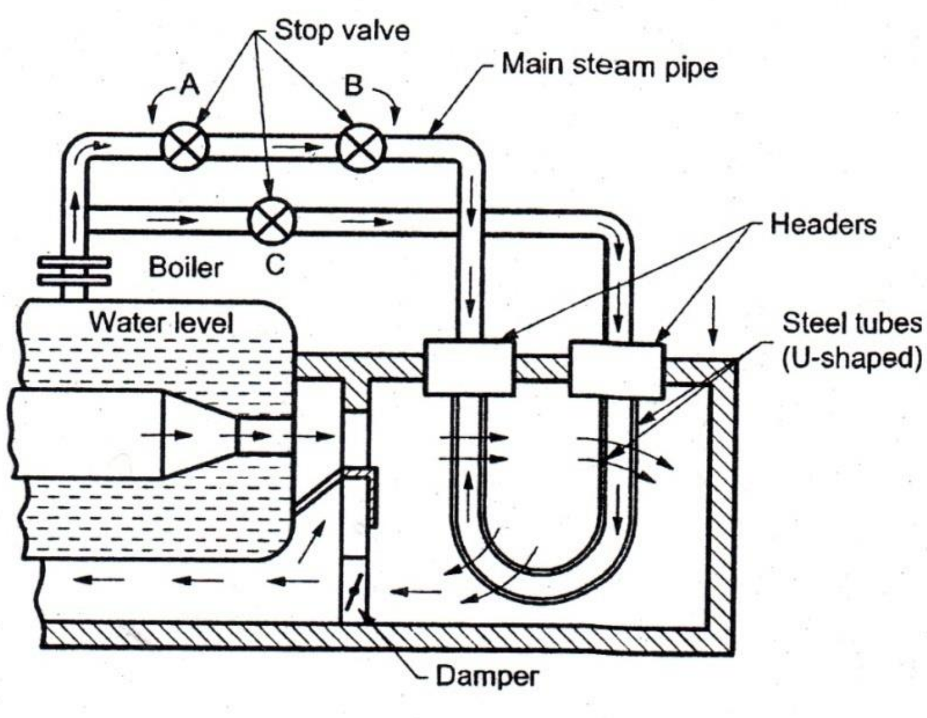


Fig. 6.15 Super Heater

Construction and working

Fig. 6.15 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 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.

Air Preheater

Function

Air preheater increase the temperature of air before it supply to the furnace using heat from flue gases passing through the chimney.

Construction and working

Air preheater is installed between economiser and the chimney. It consists of large numbers of tubes which arranged in path of flue gases shell as shown in Fig. 16. Hot flue gases enters into tubes from top of shell and leave from the bottom to the chimney. The inlet air at room temperature is admitted into shell at lower end with the help of the fan. The air passes upward around the tubes in the opposite direction to the flow of hot flue gases. The soot hopper provided at the bottom is used to collect soot during cleaning operation of the tubes.

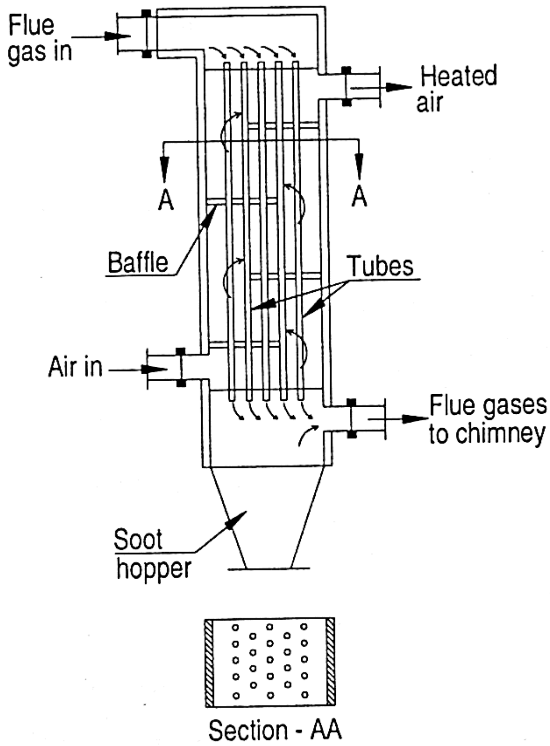


Fig. 6.16 Air Preheater

Advantages

1. Preheated air increases combustion rate and then increases steam generator rate of boiler.
2. Due to higher temperature of air furnace temperature of air, furnace temperature increases, so low grade coal can be burnt efficiently.
3. Air heated by heat of exhaust gases. It reduces fuel consumption. Therefor thermal efficiency of boiler increased.

Disadvantages

1. There are formations of clinker, on the grate due to higher combustion temperature.
2. Natural draught is not possible with air preheater because of temperature of the gases is reduced, also pressure drop take place in the flow of flue gases. Thus forced draught is required.

In 1876 German engineer Nikolaus Otto developed four stroke engine based on Otto cycle. It revolutionized the development of internal combustion engines and are even used till date. In 1892 another German engineer Rudolf Diesel developed diesel engine.

ENGINE

Engine is a device which converts 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.

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

a) External Combustion Engines (E.C. Engines)
b) Internal Combustion Engines (I.C. Engines)

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

Comparison of IC engine and EC engine is given in table 1.

Table 1 Comparison of IC engine and EC engine

Sr.	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

IC engine Classification

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) X – Type engine (6) H – Type Engine

(7)U – Type Engine (8) Opposed piston engine

(9) Delta Type Engine

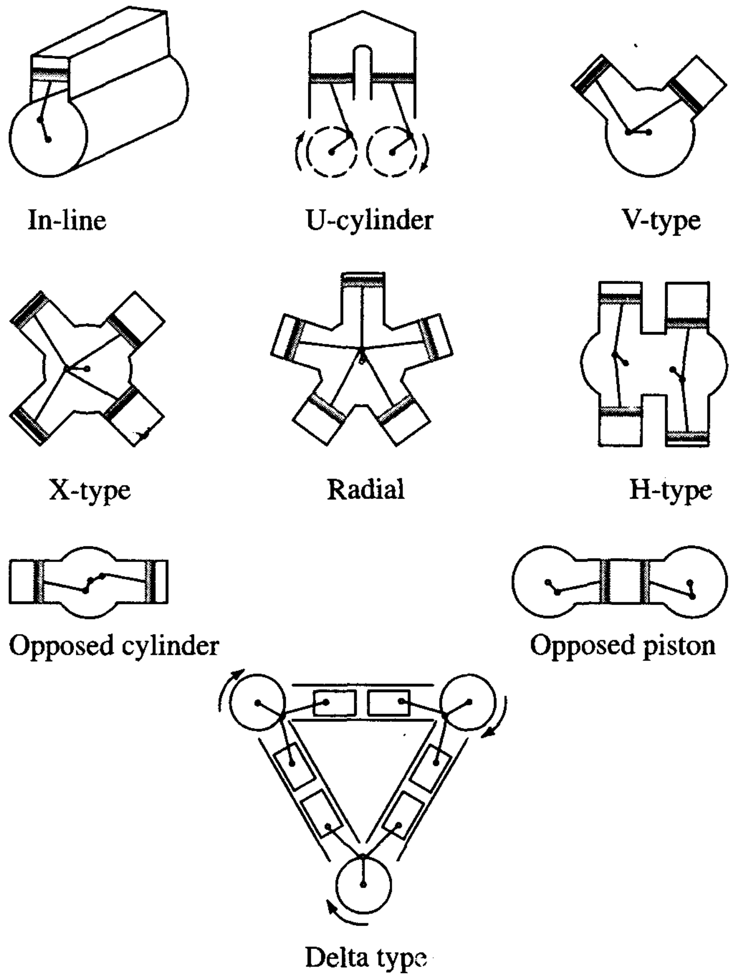


Fig. 7.1 Engine classification by cylinder arrangements

Engine details

The various important parts of an I.C. engine are shown in fig. 7.1.

1. Cylinder

It is the heart of the engine in which the fuel is burnt and the power is produced. Cylinder has to withstand very high pressure and temperature because the combustion of fuel takes place inside the engine cylinder. Therefore cylinder must be cooled. To prevent the wearing of the cylinder block, a sleeve will be fitted tightly in 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 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.

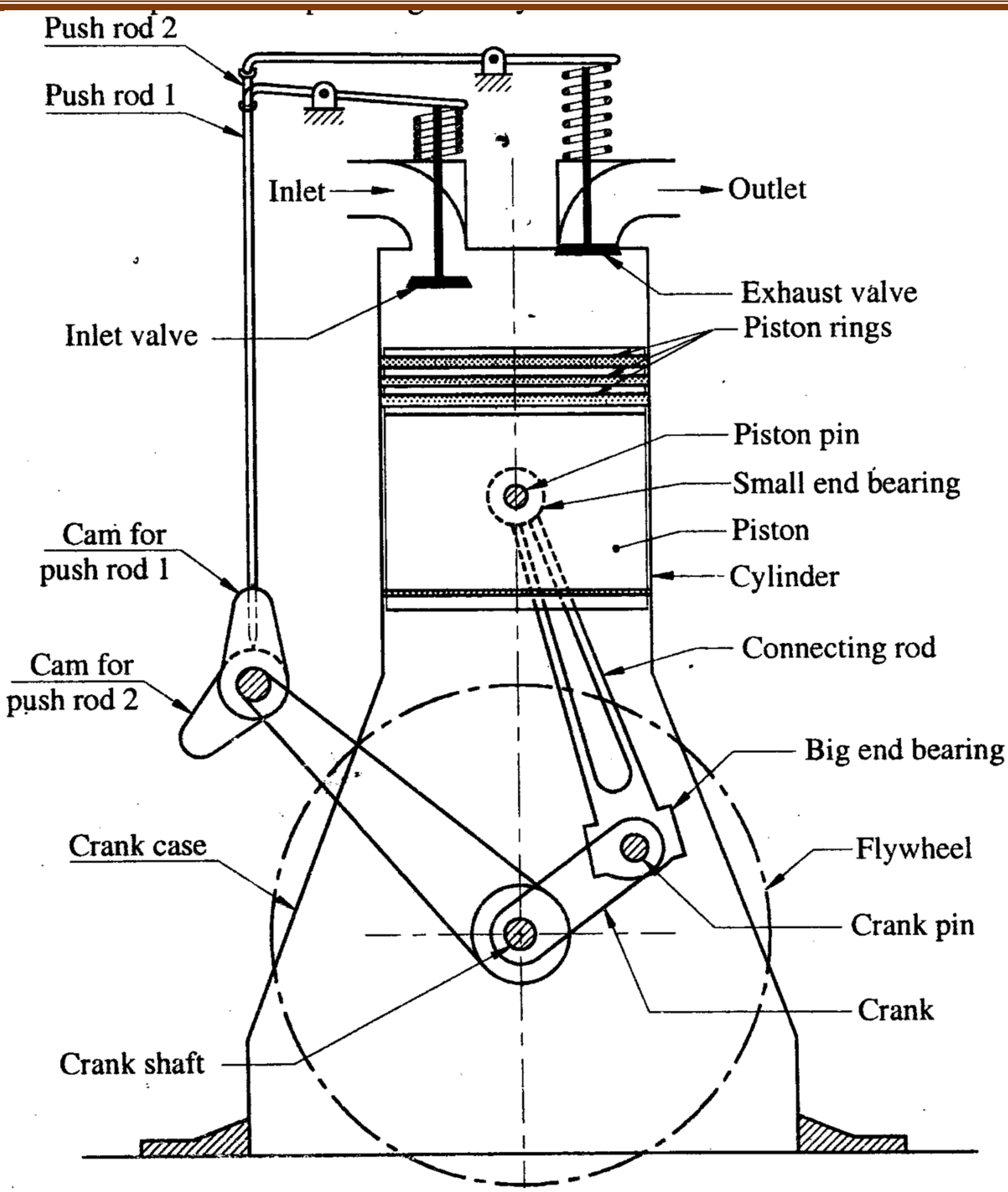


Fig. 7.2 I.C. Engine details

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 usually made of steel forging.

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 crankshaft 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. 7.2). 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.

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.

Terminologies used in IC engine

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.

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.).

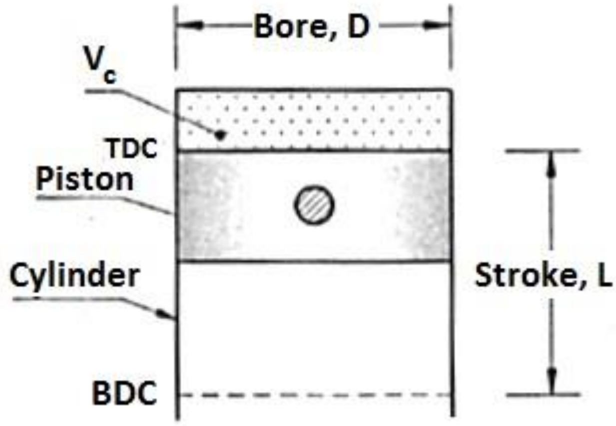


Fig. 7.3 Stroke and bore of piston

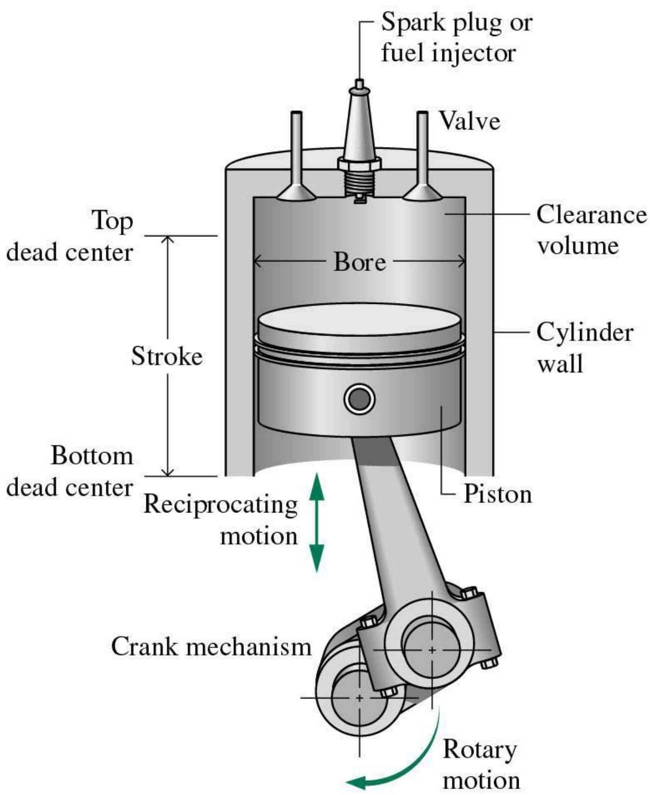


Fig 7.4 I.C engine nomenclature

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

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

This engine works on Otto cycle and uses petrol (or gas) as a fuel. In this engine spark is produced to ignite the charge. This type of engines work on constant volume combustion cycle as combustion takes place nearly at constant volume with increase of pressure.

In a petrol engine, the petrol is evaporated and also it is mixed with correct proportion of air by the device which is known as carburetor.

The whole cycle is completed in four strokes, namely

1. Suction stroke
2. Compression stroke
3. Working or Power stroke
4. Exhaust stroke

All these strokes are represented on P-V diagram in fig. 7.5.

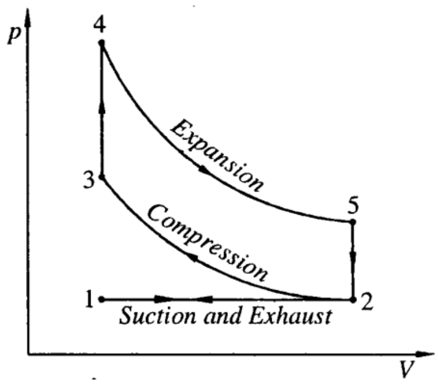


Fig. 7.5 p-V diagram of petrol engine

1. Suction stroke

During this stroke, inlet valve remains open and exhaust valve is closed, the pressure in the cylinder will be atmospheric.

The piston moves from TDC to BDC. So 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 in fig. 7.5.

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

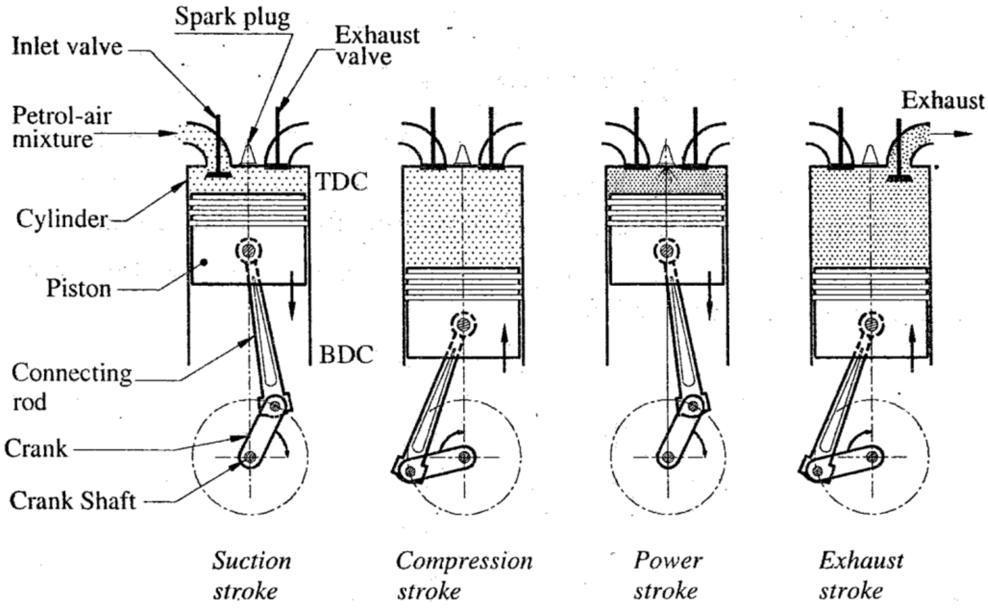


Fig. 7.6 Four stroke petrol engine

2. Compression stroke

As shown in fig., during this stroke both the inlet valve and exhaust valve remains closed. 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. 7.5 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.

3. Power or Expansion stroke

During this stroke both the inlet valve and exhaust valve remain 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 TDC 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.

4. Exhaust Stroke

During this stroke, the exhaust valve opens and the inlet valve remains closed. The piston moves from BDC to TDC 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 fig. 7.5.

At the end of the exhaust stroke, the exhaust valve is closed and inlet valve will open. Then there will be again a suction stroke and the same cycle will be repeated.

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. 7.7. The four stroke diesel engine cycle also consists of suction, compression, power, and exhaust strokes. Fig. 7.8 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. 7.8. A fuel pump supplies the fuel oil to the injector at higher pressure.

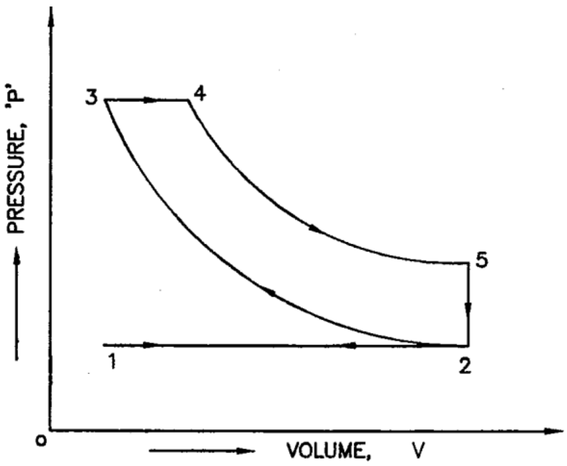


Fig. 7.7 p-V diagram of diesel engine

1. Suction Stroke

During this stroke, inlet valve remains open and exhaust valve remains closed, the pressure in the cylinder will be atmospheric. The piston moves from TDC to BDC position. Air from the atmosphere is drawn into the cylinder as the piston moves. This stroke is represented by horizontal line 1-2 on p- V diagram shown in Fig. 7.7.

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

2. Compression stroke

As shown in fig. 7.8 during this stroke, both inlet valve and exhaust valve remain closed. The piston moves from BDC to TDC. 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, 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.

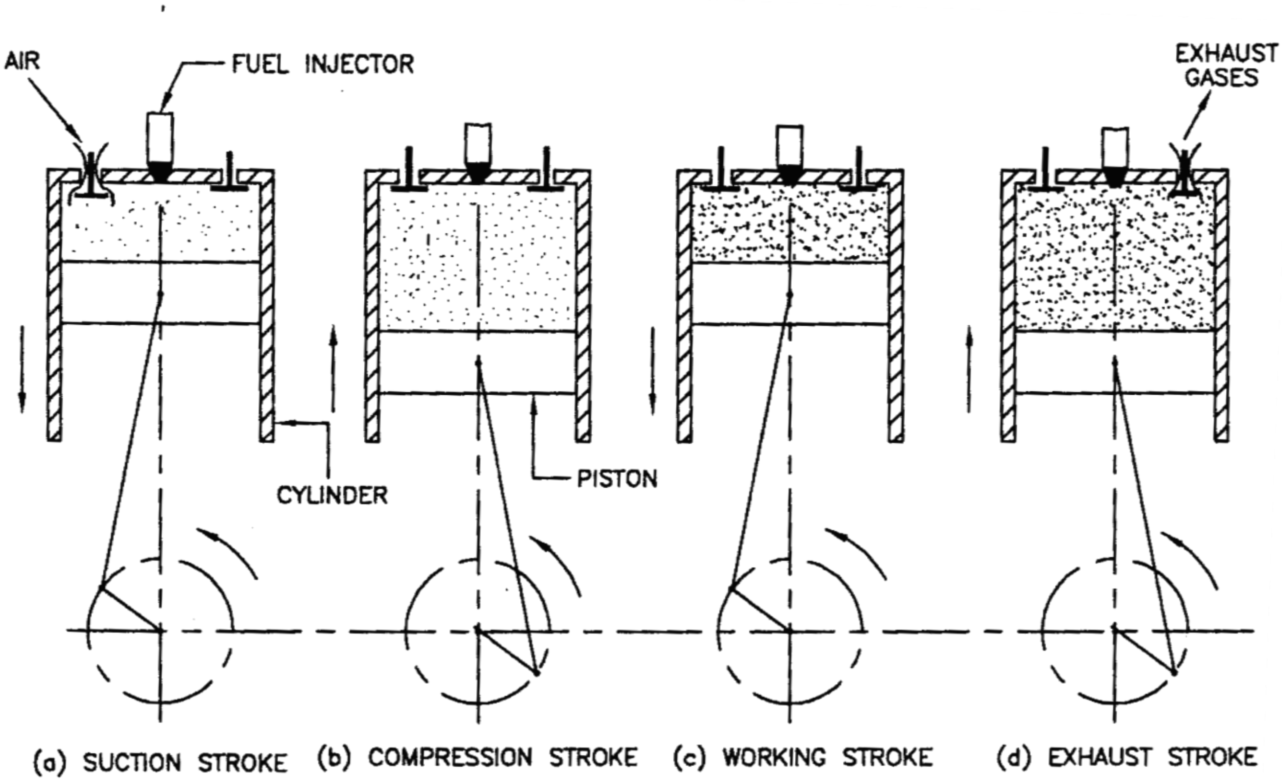


Fig. 7.8 Four stroke diesel engine

3. Power or Expansion stroke

During this stroke, both the inlet and exhaust valve remain 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. It is shown on P-V diagram by horizontal line (3-4).

The high temperature and high pressure gases expand and push the piston downward. Thus useful work is done during this stroke. As the piston moves from TDC 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. 7.7.

As the piston reaches BDC position, the exhaust valve opens and the pressure suddenly falls nearly to atmospheric pressure at a constant volume. It is shown by line 5-2 on P-V diagram.

4. Exhaust stroke

During this stroke, the exhaust valve remains opened 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. 7.7. Again inlet valve opens and a new cycle starts.

Difference between Petrol (S.I.) engine and Diesel (C.I.) engine

Sr.	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 mixture enters the cylinder during suction stroke	Diesel is pressurized with the help of fuel pump and 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	Fuel is ignited by the heat of compressed air no any external source is required
7	Engine speed	High (3000 RPM)	Low to medium (500 to 1500 RPM)
8	Thermal efficiency	Lower due to lower compression ratio	Higher due to higher compression ratio
9	Weight of the engine	Lighter	Heavier
10	Initial cost	Less	More
11	Maintenance cost	Less	Slightly higher
12	Running cost	Higher because petrol is costlier	Less because diesel is cheaper
13	Starting of engine	Easier starting even in cold weather	Difficult to start in cold weather

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.

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. 7.9. Partial vacuum is created in the crankcase until its lower edge uncovers the inlet port completely as shown in fig. 7.9(A).

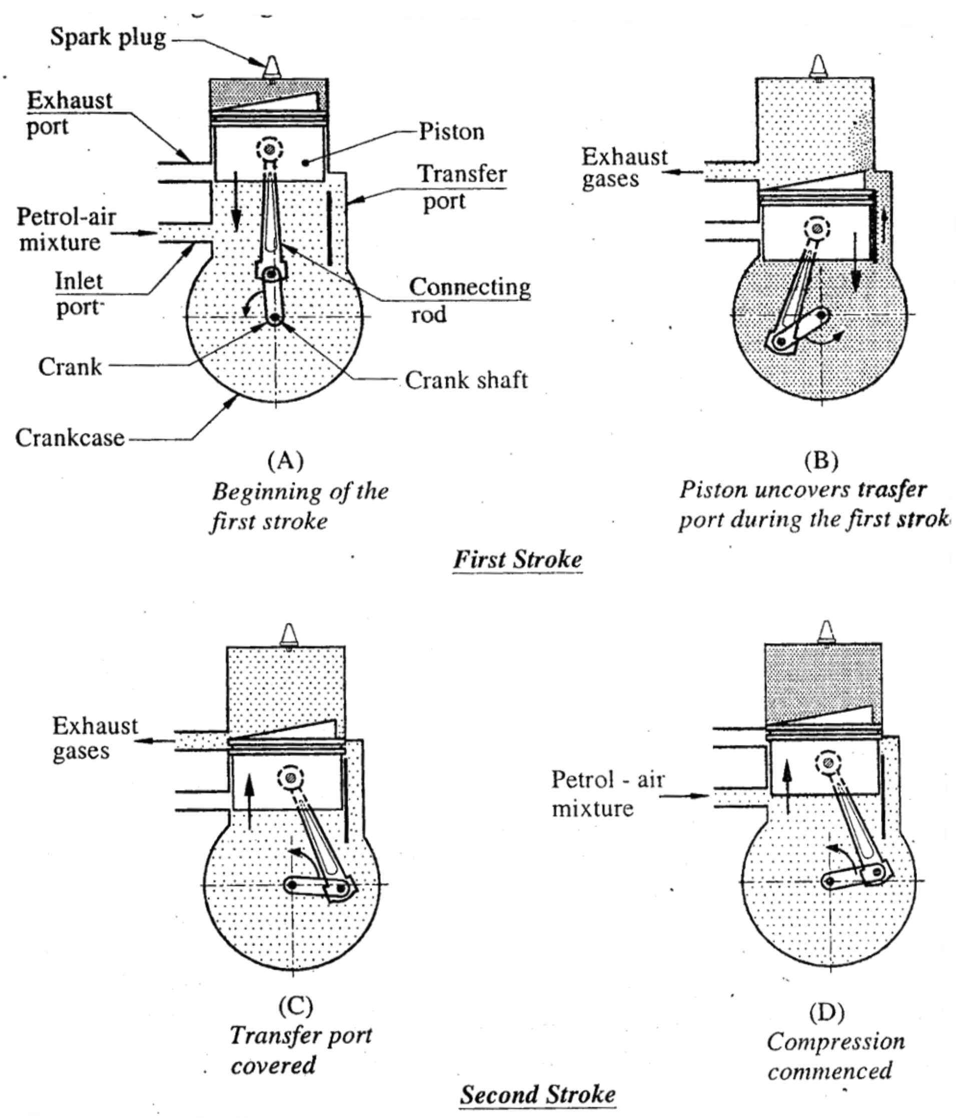


Fig. 7.9 Two stroke petrol engine

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. 7.9) to inlet port, into the crankcase as shown in fig. 7.9. 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 as shown in fig. 7.9 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. 7.9.

First stroke

At the beginning of the first stroke the piston is at TDC as shown in fig. 7.9. Piston moves from TDC to BDC. The electric spark ignites the compressed charge. The combustion of the charge will release the hot gases which will increase 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. 7.10.

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. 7.9. 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 come out through exhaust port as shown in fig. 7.9. 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 stops and then when it moves further up it covers the exhaust port completely as shown in Fig. 7.9(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.

Working of Two stroke diesel engine

Fig. 11 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.

First stroke

At the beginning of the first stroke, the piston is at TDC as shown in Fig. 7.10 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.11. 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. 7.10 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. 7.10. 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.

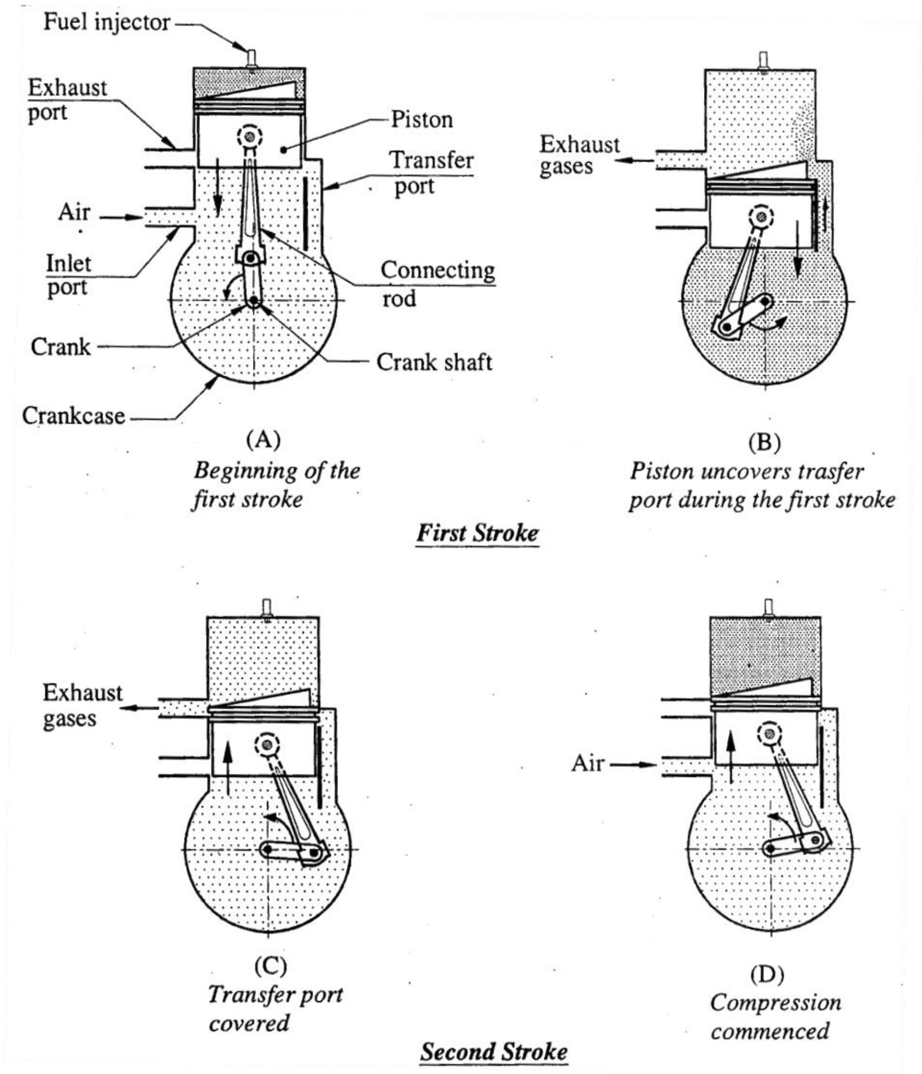


Fig. 7.10 Two stroke diesel engine

Second stroke

In this stroke the piston moves from BDC to TDC. When it covers the transfer port as shown in Fig. 7.10 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 TDC the first stroke repeats again.

Difference between two stroke and four stroke cycle engines

Sr.	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
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 they are operated by valve operating mechanism	In place of valves, ports are there which opens 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.

Engine performance parameters

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.

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

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, $N/m^2/cm$

For four stroke engine

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

$$I.P. = \frac{P_m LAn}{60000}\ \text{kW} \qquad where\ \ n = \frac{N}{2}$$

For two stroke engine

$$I.P. = \frac{P_m LAn}{60000}\ \text{kW} \qquad where\ \ n = N$$

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 = Effective radius of the brake drum, m

N = RPM of the crank shaft

T = Resisting torque, Nm

P_{mb} = Brake mean effective pressure

$$\therefore T = W \times R \quad Nm$$

$$B.P. = \frac{2\pi NT}{60000} = \frac{P_{mb}LAn}{60000} \quad \mathrm{k}W$$

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:

1. Rope brake dynamometer
2. Prony brake dynamometer
3. Hydraulic dynamometer
4. Eddy current dynamometer

Friction Power

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.

$$Friction\ power = I.P. - B.P.$$

Efficiencies

Mechanical efficiency:

It is defined as the ratio of the brake power to the indicated power. Mechanical efficiency is indicator of losses due to friction.

$$\eta_{mech} = \frac{B.P.}{I.P.}$$

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.

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

Brake thermal efficiency = Brake Power/ Heat supplied by fuel

$$\eta_{bt} = \frac{B.P.}{m_f \times CV}$$

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,

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

Relative efficiency:

It is the ratio of indicated thermal efficiency of an engine to air standard cycle efficiency.

$$\eta_{rel} = \frac{\eta_{it}}{\eta_{air}}$$

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.

$$\eta_{vol} = \frac{\text{Actual volume of charge or air sucked at atm. condition}}{\text{Swept volume}}$$

Specific power output:

The specific output of the engine is defined as the power output per unit area.

$$Specific\,output = \frac{B.P.}{A}$$

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.

$$SFC = \frac{m_f}{B.P.} Kg / \mathrm{k}Wh$$

Where,

m_f = Mass of fuel consumed in kg/hr and B.P. = Power produced in kW

Introduction

The pump is a mechanical device which conveys liquid from one place to another place.

Applications of Pumps

i. **Thermal engineering**
   a) To feed water into the boiler
   b) To circulate the water in condenser
   c) To circulate lubricating oil in the proper place
ii. **Agriculture and irrigation**
   a) To lift water from deep well
   b) To convey water from one place to another
iii. **Chemical industries**
   a) To convey liquid chemical from one place to another
iv. **Municipal water works and drainage system**
v. **Hydraulic control system**

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.

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).

i) Reciprocating pump

a) **Piston pumps**
   Single cylinder - single acting, double acting
   Double cylinder - single acting, double acting
b) **Plunger pump**
c) **Bucket pump**

ii) Rotary pump

a) Gear pump
b) Vane pump
c) Screw pump

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**
   a) Single stage
   b) Multi stage
2. **Propeller (Axial flow) pump**

3. **Mixed flow pump**
4. **Other**
   a) Jet Pump
   b) Air lift pump

Terminology used in pumps

Head

In the pumps, different forms of energy are expressed in terms of height which is called head.

Suction Head (h_s)

It is the vertical height of the centre line of pump shaft above the surface of liquid.

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.

Velocity Head (hv)

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.

Static Head (hst)

It is sum of suction and delivery heads.

Mathematically, $h_{st} = h_s + h_d$

Manometric Head (Hm)

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

Water power (Pw)

It is the power required by pump to handle the liquid to develop manometric 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

Shaft power (P_s)

It is the power input to shaft of the pump by motor.

Efficiency of pump (η_p)

It is ratio of water power to shaft power.

Mathematically, $\eta_p = P_w / P_s$

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.

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

Convert 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.

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.

Working

Forward stroke (Suction stroke):

The piston moves towards right, crank moves from 0° to 180^0, 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 180^0 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.

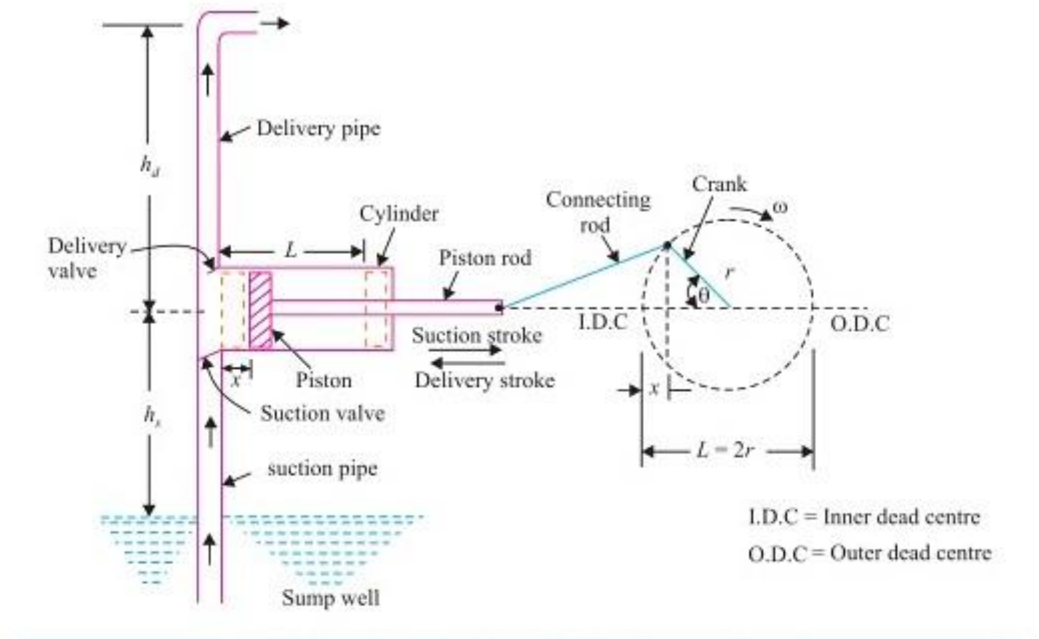


Fig. 8.1 Single acting reciprocating pump

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 fig. 8.2. 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.

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.

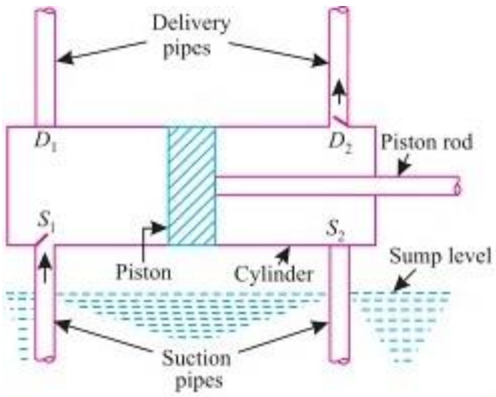


Fig. 8.2 Double acting reciprocating pump

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.

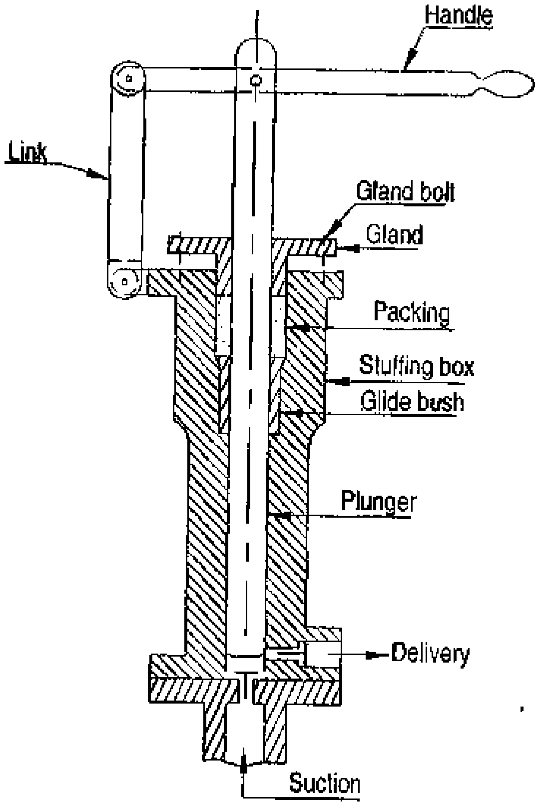


Fig. 8.3 Plunger pump

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.

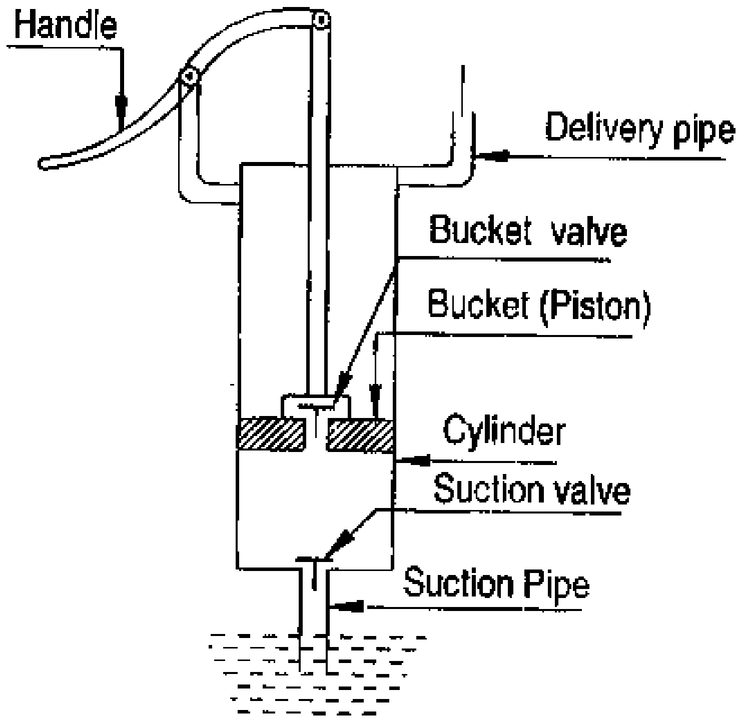


Fig. 8.4 Bucket Pump

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.

Types of rotary pumps

There are main three types of rotary pumps as,

1. **Gear pump**
2. **Vane pump**
3. **Screw pump-**

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.

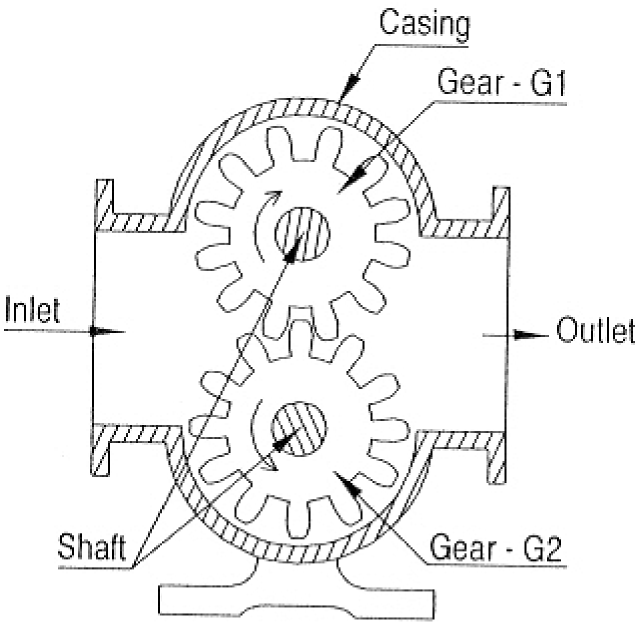


Fig. 8.5 Gear Pump

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 fig 8.6.

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.

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.

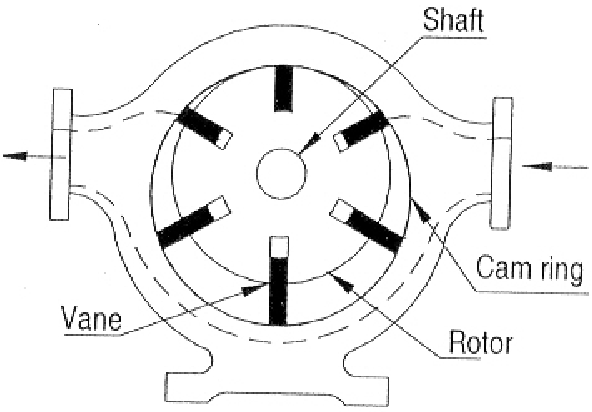


Fig. 8.6 Vane Pump

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 fig 8.7.

The liquid is carried between screw threads in pair of screws in mesh and is displaced axially as the screws rotate.

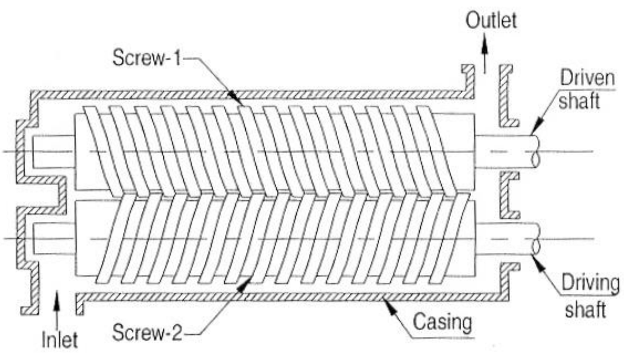


Fig. 8.7 Screw Pump

Classification of centrifugal pump

1. 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

2. According to number of stages,

a) Single stage
b) Multi-stage
  a) Impeller in series b) Impeller in parallel

Main parts of centrifugal pump

The impeller, casing, suction pipe, foot valve and strainer is main parts of centrifugal pump shown in fig 8.8. and are explained as under.

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.

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.

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.

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.

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.

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.

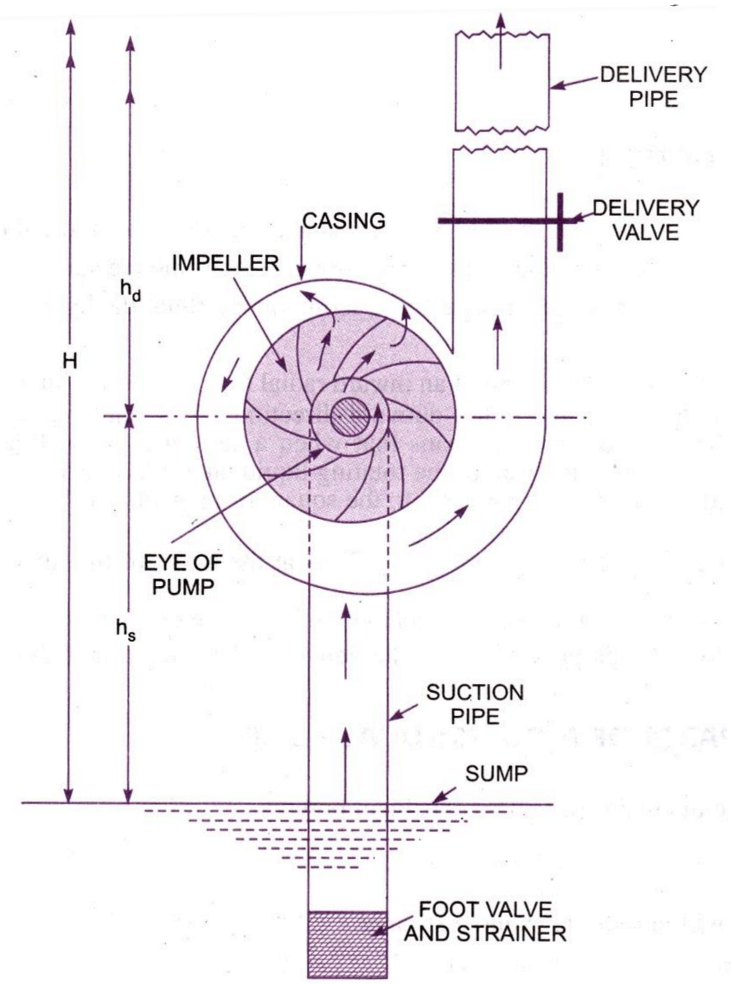
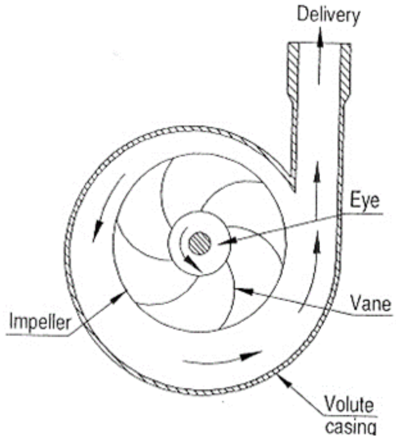


Fig. 8.8 Main parts of centrifugal pump

Volute type pump

In this type of centrifugal pump, impeller is surrounded by the spiral casing known volute chamber as shown in fig. 8.9. 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.



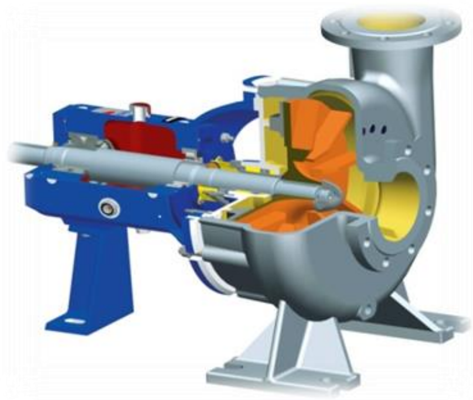


Fig. 8.9 Volute type pump

Disadvantage

Volute casing has greater eddy losses which decrease overall efficiency.

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 8.10. this chamber is known as vortex or whirlpool chamber.

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.

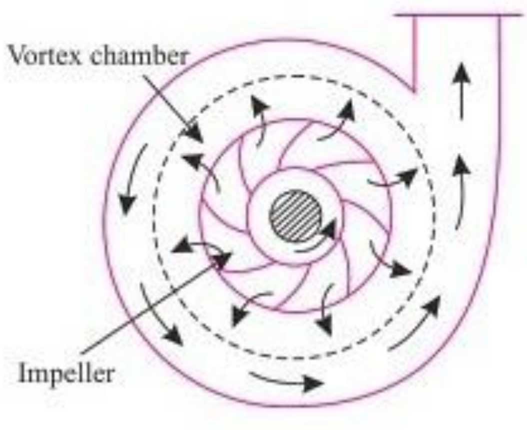


Fig. 8.10 Vortex type pump

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 8.11.

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.

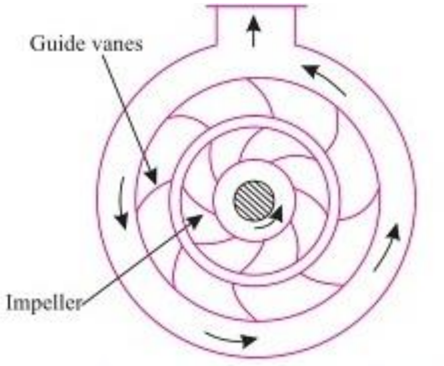


Fig. 8.11 Diffuser type pump

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.

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.

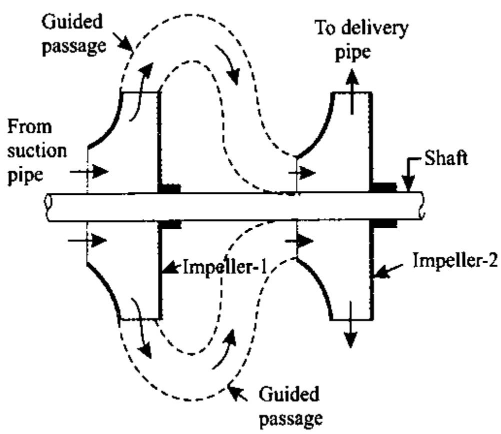


Fig. 8.12 Impeller in series

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.

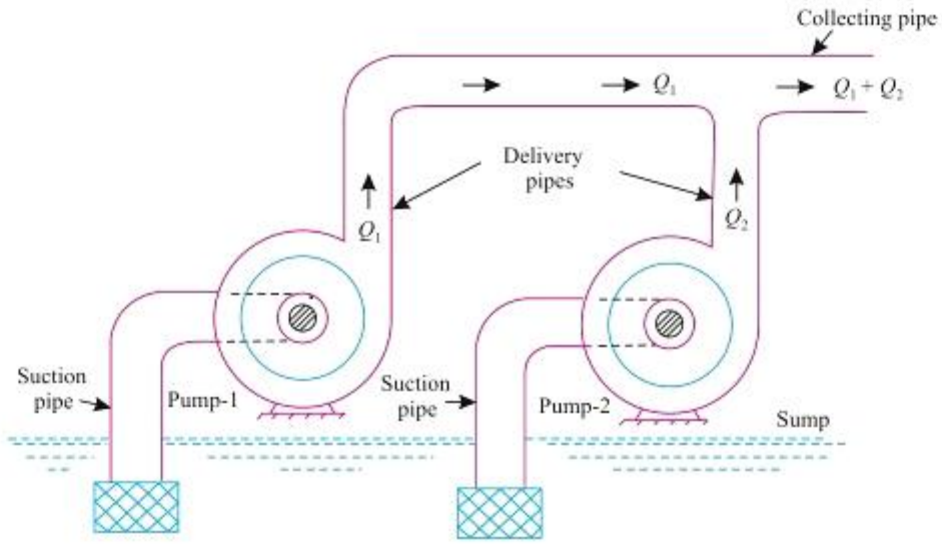


Fig. 8.13 Impellers in parallel

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 starting the pump air must be 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.

Types of priming

The pump can be primed by any of the following methods.

Priming by hand (Manually priming)

In this method of priming water is poured in the pump through priming funnel as shown in fig. 8.14. When priming is being done, an air escapes through air vent valve. When all air is exhausted from the casing, suction pipe and portion of delivery pipe, the water will flow out through vent valve, indicating that priming is completed. The air vent valve is closed once the priming is completed.

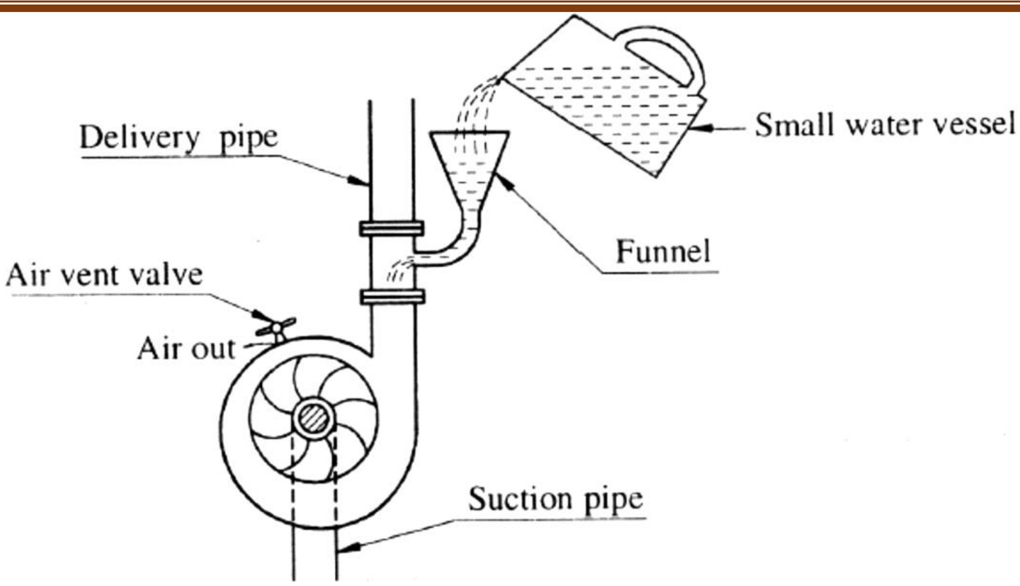


Fig. 8.14 priming by hand

Priming with vacuum pump

In this method, the small size reciprocating pump is used to priming the main centrifugal pump. The suction line of reciprocating pump is connected to the delivery line of main centrifugal pump. When manually operated reciprocating pump is started, this pump lifts the water from sump to suction line, casing and portion of delivery line of centrifugal pump. If now centrifugal pump is started, it will able to deliver the water to desired level.

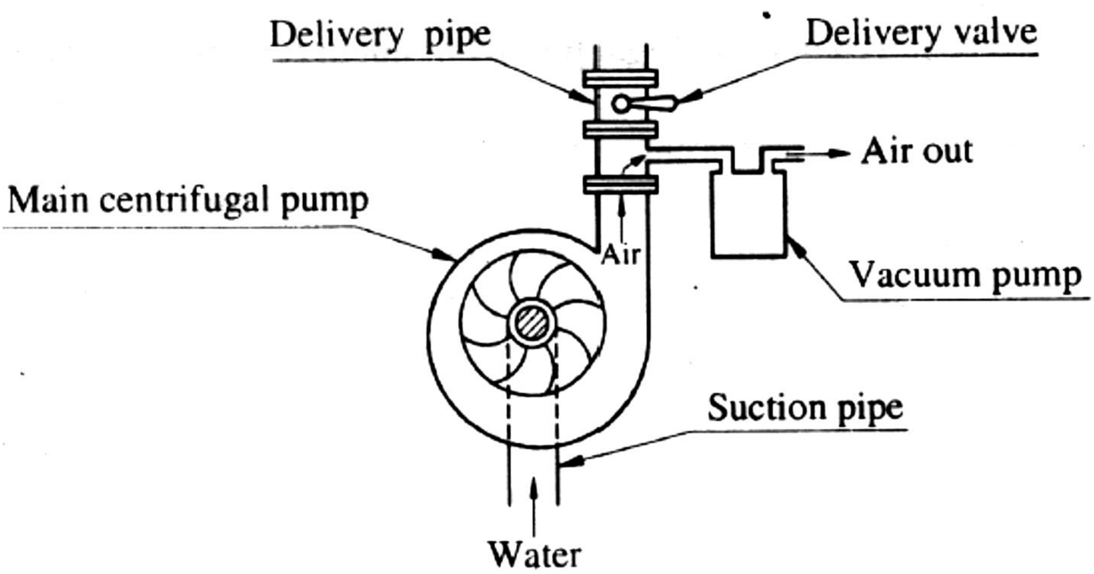


Fig. 8.15 Priming with vacuum pump

Priming with jet pump

In this method, water available at high head is allowed to flow through a nozzle as shown in fig. The nozzle is so designed that at the jet outside the nozzle the pressure is less than the atmospheric pressure so it is possible to suck water from the sump. The nozzle is generally fixed in suction pipe of centrifugal pump near the sump level.

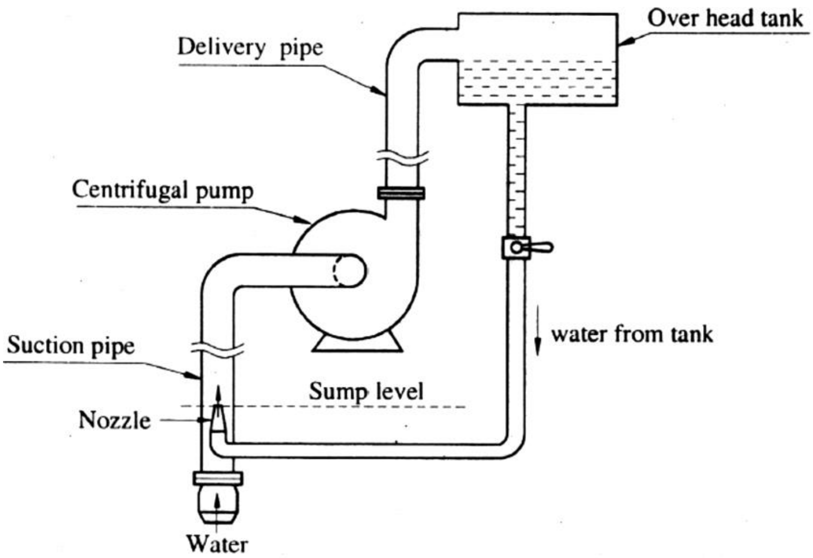


Fig. 8.16 priming with jet pump

Priming with separator

In this method, air separator is provided on delivery side of pump and bent suction pipe portion is provided at inlet of the pump as shown in fig 8.17.

Bent suction pipe portion always contain some liquid. When pump is stared, this liquid along with air from rest of suction pipe is sucked into impeller and is delivered to separator.

Since head developed initially is not sufficient, no liquid is delivered at delivery end. The liquid heavier than air, so it falls back into separator and air moves in upward direction.

Therefore the liquid and air are separated in separator, the air escapes through delivery pipe and liquid return back to impeller. The Return of liquid to impeller makes the mixture sucked and this process is continued until all air is removed from suction side. Then liquid is lifted by pump from the sump.

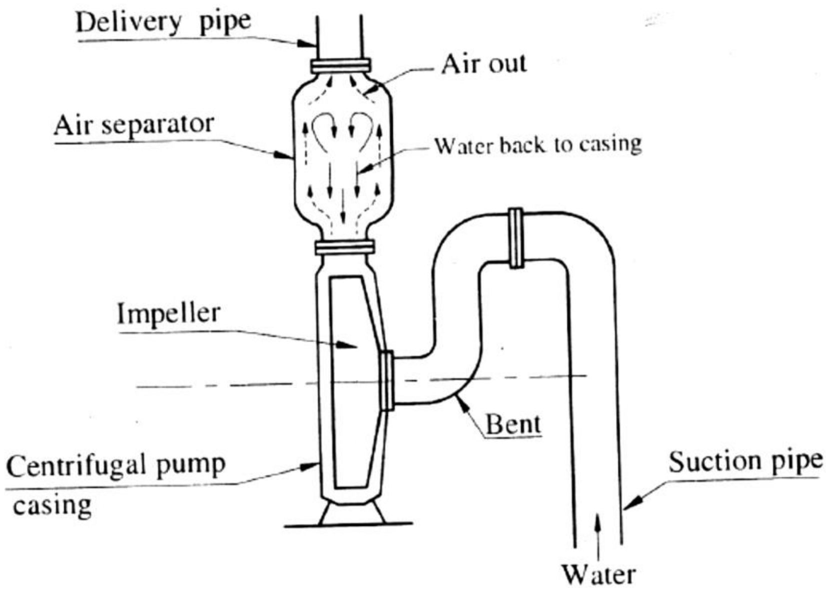


Fig. 8.17 priming with separator

Introduction

A machine which takes in air at low pressure and compress it to high pressure with the help of some suitable arrangement i.e. a reciprocating piston and cylinder arrangement or a rotary arrangement, is called an air compressor.

Uses of Compressed air

1. The compressed air has number of application in different industries. They are listed as under:
2. Operating pneumatic drill, hammers for the formation of rivet heads.
3. For filling air in automobile tyres.
4. For spray painting.
5. Increasing inlet pressure of I.C. Engine.
6. To operate air motor in mines where fire risks are more.
7. Pumping of water.
8. Gas turbine power plant.
9. Conveying the materials like sand and concrete along a pipe line.
10. For sand blasting.
11. Operating blast furnaces.
12. Operating air brakes used in buses, trucks, trains etc.

Classification of compressors

The air compressor can be classified in number of ways.

1. According to method of compression

a. Reciprocating compressor

This type of compressor compresses air by reciprocating action of piston inside a cylinder. It is suitable for producing high pressure.

b. 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.

c. 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

a. Low pressure - up to 1.1 bar
b. Medium pressure - 1.1. to 8 bar
c. High pressure – 8 to 10 bar
d. Very high pressure - above 10 bar

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. These are capable with low volume flow rate. Examples: Reciprocating compressor, Roots 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**
   a. Single stage compressor - pressure up to 5 bar
   b. Multistage compressor - pressure above 5 bar

5. **According to method the number of cylinder**
   a. Single cylinder
   b. Multi cylinder

6. **According to method the pressure limit**
   a. Fans - pressure ratio 1 to 1.1
   b. Blowers - pressure ratio 1.1 to 2.5
   c. Compressor - pressure ratio above 2.5

7. **According to volume of air delivered**
   a. Low capacity - volume flow rate up to 9 m^3/min
   b. Medium capacity - volume flow rate 10 m^3/min to 300 m^3/min
   c. High capacity: Volume flow rate above 300 m^3/min

8. **According to fluid to be compressed**
   a) Air compressor
   b) Gas compressor
   c) Vapour compressor

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.

There are two valves, i.e. intake valve and delivery valve. The valves are generally pressure differential type. Thus they operate automatically by the difference of pressure across the valve.

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 TDC, 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.

The piston moves towards the TDC 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.

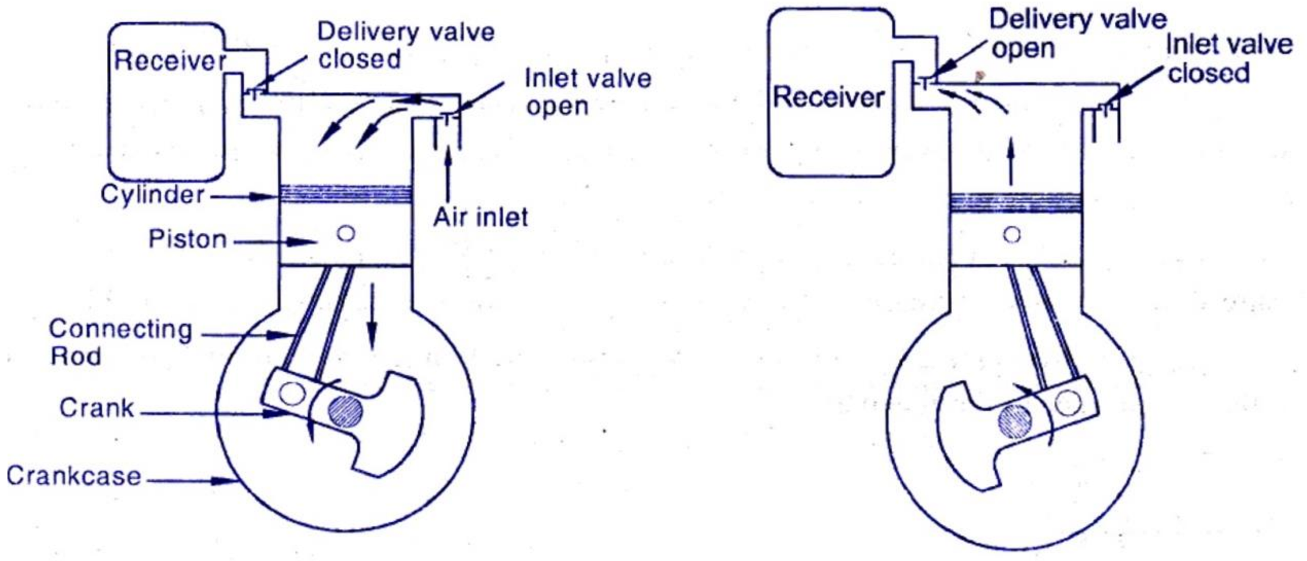


Fig. 9.1 Reciprocating air compressor

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.

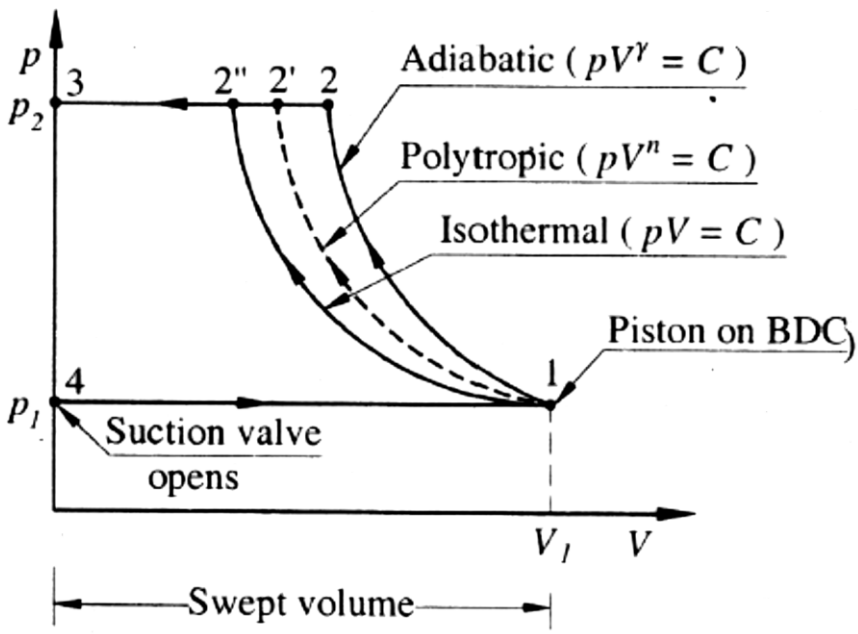


Fig. 9.2 P-V diagram without clearance

Case- (2) Operation with clearance

In actual compressor always there is 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 follows $PV^{\gamma} = C$

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 fig.

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, 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.

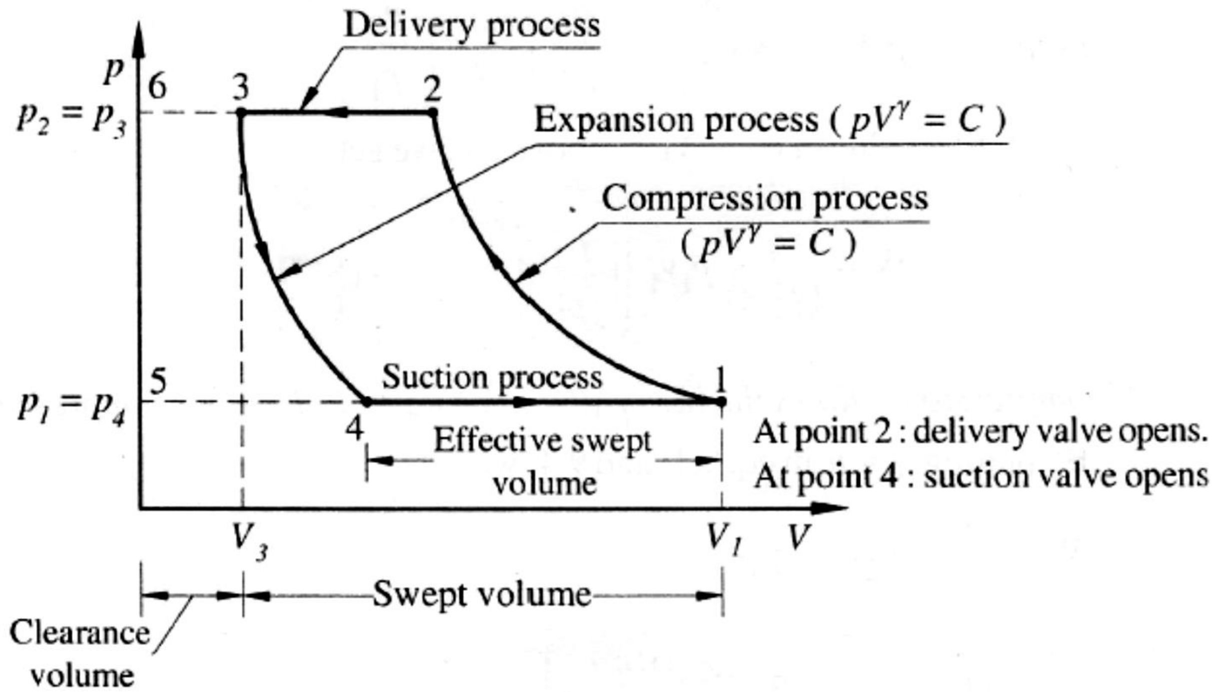


Fig. 9.3 P-V diagram with clearance

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.

Problems with single stage compression are,

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.

The increase in temperature of air causes reduction in density of air, hence the mass flow through compressor decreases.

The operation at high pressure and temperature will need heavy working parts.

Working

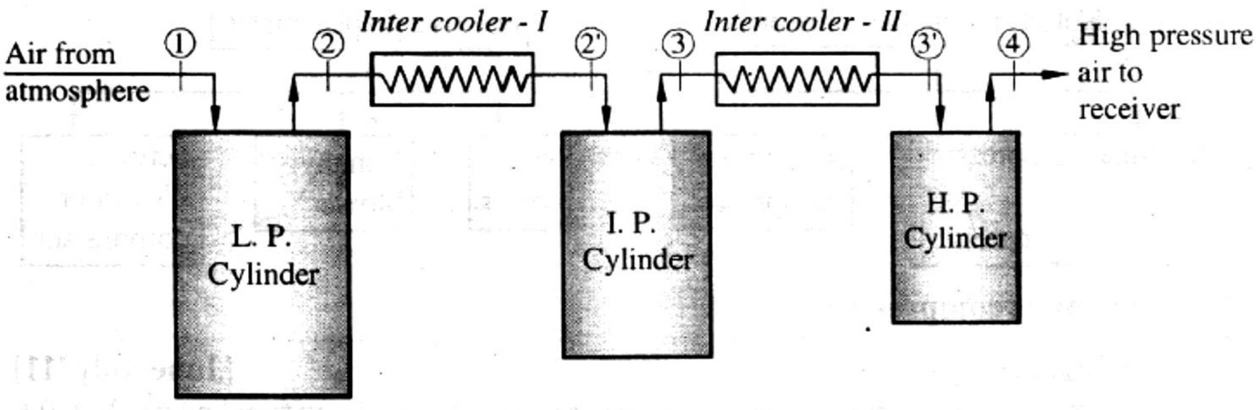


Fig. 9.4 Concept of multistage compressor

In low pressure (L.P.) cylinder, air is compressed adiabatically from point 1 to 2. This compressed air is passed through intercooler-I where it is cooled from 2 to 2'. The air coming from intercooler-I is then admitted into the intermediate pressure (I.P.) cylinder where it is compressed adiabatically from 2' to 3. The compressed air from I.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.

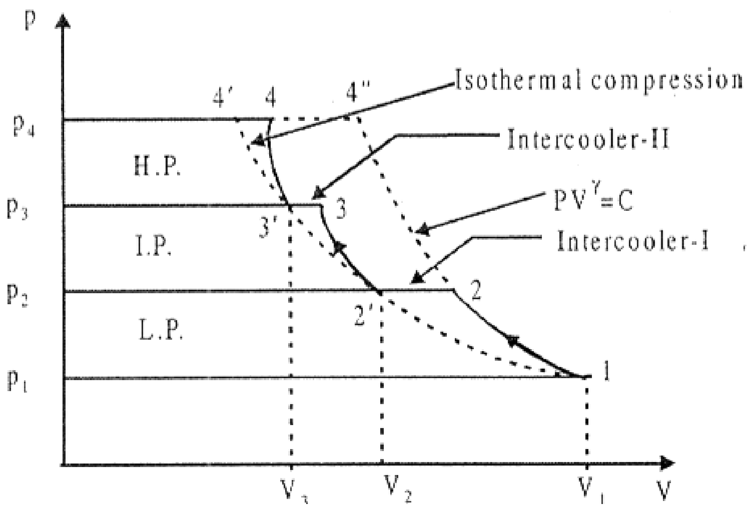


Fig. 9.5 P-V diagram of multistage compressor

Advantages

1. Without inter-cooling, the curve of compression will follow the path (1- 4”), hence the saving in work input due to inter-cooling.
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.

Rotary air compressor

In rotary air compressor, the air is entrapped between two sets of engaging surface and the pressure of air is increased by squeezing action or back flow or the air.

Types of Rotary air compressor

1. Positive Displacement Compressor

a) Roots blower
b) Vane compressor

2. Dynamic Compressor

a) Centrifugal compressor
b) Axial-flow compressor

Roots Blowers

Construction

The two lobe type roots blower is shown in fig. 9.6. For higher pressure ratios, three and four lobes versions are used.

One of the rotor is connected to the drive. The second rotor is gear driven from the first. Thus both the rotors, rotate in phase. In order to seal delivery side from the inlet side, the profile of the lobs is of cycloidal or involute. This sealing continues until delivery commences.

To reduce wear, there must be some clearance between the lobes and between the casing and the lobes. Although this clearance will form a leakage path for compressed air and will have an adverse effect on efficiency when pressure ratio increases.

In order to achieve the acceptable efficiency of the blower a very small clearance of about 0.2 to 0.5 mm is provided. The pressure at the delivery is not constant. Single acting blower can develop the pressure up to twice the inlet pressure.

Principle of operation

The operation can be considered as taking place in two distinct phases suction and discharge as describe below.

Suction phase

The rotation of the rotors produces space, which increases the volume as rotation continues. The gas therefore flows into the machine to fill the space.

The flow of gas into the blower continues involving both the rotors.

A quantity of gas is trapped between one rotor and the casing for a very brief interval. This part of the blower is not open to the suction. No gas flows into it. The gas continues to flow into the space produced by the rotation of the other rotor. This rotor is carrying out the same cycle as the first but 90 ^{0} behind it.

Discharge Phase

The trapped volume is at suction pressure as it has simply been drawn in by the movement of the rotors. There is no internal compression of gas as there is no meshing of rotors prior to the release to discharge. Continued rotation of rotors, opens \ the trapped space to the discharge port.

As the Pressure in the discharge port is higher than suction pressure, the movement that the trapped volume opens to the discharge Port, a back flow of gas from discharge takes Place. This will increase its Pressure up to discharge level. The continued rotation then pushes out the gas into the chamber (Receiver).

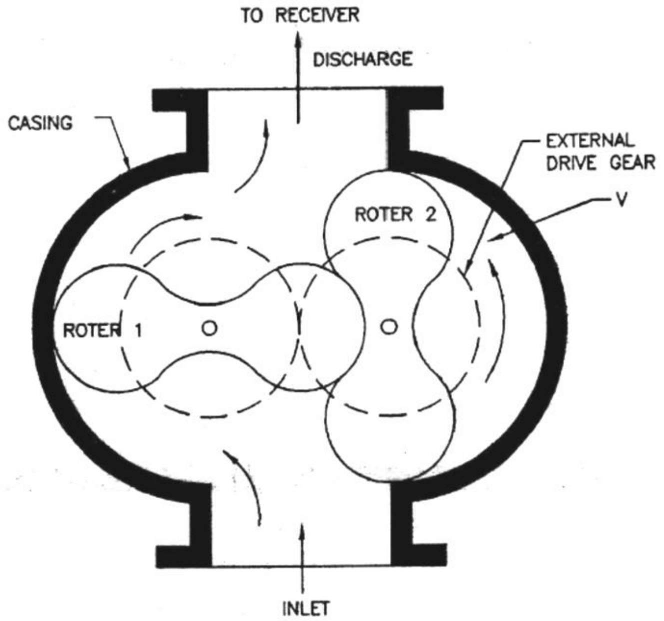


Fig. 9.6 Roots blower

Vane compressor

Construction

It consists of a rotor mounted eccentrically in the body. This rotor is supported by ball and roller bearings in the end cover of the body. The rotor is slotted to take the blades. These blades are made from non-metallic material usually fiber. The casing of the compressor is circular in which the drum rotates during rotation.

The vanes remain in contact with the cylinder. The slots in which the blades are fixed are cut radially into the rotor. The blades or vanes can slide in and out due to the centrifugal forces setup by the rotary motion of the rotor. The circular casing is provided with one inlet and one outlet port. The space between the rotor and its casing is sub-divided into a number of compartments by these, vanes. Two consecutive vanes form one compartment. Due to eccentric motion of the rotor the volume of each compartment keeps on changing. It can develop the pressure up to 9 bar and delivered 15 m^3/min of air.

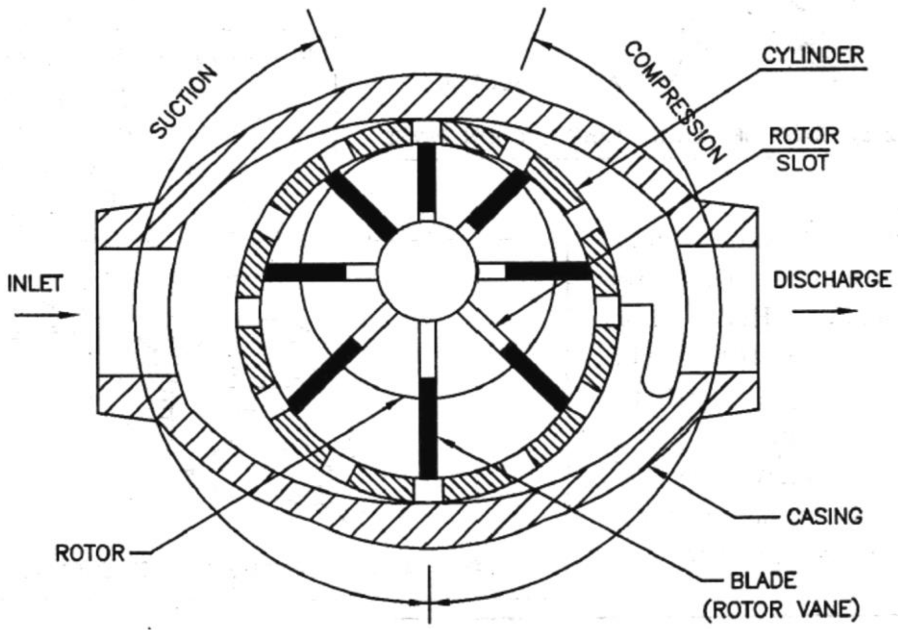


Fig. 9.7 Vane compressor

Principle of operation

The operation can be considered to take place in three phases. Suction, internal compression and discharge.

Suction phase

The relative position of the rotor and casing is clearly shown in fig. The start of the suction phase is indicated for one space between two of the vanes. The rotation of the rotor causes space to be formed between the vanes, the rotor and casing. This space is connected to the suction port so that gas from the suction passes into the space to fill it.

The continued rotation of the rotor increases the space open to the suction. Hence more gas flows in, to fill it. This process continues until the space into which the gas is flowing stops increasing. This will depends on the numbers of vanes in the compressor.

After this point the enclosed volume starts to reduce if it is still connected to the compressor suction gas will be dispelled. The suction port is positioned to be cut off as soon as the vanes move beyond this point.

Internal Compression Phase

The reduction in volume which occurs due to continued rotation, thus causes internal compression to take place. This will continue until the leading vane moves over discharge port. This will allow , the trapped gas to be released. The positioning of the discharge port determines the amount of internal compression.

Discharge phase

It is the final phase of operation. When the leading vane passes the discharge port , the gas is open to discharge and is expelled.

Centrifugal Compressor

A centrifugal compressor is used to supply large quantities of air at low pressures. The main features of the compressor are shown in Fig..

Construction

It consists of an impeller I. It carries a disc D. On this disc D, a large number of radial vanes or blades B are mounted. The impeller is mounted on the compressor shaft S. This shaft is usually rotates at high speed (20.000 to 30,000 RPM). C is a volute casing, it is known as diffuser. The impeller is shrouded by means of the casing. It surrounds the impeller in such a way that it forms the diverging passages for the air. Air coming out of the diffuser is collected in the casing of the compressor. It is then taken out from the out let O.

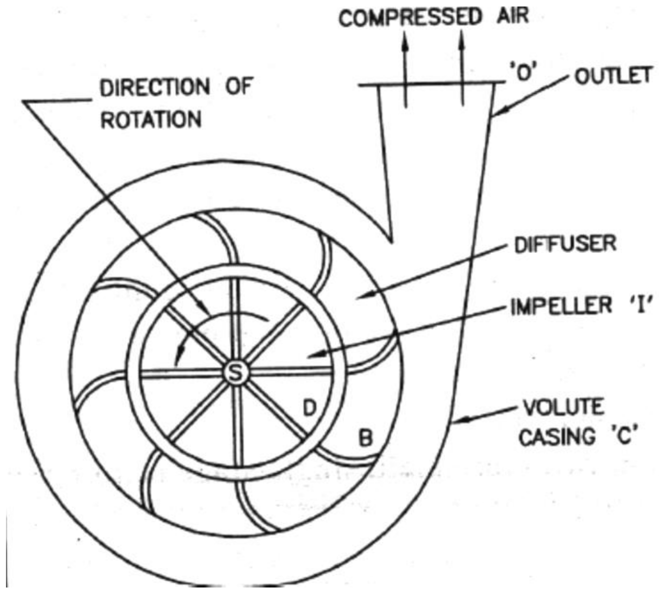


Fig. 9.8 Centrifugal compressor

Working

Air at low velocity and atmospheric pressure enters the compressor through eye E. It flows radially outward through the impeller blades. This air is subjected to a centrifugal force while passing through the impeller. The pressure and velocity increases in the impeller. The high-velocity air passes through the convergent passages formed by diffuser blades. The velocity is reduced. This decrease in velocity (K.E) of the air increases its pressure. It is found that, nearly half the pressure of the air is developed in the impeller and the remaining half in the diffuser. The compressor shown in fig. 9.8 is a single stage centrifugal compressor. The pressure ratios of 4 to 6 are common. For higher pressure ratios, multi-stage compressors are used

Axial Flow compressor

Construction

An axial flow compression stage consists of a row of moving blades arranged round the circumference of a rotor. A row of fixed blades arranged round the circumference of a stator.

The air is flowing axially through the moving and fixed blades in turn. At the entry, stationary guide vanes are provided at the entry to the first row of moving blades.

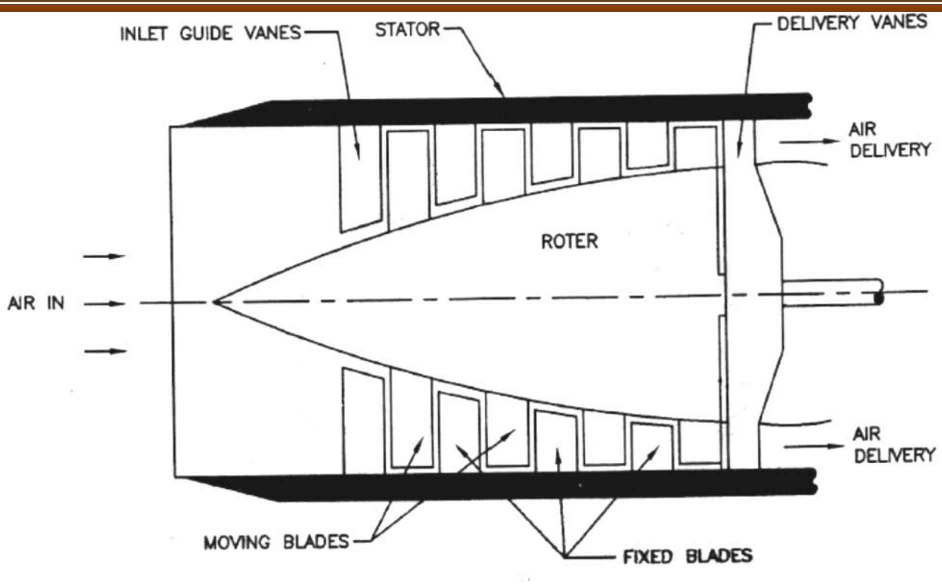


Fig. 9.9 Axial flow compressor

Working

The compression is performed in a similar manner to that of the centrifugal type. The work input to the rotor shaft to the air is by the moving blades. This will accelerate the air. The velocity of the air relative to the blades is decreased as the air passes through them because of the space provided between blades. This reduction in velocity increases the pressure. The air is then further diffused in the stator blades.

The stator blades are also arranged to form diffuser passages. The fixed stator blades guides the air by changing its angle in order to enter the second row of moving rotor blades. The number of stages are usually large.

These compressors are capable of developing pressure ratios of 1.2 to 1.3 per stage. These compressors can develop pressures up to 8 bar and deliver 1 to 50 m^3/s of air. Thus in order to achieve above pressure ratio of 8, about 6 stages is required.

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 heat pump and refrigerator.

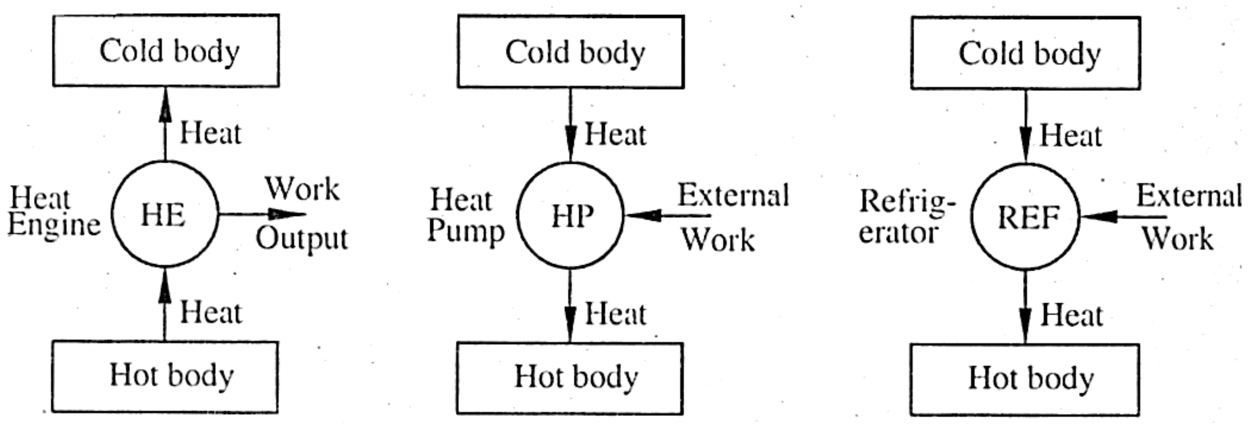


Figure 10.1 Heat Engine, Heat Pump and Refrigerator

Heat pump

It is device which absorbs the heat from cold body (surrounding) and deliver to hot body as shown in fig. 10.1 and maintain constant temperature of hot body for useful purpose. In this devise, external work required to convey heat from cold body to hot body.

Refrigerator

It is a device which removes heat from cold body and reject to hot body (surrounding) and maintains low temperature for useful purpose. In 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.

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.

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). The refrigerant is working medium under goes various processes of refrigeration cycles which are used to produce refrigeration.

Properties of a good refrigerant

a) It should have high latent heat of evaporation and low specific volume.
b) It should have good thermal conductivity for rapid heat transfer.
c) It should be non-toxic, non-flammable and non-corrosive.
d) It should have low specific heat in liquid state and high specific heat in vapour state.
e) It should have high co-efficient of performance.
f) It should be economical in initial cost and maintenance cost.

Application of refrigeration

a) Storage and transportation of food stuffs as dairy products, fruits, vegetables, meat, fishes etc.
b) Preservation of medicines and syrups.
c) Manufacturing of ice, photographic films, rubber products.
d) Processing of petroleum and other chemical products.
e) Liquification of gases like N_2, O_2, H_2 etc.
f) Cooling water.
g) Comfort air conditioning of auditoriums, hospitals, residence, offices, factories, hotels, computer rooms etc.

Refrigerants commonly used in practice

1) NH_3 (Ammonia)

Properties

Highly toxic, flammable, good thermal properties, highest refrigerating effect per kg of refrigerant.

Uses

It is widely used in large industrial and commercial refrigeration system. It is mostly used with 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. It gives low refrigeration effect.

Uses

It is used in marine refrigeration system.

3) Air

Properties

Easily available without cost, non-toxic, completely safe refrigerant, low COP.

Uses

It is used in aircraft air-conditioning system.

4) R-11 (Trichloro monofluoro methane) or Freon-11

Properties
Non-toxic, Non-flammable and Non-corrosive.

Uses
It is used in 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 and most suitable refrigerant.

Uses
It is used in domestic vapour compression refrigeration.

6) R-22 (Monochloro - difluro methane) or Freon -22

Properties
Non-toxic, Non-flammable, Non-explosive Required less compressor displacement.

Uses
It is used in commercial and industrial low temperature applications (in air conditioning).

Refrigeration effect and unit of refrigeration

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 of refrigeration.

1 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 0 ^{0}C.

The latent heat of ice is 335 kJ/kg, the refrigeration effect produced by 1 ton ice in 24 hours is,

$$=\frac{335\times1000}{24}\,{}^{KJ}\!/_{hr}=14000\,{}^{KJ}\!/_{hr}=\frac{14000}{60}\,{}^{KJ}\!/_{\min}=232.6\,{}^{KJ}\!/_{\min}=\frac{232.6}{60}\,{}^{KJ}\!/_{s}=3.8888KW$$

In actual practice, 1 ton = 900 kg considered for calculation of 1 ton of refrigeration,

$$\therefore 1\text{ ton}=\frac{335\times900}{24}\,{}^{KJ}\!/_{hr}=210\,{}^{KJ}\!/_{\min}=3.5KW$$

$$\therefore 1\text{ ton of refrigeration}=210\,{}^{KJ}\!/_{\min}=3.5KW$$

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.

Mathematically, $\text{COP} = \dfrac{\text{Refrigerating effect}}{\text{Work of compressor}}$

Types of refrigerators

The refrigerator can be classified as follows.

1. 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.

2. 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

Vapour Compression Refrigeration system (VCRS)

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.

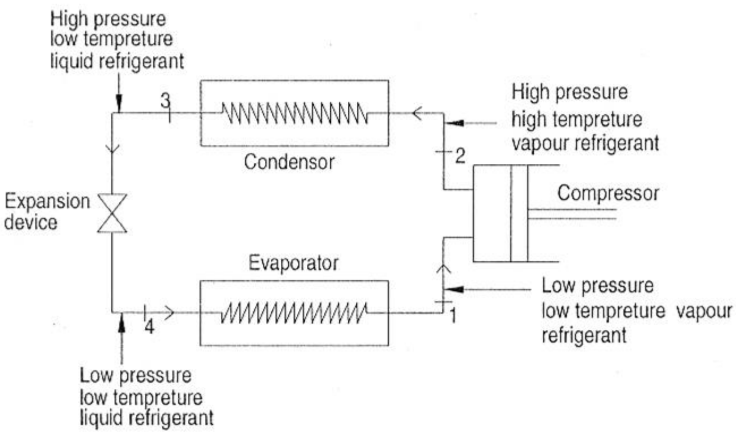


Fig. 10.2 Vapour compression refrigeration system

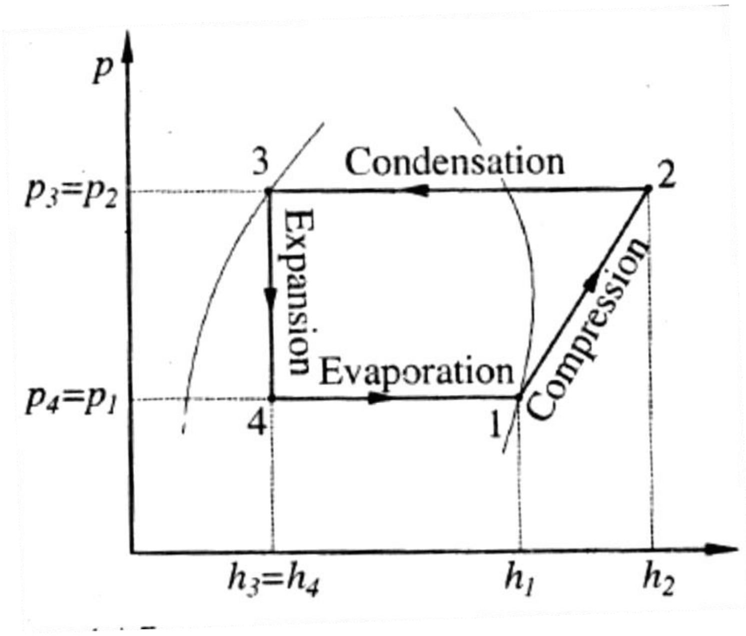


Fig. 10.3 P-h diagram

Functions of main parts of vapour compression system are,

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.

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.

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.

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.

Domestic vapour compression refrigerator

Construction

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, 275litres,1000 liters.

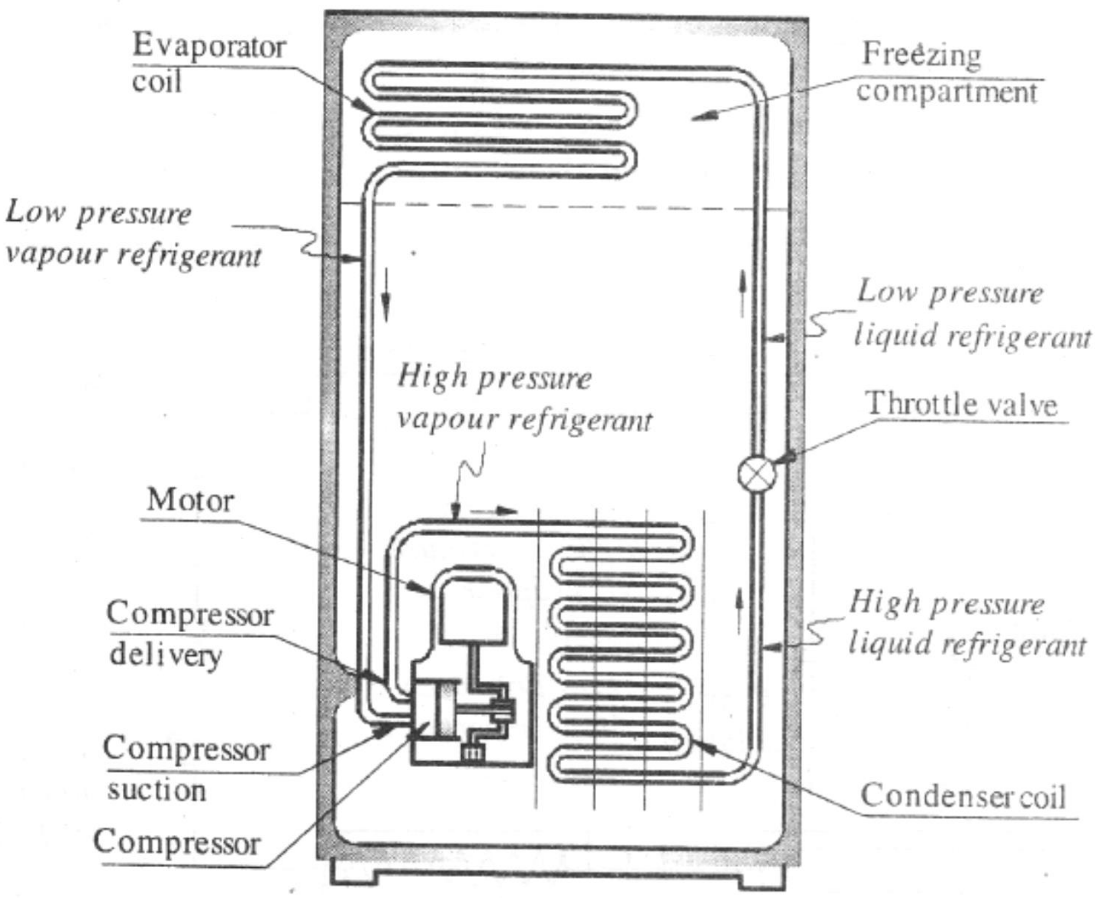


Fig. 10.4 Domestic vapour compression refrigerator

Vapour Absorption Refrigeration System (VARS)

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.

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.

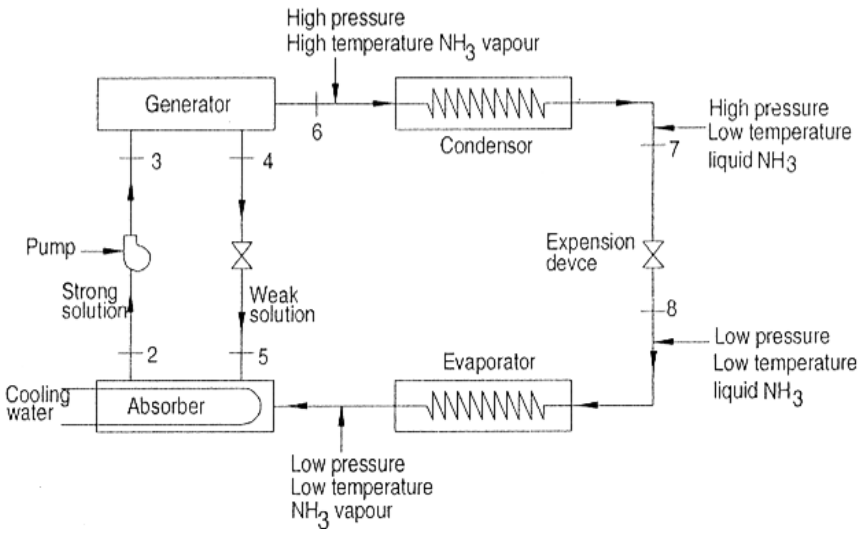


Fig. 10.5 vapour absorption refrigeration system

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.

Comparison between vapour compression and vapour absorption systems

Table 10.1 Comparison between VCR and VAR

Sr. No	Particulars	Vapour compression system (VCR)	Vapour Absorption 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

Air conditioning

Air conditioning is not a process of only heating or cooling to some desired temperature. Air conditioning is dealing with conditioning or controlling the air. The complete process of air conditioning includes following processes.

1. Cooling or heating air
2. Addition of moisture in air (Humidification) or removal of moisture from air (Dehumidification)
3. Controlling movement of air
4. Purification of air
5. Addition of fresh air from outside
6. Distribution of air

The **air conditioning** is defined as the simultaneous control of temperature, air humidity, air movement and air cleanliness.

Applications of air conditioning

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.

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.

Components of air conditioning system

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

Classification of Air conditioning system

1. **According to arrangement of equipments**
   - **a.** 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.

     Example : Window air conditioner and Split air conditioner

   - b. 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.
2. **According to the purpose**
   - *a.* Comfort air conditioning system
   - *b.* Industrial air conditioning system
3. **According to season of year**
   - *a.* Winter air conditioning system
   - *b.* Summer air conditioning system

Window air conditioner

The window air conditioner mainly used for conditioning of air in the room. Commonly it is mounted in a window, hence it is known as window air conditioner.

The window air conditioner unit consists of following components as shown in fig 10.6.

Refrigeration unit
Evaporator/cooling coil, condenser, compressor, expansion device

Air circulation fan

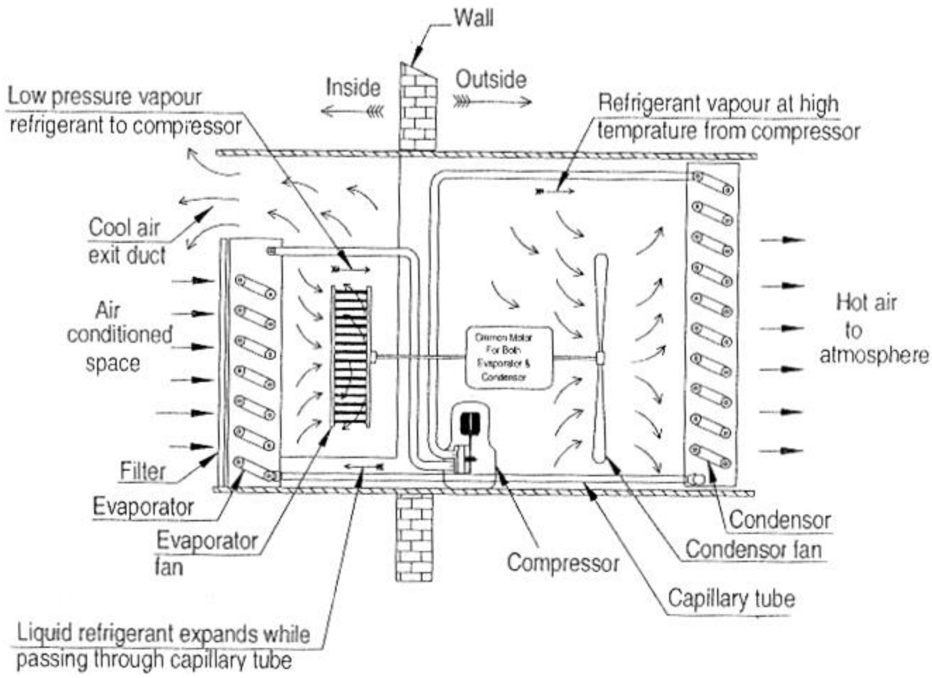


Fig. 10.6 window air conditioner

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.

Limitations

It produce noise in the room because of compressor is very near to the room.

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.

It requires appropriate size of window or hole in wall to fit the conditioner.

Split air conditioner

It is modification of window air conditioner.

Construction

This unit differs from window air conditioner. In terms of splits 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.

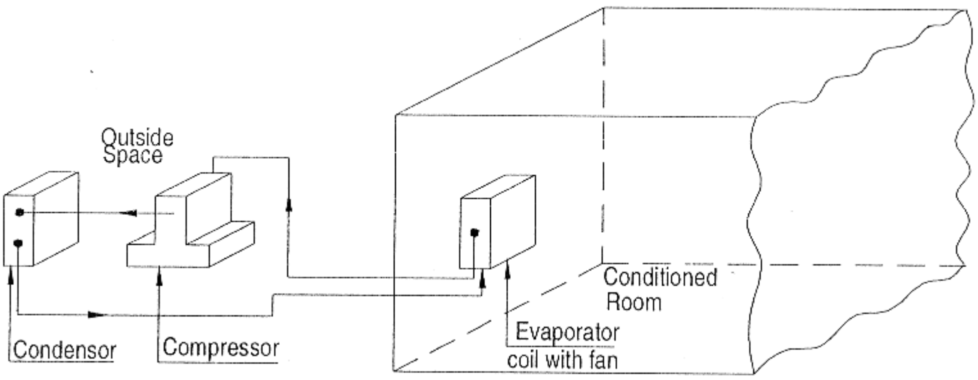


Fig. 10.7 split air conditioner

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.

The advantages of split air conditioner over window air conditioner

The compressor is outside of room, therefore no compressor noise in the room.

No window opening and fixing needed.

The compressor is outside of room, therefore no compressor noise in the room.

Introduction

The power is required in various workshop operations. The electricity is main source of power for machinery. The electricity is converted into mechanical energy by means of an electric motor. The machine uses this mechanical energy to perform various operations.

Drive is an intermediate mechanism which transmits power and motion from the prime mover (or electric motor) to the machine. 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.

Mechanical Drives

Why to use drives?

To vary the speed and torque.
To run several machines by single prime mover.
To avoid thrust, shocks etc.
For convenience and safety purposes.

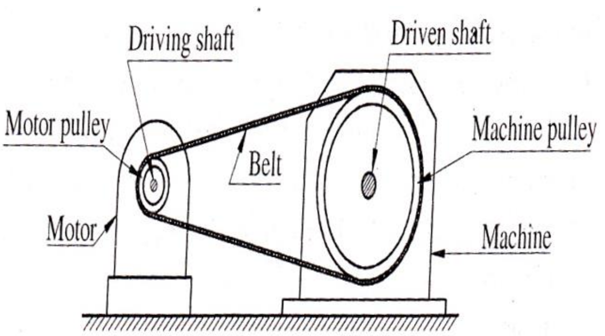
Methods of drive

There are two methods of Drive

1 Individual Drive
2 Group Drive

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.



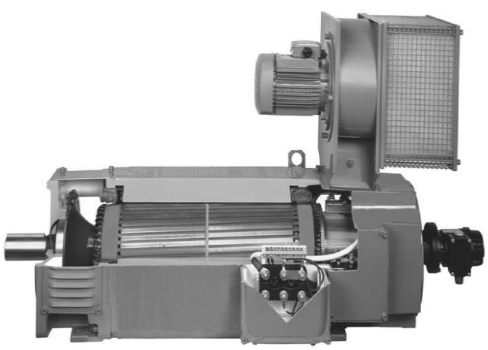


Fig. 12.1 Individual drive

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 and pulleys.

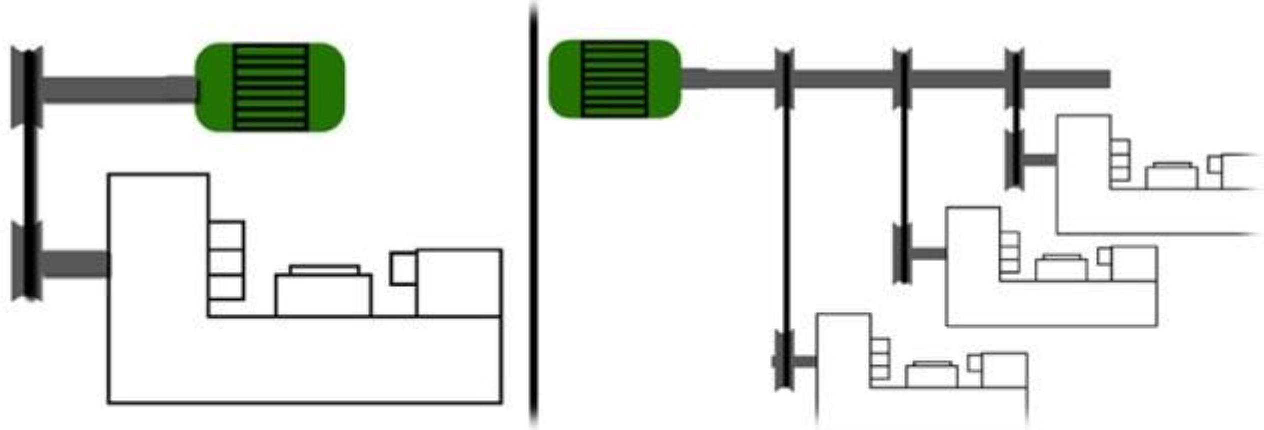


Fig. 12.2 Individual drive and Group Drive

Comparison between individual drive and Group drive

Table 12.0.1 Comparison between Individual and Group drive

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 be controlled separately.	Cone pulleys required to obtain wide range of speed.
3	Machine shaft can be rotated in any direction.	Difficult to change the direction of main shaft.
4	Individual machine does not affect other machines when failure of a motor occurs.	Failure of main motor will stop entire group of machines.
5	Less power is wasted if less machines are working.	More power is wasted if less machines are running but more economical when all machines are working in full load.
6	High initial capital investment.	Less initial capital investment.

Elements of power transmission

The main elements of power transmission system are **Nuts, bolts, pins, keys and couplings**, etc. which are provided to hold the two components of machine elements together.

Driving and driven shafts for transmit motion and power from one place to another place.

Belts, chains, gears are as connectors for transmission of motion and power from driving shaft to driven shaft.

Axles, bearings, brackets etc. to provide support to other elements of a machine.

Shaft, spindle and axle

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.

Generally shafts of cylindrical 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. Hollow shafts also used whenever it is required to pass through components of a machine.-

Fig. 12.3 Shaft

Fig. 12.4 Spindle

Spindle

A spindle is a short revolving shaft that transmits motion either to a cutting tool or a work piece.

Axle

An axle is a machine element which is used for transmitting bending moment and carries such rotating parts as wheels and gears. An axle gives support to the rotating body.

Fig. 12.4 Axle

Fig. 12.5 Axle of Truck

Types of mechanical drives

There are mainly three types of mechanical drives

1. Belt drive
2. Chain drive
3. Gear drive

Belt drive

The belts or ropes are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds. The amount of power transmitted depends upon the following factors

1. The velocity of belt.
2. The tension under which belt is placed on pulleys.
3. The arc of contact between the belt and the smaller pulley.

Belt drives are one of the common methods used whenever power or rotary motion is required to transmit between two parallel shafts.

Fig. 12.7 Belt drive

Types of Belt drive

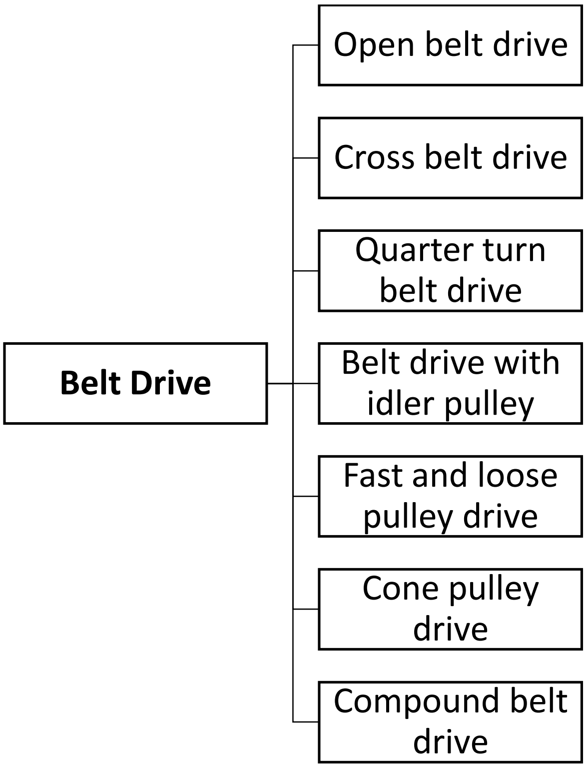


Fig. 12.8 Types of belt drive

1. Open belt drive

This type of belt drive is used to transmit power when two parallel shaft rotating is same direction. The portion of belt having high tension called tight side and portion of belt having less tension will be slack side.

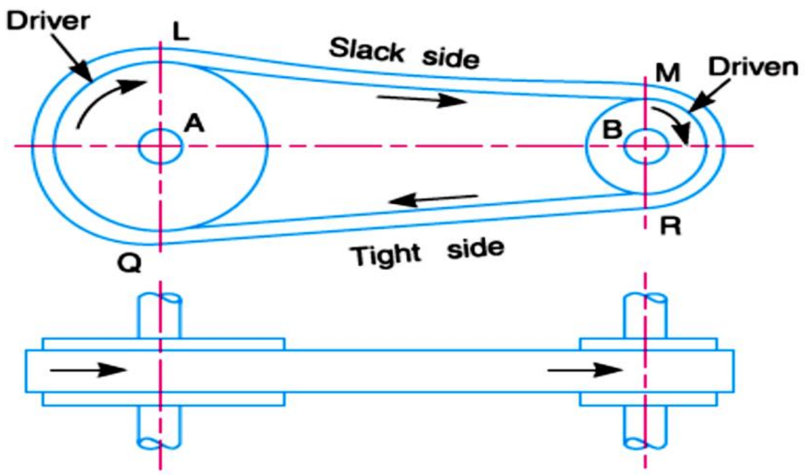


Fig. 12.9 Open belt drive

2. Cross belt drive

This drive transmits power when shafts are parallel but rotate in opposite direction. This type of drive should be used for large distance between two shafts and for lower speed.

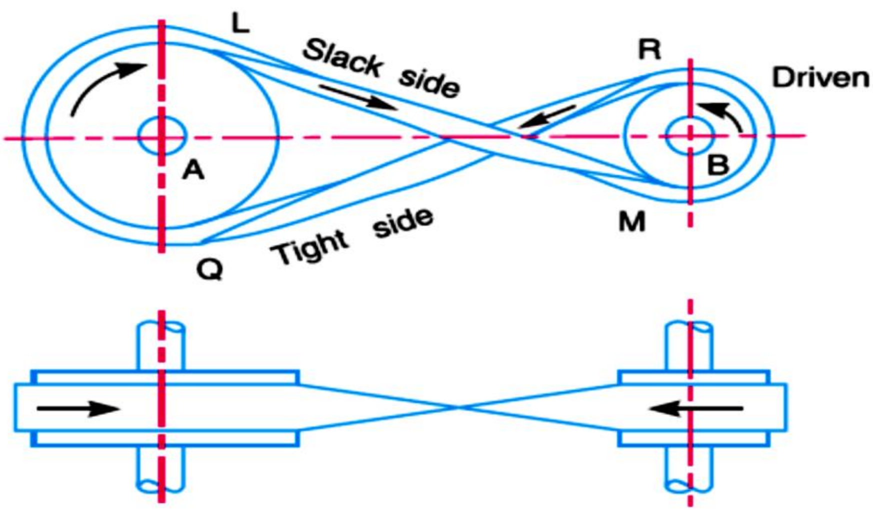


Fig. 12.10 Cross belt drive

3. Quarter turn belt drive

The quarter turn belt drive is also known as right angle belt drive. It is used to transmit power between two shafts at right angle. When the reverse motion is desired this arrangement is not suitable.

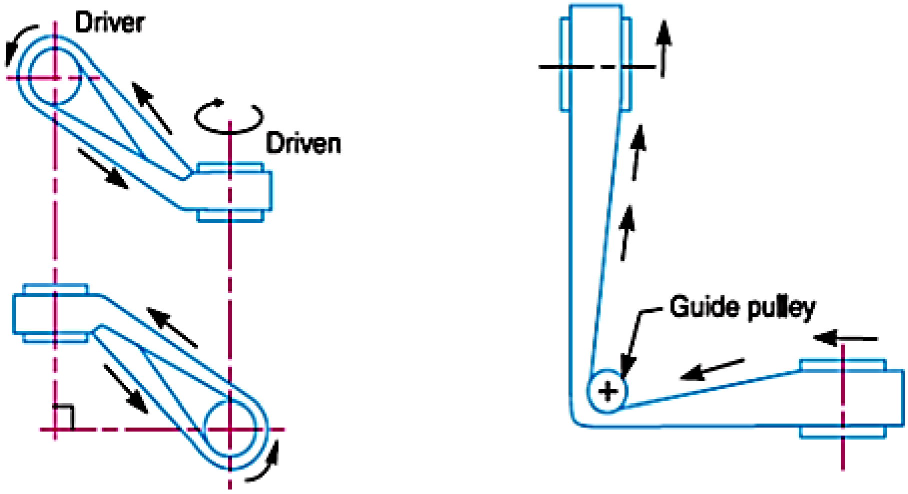


Figure 12.11 Quarter turn belt drive

4. Belt drive with Idler pulley

After long time of running the length of belt may be increases, so angle of contact decreased. To increase it, it is required to increase tension. To increase tension in belt, Idler pulley is used.

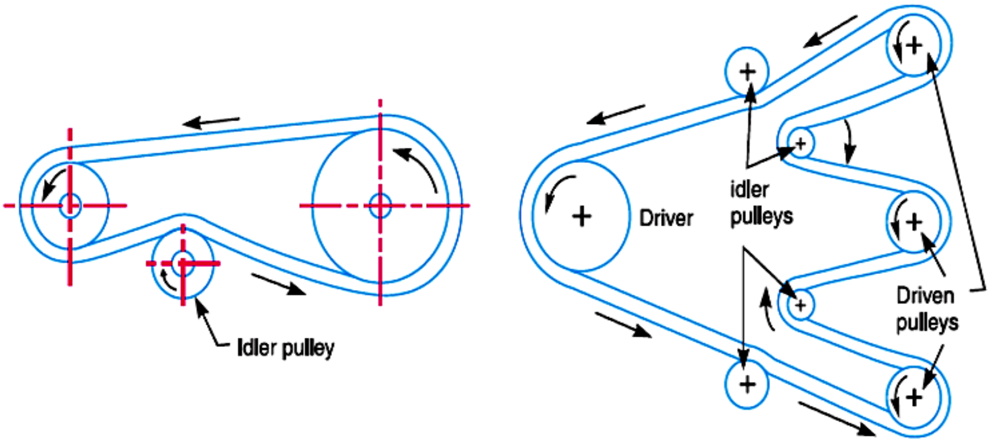


Fig. 12.12 Belt drive with idler pulley

5. Fast and Loose pulley drive

This drive is used when it is need to start or stop driven shaft without stopping driver shaft.

The pulley which is keyed to driven shaft is called fast pulley and a loose pulley runs freely over the machine shaft and not transmitting any power.

When the driven shaft is required to be stopped, belt is pushed on loose pulley by sliding bar.

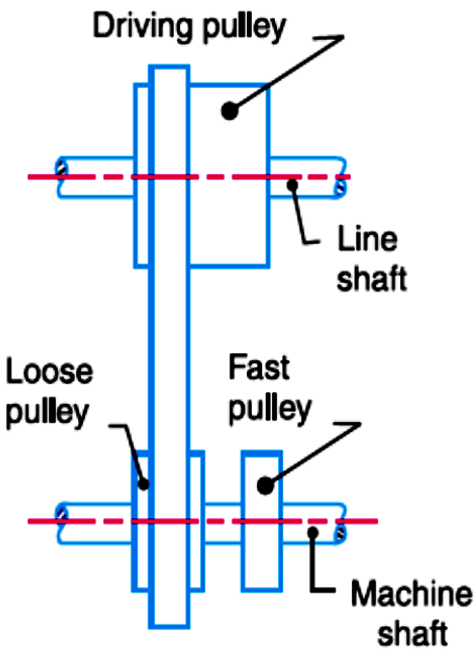


Fig. 12.13 Fast and loose pulley drive

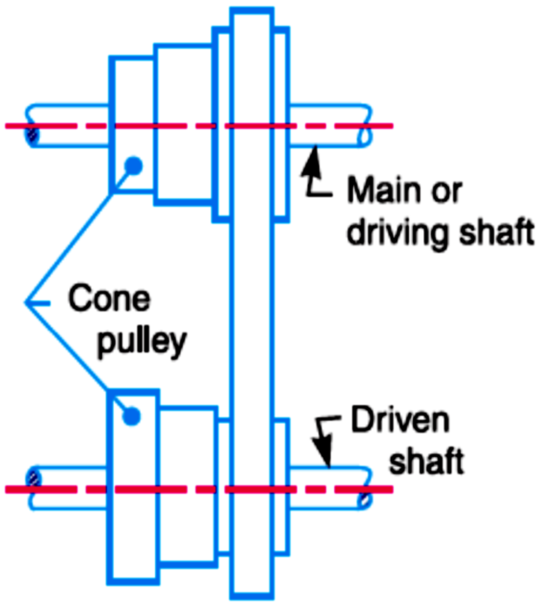


Fig. 12.14 Stepped or cone pulley drive

6. Stepped or Cone pulley drive

A stepped or cone pulley drive used where different speed are required at driven shaft while driving shaft runs at constant speed.

7. Compound belt drive

A compound belt drive is used when large speed ratio required and there is large center distance between two shafts. As shown in fig. 12.15 power is transmitted from pulley 1 to pulley 4 through intermediate pulley 2 and 3.

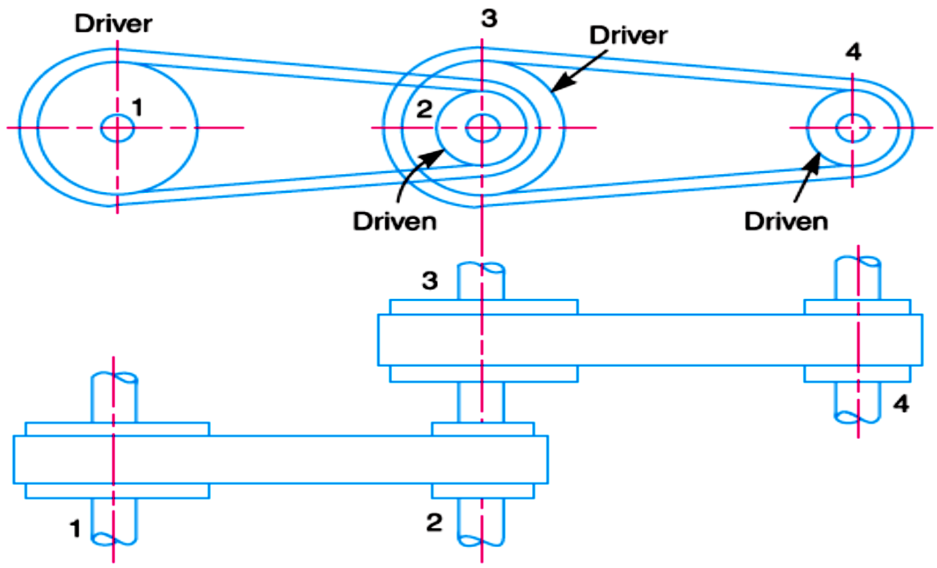


Figure 12.15 Compound belt drive

Types of Belt

1. Flat belt

The flat belt is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another when the two pulleys are not more than 8 meters apart.

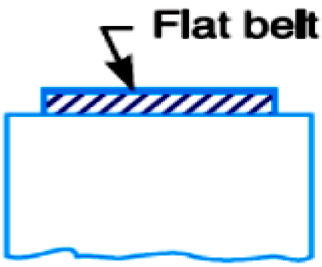


Figure 12.16 Flat belt

Figure 12.17 Flat belt

2. V belt

The V-belt is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another, when the two pulleys are very near to each other.

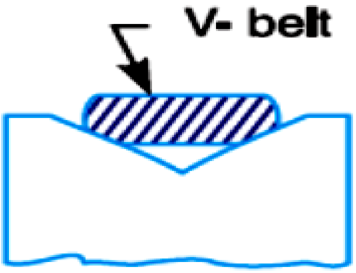


Fig. 12.18 V belt

Fig. 12.19 V belt

3. Circular belt or Rope

The circular belt or rope is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are more than 8 meters apart.

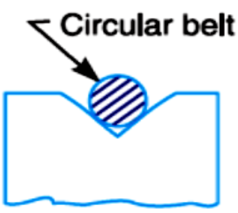


Fig. 12.21 Circular belt

Fig. 12.2 Timing belt

4. Timing belt

Timing belts are modification of flat belts. On the flat belt teeth mounted on underside face. They are made from high quality rubber. Timing belts are used for relatively small distance. It is costlier than flat belt and v belt.

Difference between Flat belt and V-belt drive

Table 12.2 Difference between Flat belt and V-belt

Sr. No.	Flat Belt	V-Belt
1	It is suitable for moderate power transmission when distance between the shafts is large.	It is suitable for large power transmission when distance between the shafts is small.
2	There is chance of slip due to 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	It requires 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.

Chain drive

Construction of chain drive

Slipping occurs in belt and rope drives. In order to avoid this slipping phenomenon chain drives are used. A chain drive consists of three elements

1. Driving sprocket
2. Driven sprocket
3. An endless chain which is wrapped around two sprockets.

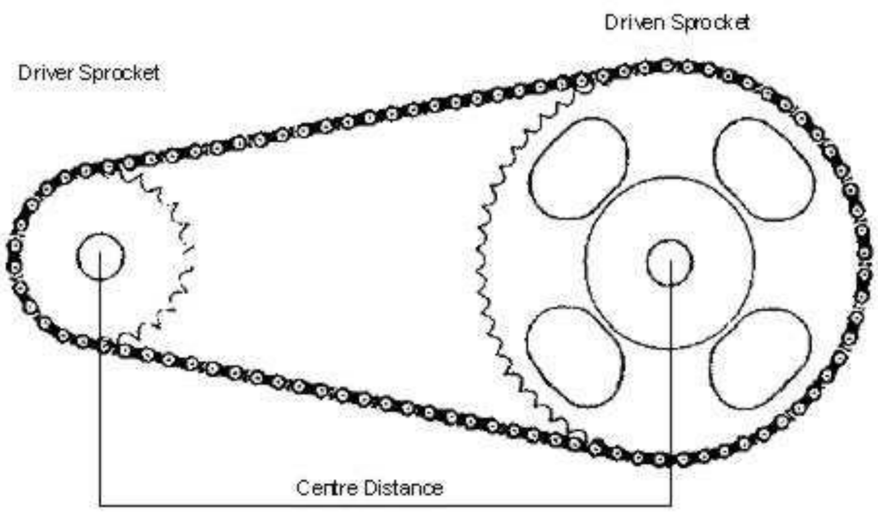


Fig. 12.22 Chain drive

Advantages of chain drive

It provides a positive transmission and no chances of slip is there.
It gives a constant velocity ratio.

Applications

It is used in bicycle, motorcycles, agricultural machinery and textile machinery, material handling equipment etc.

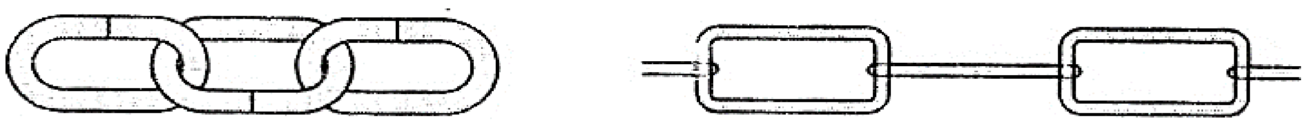
Types of Chain

1. Hoisting and Hauling chains
2. Conveyor chains
3. Power transmission chains

Hosting and Hauling chain

It used for hoisting and hauling purposes. These are further classified as,

a) Chain with oval links
b) Chain with square links



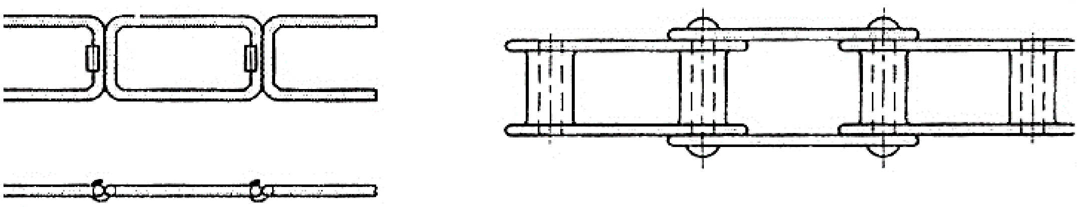
(a) Chain with oval links (b) Chain with square links

Fig. 12.23 Hosting and hauling chain

Conveyor Chain

It used for elevating and conveying the material continuously and they run at low speeds. These are further classified as,

a) Detachable or hook joint type chain
b) Closed joint type chain



(a) Hooke joint (b) Closed joint chain

Figure 12.24 Conveyor chain

Power transmission chain

It is used for transmitting motion from one shaft to another shaft. These chains operate at maximum speed of 15 m/sec.

These are further classified as,

a) Roller chains
b) Silent chain or inverted tooth chain
c) Bush or Block chain

Fig. 12.25 Roller Chain

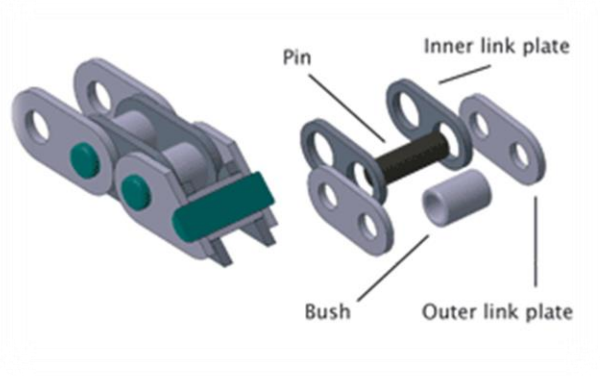


Fig. 12.26 Bush chain

Fig. 12.28 Silent Chain

Gear drive and Friction drive

A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part in order to transmit toque and power.

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.

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

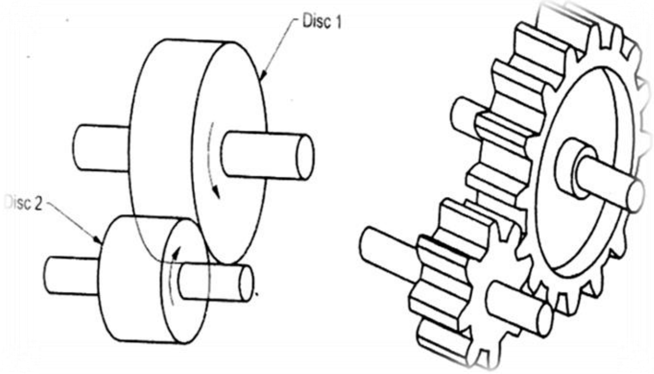


Figure 12.28 Friction drive and Gear drive

Advantages of gear drive

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. It requires less space.
5. This drive is more reliable.

Disadvantages of gear drive

1. Manufacturing cost is high.
2. Maintenance cost 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.

Types of gears

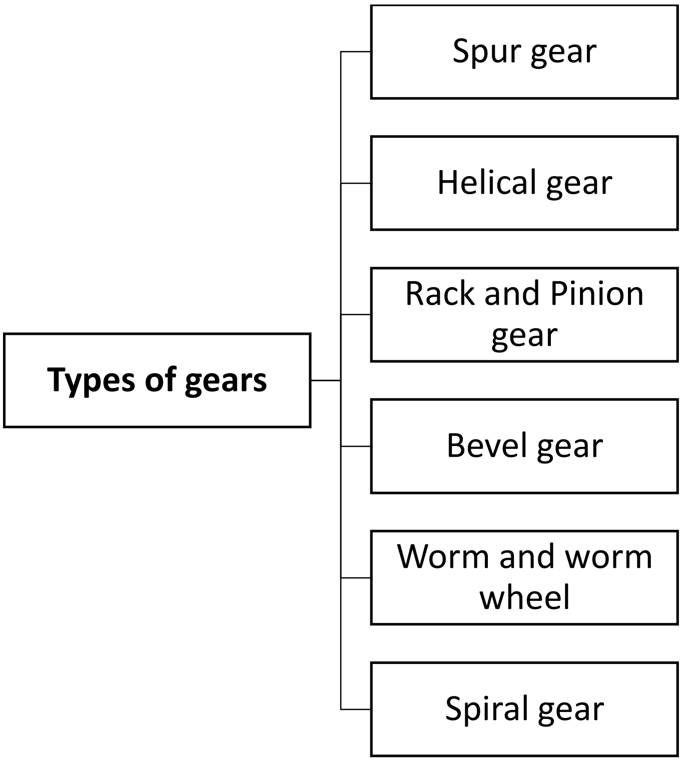


Figure 12.29 Types of gears

Spur gear

In spur gears, teeth are parallel to axis of rotation.

It transmit power from one shaft to another parallel shaft. It uses in Electric screwdriver, oscillating sprinkler, windup alarm clock, washing machine, clothes dryer etc.

Fig. 12.30 Spur gear

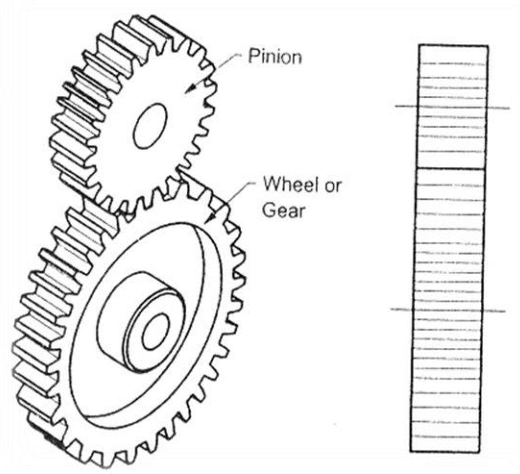


Fig. 12.31 Spur gear

Helical gear

The teeth on helical gears are cut at an angle with axis of gear.

In helical gears engagement of gear teeth is gradual. This gradual engagement makes helical gears operate much more smoothly and quietly than spur gears. In helical gears transmission of load is gradual which results in low impact stresses and reduction in noise. Thus they are used for high speed transmission.

Only disadvantage in helical gear is that, it induces axial thrust in one direction on the bearings. To overcome this disadvantage double helical gear or herringbone gear is used as shown in figure. Herringbone gears are mostly used in heavy machinery.

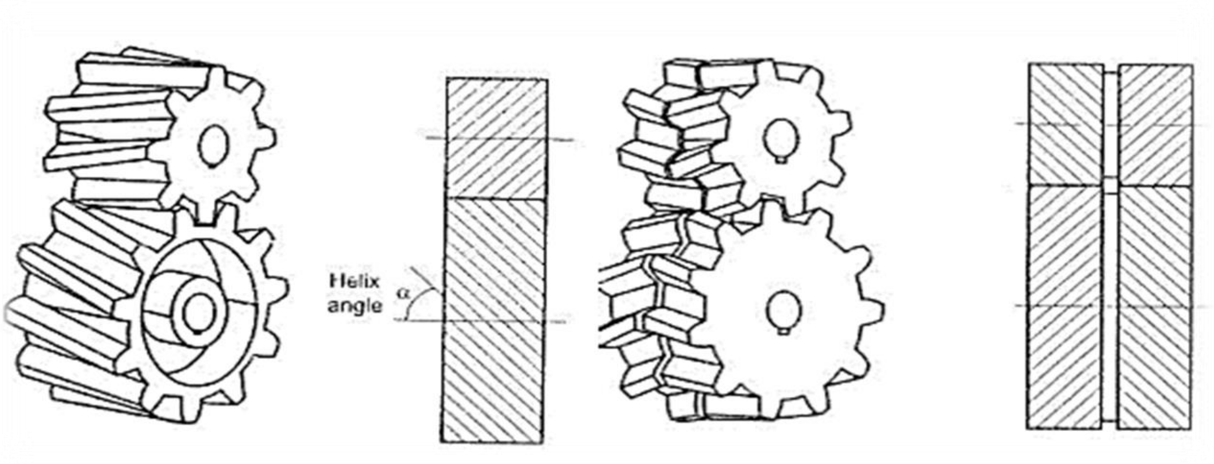


Fig. 12.32 Helical gear and double helical gear

Fig. 12.33 Double helical gear

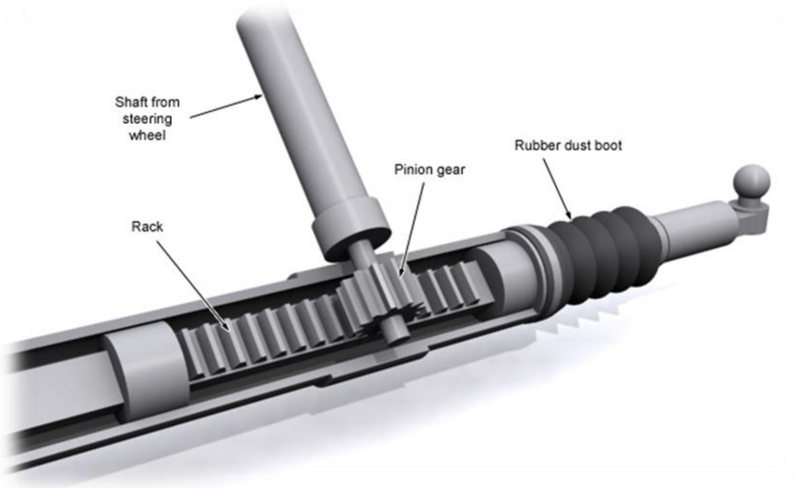


Fig. 12.34 Steering Mechanism

Rack and Pinion gear

Rack and pinion gears are used to convert rotary motion into linear motion. It is a special case of spur gear in which one gear is having infinite diameter called "Rack". A perfect example of this is the steering system of car. It is also widely used in measuring instruments.

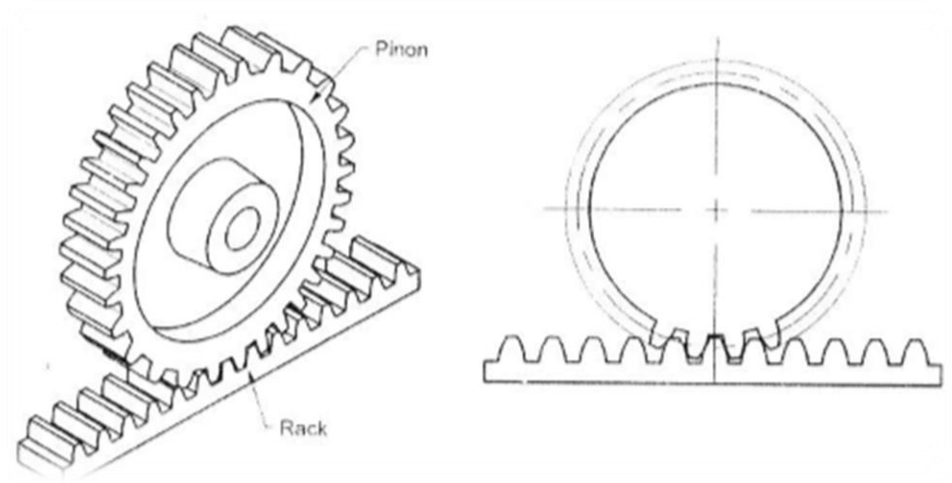


Fig. 12.35 Rack and Pinion

Bevel gear

When power is required to be transmitted from one shaft to another shaft which are intersecting to each other, bevel gears are used. Generally, the angle between two shafts is 90^o. It is used in locomotives, marine applications, automobiles, printing presses, cooling towers, power plants, steel plants, railway track inspection machines, etc. The bevel gears are of two types,

1. Straight bevel gear
2. Spiral bevel gear

Fig. 12.36 Straight bevel gear

Fig. 12.37 Spiral bevel gear

Worm and Worm wheel

Worm gears are used when large gear reductions are needed.

It is common for worm gears to have reductions of 20:1, and even up to 300:1 or greater.

Worm gears are used widely in material handling and transportation machinery, machine tools, automobiles etc.

It is used to transmit power from one shaft to another shaft which are non-intersecting and their axes are normally at right angles to each other.

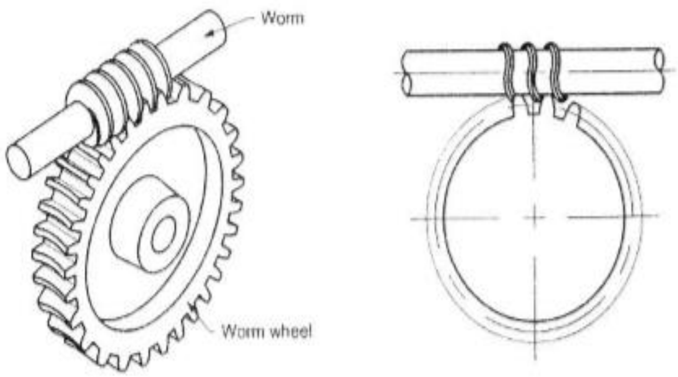


Fig. 12.38 Worm and worm wheel

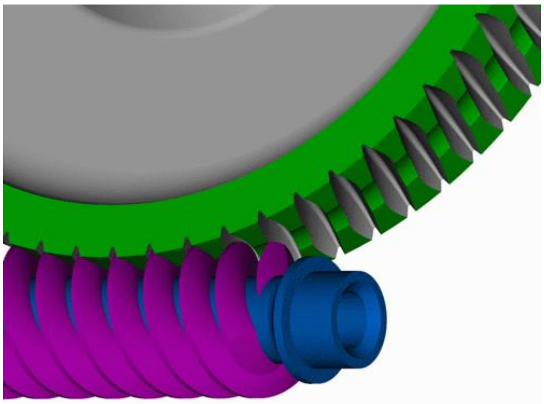


Fig. 12.39 Worm and worm wheel

Spiral gear

It is used to transmit power from one shaft to another shaft which are non-parallel and non-intersecting.

It is suitable for low load transmission due to having point contact between mating teeth.

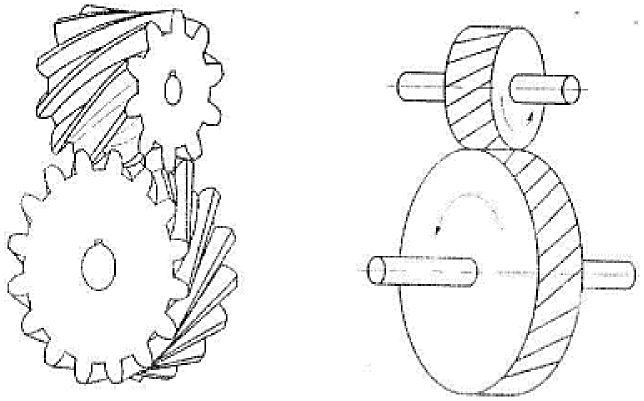


Fig. 12.40 Spiral gear

Fig. 12.41 Spiral gear

Comparison between Belt drive, Chain drive and Gear drive

Table 12.3 Comparison of Belt, Chain and Gear drive

Sr. No.	Particulars	Belt drive	Chain drive	Gear drive
1	Main element	Pulleys, belt	Sprockets, chain	Gears
2	Slip	Slip may occurs	No slip (Positive drive)	No slip (Positive drive)
3	Suitability	For large center distance	For moderate center distance	For short center distance
4	Space requires	Large	Moderate	Less
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	Required	Requires proper lubrication
9	Installation cost	Less	Moderate	More
10	Use	For low velocity ratio	For moderate velocity ratio	For high velocity ratio

Introduction to Engineering Materials

Since the earliest days of the evolution of mankind, the main distinguishing features between human beings and other animals 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 an ores. During the present century scope of metallurgical science has expanded enormously. In the recent years studying the metallurgy science gave humanity an ever growing range of useful alloys.

Appropriate 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 while causing minimum pollution in their extraction, refinement and manufacturing.

Classification of Engineering Materials

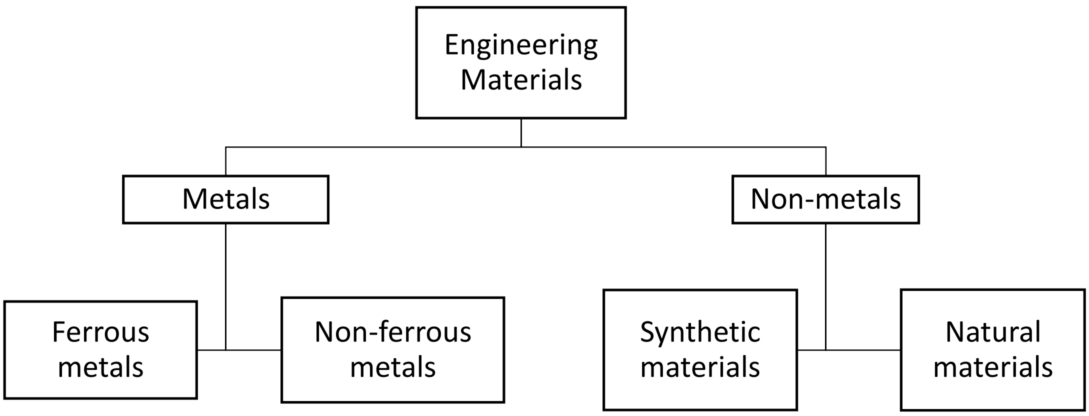


Fig. 13.1 Classification of Engineering Materials

Metals

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.

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.

Non – metallic materials

1. 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.

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.

2. 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, and 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.

Composite materials

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.

Types of 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.

General Properties of Engineering Materials

1. Tensile strength

Strength is the ability of a material to resist applied forces without fracturing.

It is the ability of a material to withstand tensile (stretching) loads without breaking.

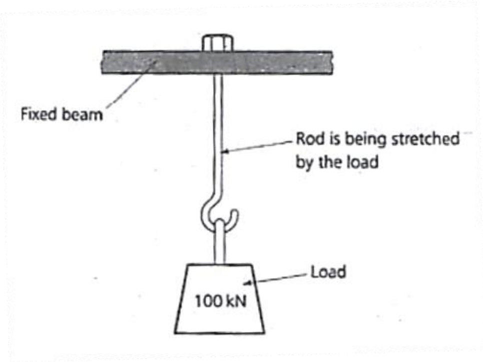


Fig. 13.2 Tensile Strength

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 broke by impact loading.

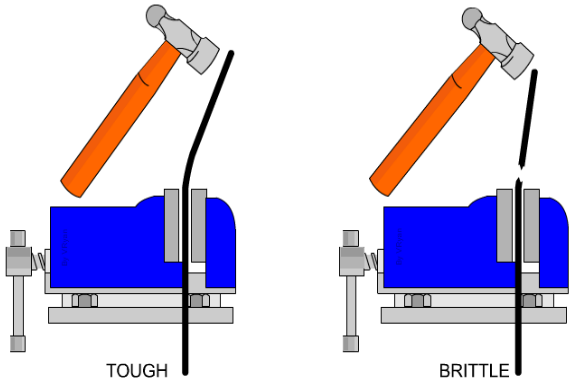


Figure 13.3 Toughness and Brittleness

3. 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.

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.

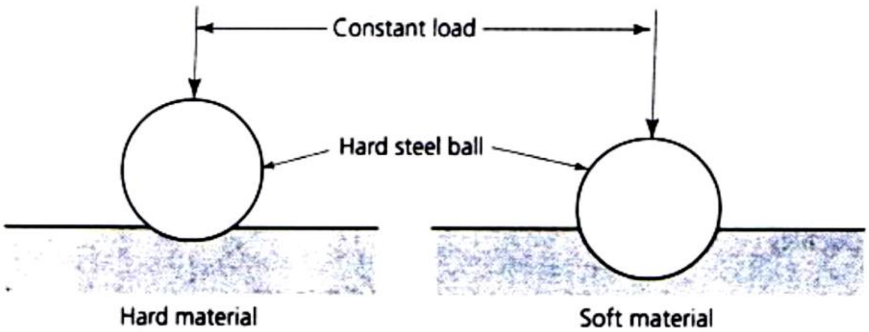


Fig. 13.4 Hardness

5. Ductility

It refer to the capacity of substance to undergo deformation under tension without rupture as in wire drawing tube drawing operation.

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.

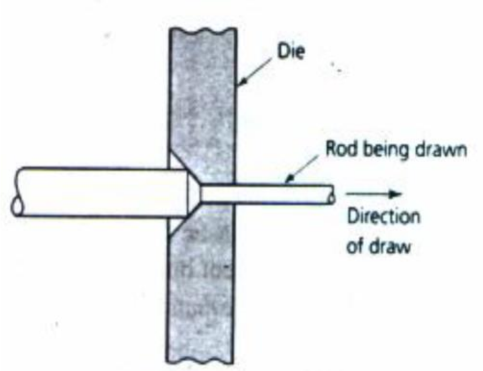


Fig. 13.5 Ductility

7. 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.

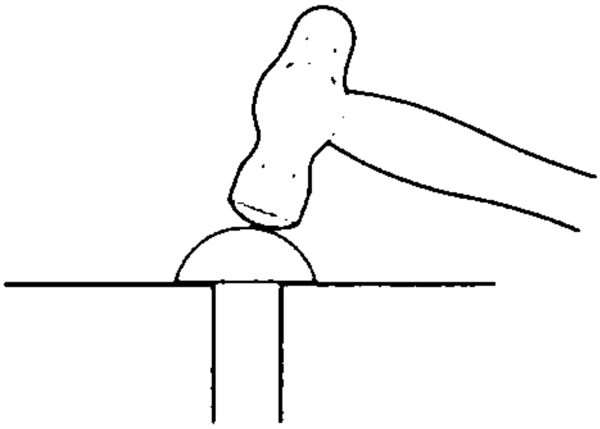


Fig. 13.6 Malleability

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.

Fig. 13.7 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.

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).

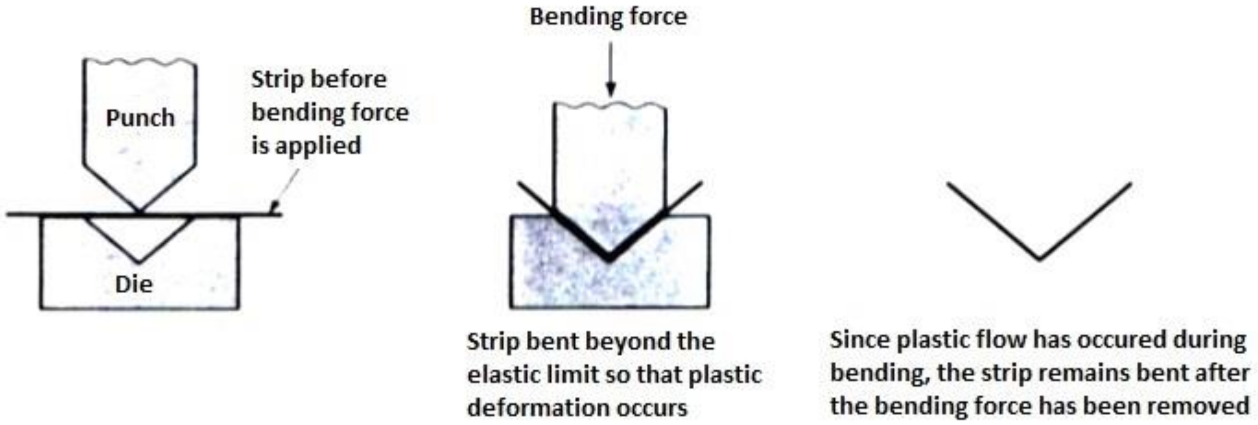


Fig. 13.8 Plasticity

10. Creep

When 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. Thermal conductivity

This is the ability of the material to transmit heat energy by conduction.

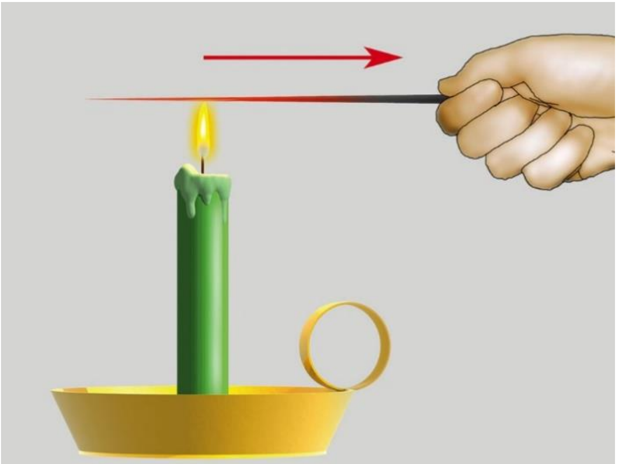


Fig. 13.9 Thermal Conductivity

13. 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.

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.

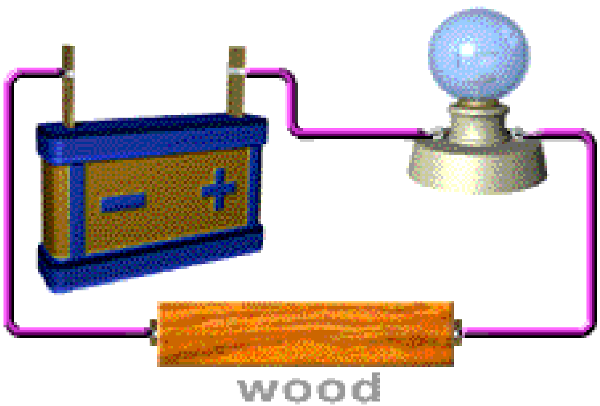


Fig. 13.10 Electrical Conductivity