LECTURE NOTES

ON

ELEMENTS OF MECHANICAL ENGINEERING

COURSE CODE : AME551

V semester (IARE-R16)

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UNIT-I
INTRODUCTION TO ENERGY SYSTEMS

Introduction

Prime movers

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

Sources of energy

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

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

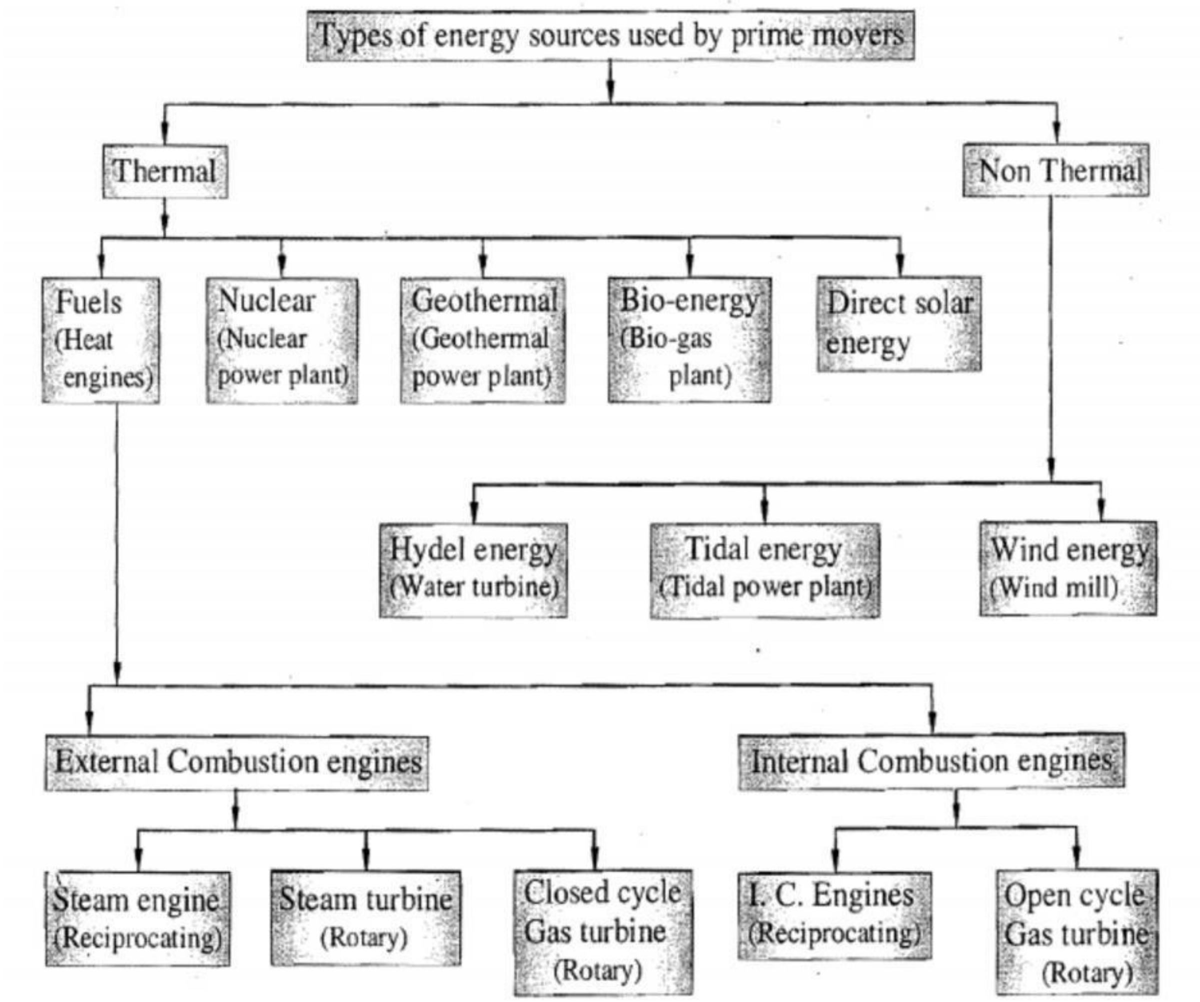
(ii) Flow of river water: This is another useful source of energy. Water stored at high elevation contains potential energy. When water starts flowing, potential energy gets converted to kinetic energy. Hydraulic turbine is a prime mover which converts kinetic energy of flowing water into mechanical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

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

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

Types of prime movers

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



Force and mass

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

As per Newton's second law of motion

Force α acceleration

$$F = m \times a \quad ... (1.1)$$

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

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

Weight = Mass x Gravitational acceleration

$$w = m \times g$$

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

Pressure

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

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

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

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

• Pressure gauges, Manometers etc are used to measure gauge pressure and Barometer is used to measure atmospheric pressure. Atmospheric pressure is the pressure exerted by atmosphere. It varies with location on earth. Standard atmospheric pressure is a pressure of atmospheric air at mean sea level. It is defined as the pressure developed by a mercury column of 760 mm. If we take density of mercury equal to 13595.09 kg/m3 and gravitational acceleration m/s^2 with reference to absolute zero pressure. It is the pressure related to perfect vacuum.

Mathematically, Absolute pressure = Atmospheric pressure + Gauge pressure

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

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

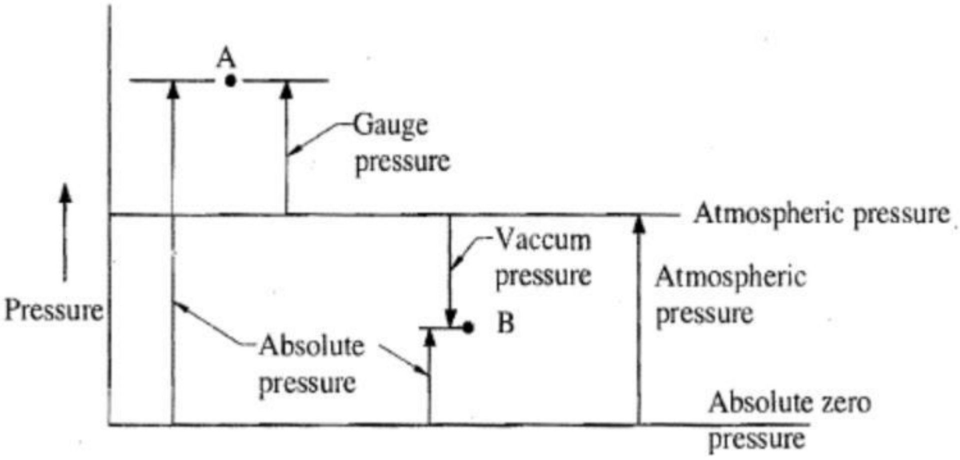


Fig. 1.1. *Relation between different pressures*

Work

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

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

Work output of the system = + W

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

Work output of the system =- W

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

= N × m or joule

Power

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

Mathematically

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

unit Joule/second is called Watt (W)

Watt is very small unit, so recommended larger units are

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

- The power available at the engine shaft is called Brake power (B.P.) and the powerdeveloped by the engine is called Indicated power (LP.).

Energy

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

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

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

• Forms of energy:-

The different forms of energy are;

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

(3) Chemical energy (4) Electrical energy

(5) Nuclear energy

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

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

. • High and Low Grade energy

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

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

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

- (b) Low Grade energy: Only a certain portion of energy that can be converted into mechanical work (shaft power), that energy is called low grade energy.
- Examples: Thermal or heat energy, Heat derived from combustion of fuels, Heat of nuclear fission.

Types of energy:

Energy may be classified as

(1) Stored energy

(2) Energy in transition

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

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

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

• Types of Mechanical Energy:

There are two types of mechanical energy

(a) Potential energy (b) Kinetic energy

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

Example: Water stored at higher level in a dam

g=Gravitational acceleration = 9.81 m/s2.

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

Heat

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

• Definition of Heat:

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

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

• Positive and negative heat

In general, the heat transferred to the system is considered as *positive heat* while the heat transferred from the system is considered as *negative heat.* Mass of the substance, specific heat, and temperature difference are the factors on which the heat transfer rate depends.

• Comparison of work and Heat

Similarities:

(a) Both are path functions
(b) Both are boundary phenomenon
(c) Both are associated with a process, not a state
(d) Systems possess energy, but not work or heat

Dissimilarities:

(a) In heat transfer, temperature difference is required.
(b) In a stable system there cannot be work transfer, however, there is no restriction for the transfer of heat.
(c) Heat is low grade energy while work is high grade energy.

Temperature

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

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

• Unit of temperature

In the International system (SI) of unit, the unit of thermodynamic temperature is Kelvin. It is denoted by the symbol K. However, for practical purposes the Celsius scale is used for measuring temperature. It is denoted by degree Celsius (OC)

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

• Temperature Scale:

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

		Table 1.1	
Sr No.	State	Temperature	
		°C	K
1	Ice Point	0	273.15
2	Steam Point	100	373.15
3	Triple point of water	0.010	273.16
4	Absolute zero	–273.15	0

Units of Heat

Heat is a form of energy. In SI system, unit of heat is taken as joule. Kilojoules (kJ) and Mega joule (MJ) are recommended larger units of heat. Calorie (cal.) is also unit of heat. Generally Kilocalorie (kcal) is quantity of heat required to raise temperature of unit mass of water through one degree Celsius or Kelvin.

1 kcal = 4186.8 joules = 4.1868 kilojoules

Specific heat capacity

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

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

Mathematically, the heat transfer rate Q is written as

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

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

• Specific heats in thermodynamics:

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

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

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

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

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

Internal Energy

In non flow processes, fluid does not flow and has no kinetic energy. There is very small amount of change in potential energy because change in centre of gravity is negligible. From the first law of thermodynamics, we can say that the amount of heat transferred to a body is not fully converted tp 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. The eq. (1.6) is referred as nonflow energy equation. In other words, for nonflow process

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

Enthalpy

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

Internal energy Flow energy
On unit mass basis, the specific enthalpy could be given as
$h = u + pv$ ..(1.7)

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

Efficiency

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

Hence,

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

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".

First law of thermodynamics

First law of thermodynamics provides for studying the relationships between the various forms of energy and energy interactions.
This law states that energy can neither be created nor destroyed; it can be converted from one form to another form.

Thermodynamic systems

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

Examples: piston cylinder assembly, turbine etc.
The system is identified by a boundary around the system. The boundary may be real or imaginary. Everything outside the system boundary is called surroundings. A system and its surroundings together are called the universe.
Universe = system + surroundings

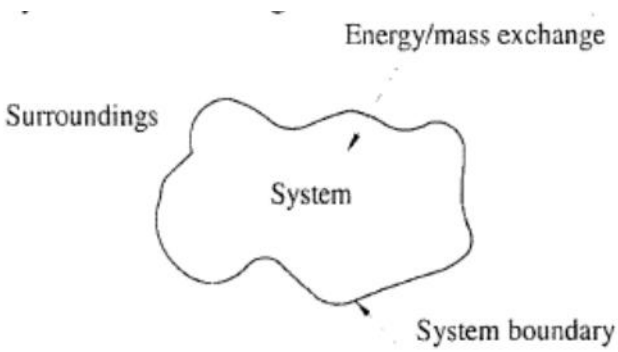


Fig. 1.7 Thermodynamic system

• Types of system: The systems may be classified as

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

1. Open system: Open system in which energy and mass transfers take place at the system boundary. Examples: Turbine, I.C. engines etc.
In Fig. 1.8 an open system is shown consisting of a turbine.

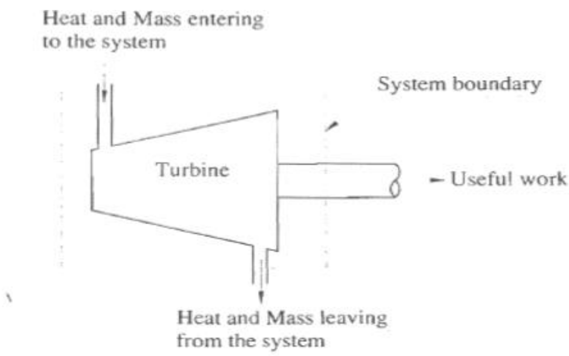


Fig. 1.8 Open system

close system

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

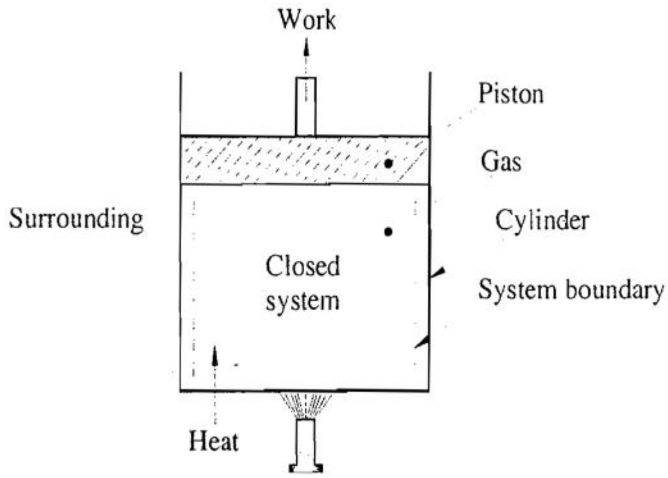


Fig. 1.9 closed system

Isolated Systems:

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

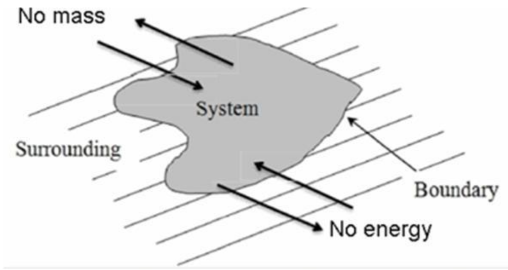


fig. 1.10 Isolated systems

Thermodynamic properties

Properties are any measurable characteristics of a system. eg. Pressure, temperature, volume, mass and density.

Extensive properties are the mass-dependent properties of a system. i.e. the properties that will vary proportionally with mass of the system. E.g. volume

Intensive properties are the properties that are not dependent on mass. Eg. Temperature, density. If any Extensive Property is divided by the mass we would also obtain an intensive property.

Properties:-systems have certain characteristics by which its physical condition can be described such as pressure, temperature, etc. these are called properties.

all system properties having definite values, the system is said to be in definite state. any operation in which one or more properties change is called change of state.

Path:-succession of states passed through change of state is called path

Process:-if path is completely specified it is called process

Cycle:-a series of change of state such that final state is same as initial state it is called cycle

ENERGY

Sources of energy

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

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

The various sources of energy can be listed as follows:

(1) Fossil Fuels
(2) Nuclear Fuels (Nuclear Energy)
(3) Stored or flowing water (Hydel Energy)
(4) Sun (Solar Energy)
(5) Wind (Wind Energy
(6) Rise and fall of tides (Tidal Energy)
(7) Geothermal Energy
(8) Biomass and bio-fuels

Energy from fossil fuel

Fuel is defined as "a substance composed mainly of carbon and hydrogen which produces a large amount of heat while burning with oxygen. “The main combustible elements of each fuel are carbon, hydrogen, compounds of hydrocarbons and small amount of other substances, such as sulphur, oxygen, nitrogen etc. The combustion of fuel is one of the most important sources of energy utilized for driving prime movers. The combustion of fuel is the process of chemical combination of carbon, hydrogen and sulphur with oxygen which comes from air. When the fuel is burnt in presence of O2 (air), it produces heat and flue gases. This heat is utilized for heating purpose or for produce mechanical energy with help of prime movers (steam turbine, gas turbine, internal combustion engine etc.).

Classification of fuel

Fuel can be classified as under

According to nature of their existence

(i) Solid

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

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

(a) Natural: Petroleum

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

(iii)Gaseous
(a) Natural: Natural gas, Liquefied Natural Gas (LNG)
(b) Artificial : Petroleum gas, Producer gas, Coal gas, Coke-over gas, Blast furnace gas, LPG, CNG, Sewer gas, Water gas

According to nature of their origin
(i) Natural fuels: They occur in nature. They are also known as primary fuels.
(ii)Artificial fuels: They are prepared by further processing of primary fuels. They are also known as secondary fuels.

Solid fuels
(A) Natural (primary) solid fuels

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

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

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

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

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

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

Artificial or Prepared solid fuels:
Wood Charcoal: It is produced from wood by Carbonization process. Charcoal can be

produced from the incomplete burning of wood with insufficient air. Wood charcoal is a source of pure carbon. It easily ignites and burns at low rates. It is extensively used as a fuel in blacksmiths, metal work, and for cottage industries.

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

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

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

Liquid Fuels

The liquid fuels are hydrocarbons and can be classified as
Natural fuel - Petroleum (crude oil)
Artificial prepared fuel - Petrol, Diesel, Kerosene, Light Diesel oil, Heavy fuel oil' Tar
Liquid fuel commonly used in internal combustion engines and oil fired boilers’

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

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

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

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

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

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

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

The advantages and disadvantages of liquid fuels compared to solid fuel

Advantages:

(1) It is easy to store and requires less space for storage.
(2) Higher calorific value.
(3) Easy to control the combustion.
(4) Easy handling and transportation.
(5) Cleanliness.
(6) No ash problem.
(7) Ease of ignition and stopping off the operation.
(8) Changes in load in a power plant can be met easily.

Disadvantages:

(1) Cost of fuel is higher than other fuels.
(2) Greater risk of fire.
(3) Special container required for storage and transport.

Gaseous fuel

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

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

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

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

(4) Producer gas: This gas is produced by partial combustion of solid fuels(gasification), by in complete combustion of coal in presence of limited amount of air supplied. This

gas is mainly mixture of carbon monoxide, hydrogen and little amount of other elements It is used in steel industry for firing open hearth furnace. The gross calorific value of producer gas is about 6,000 kJ/m^3.

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

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

(7) Sewer gas: It is produced from sewage disposal waste in which fermentation and decay occurs. It consists of CH4 collected at large disposal plants. It is used as fuel for gas engine which is turn drives the plants pumps and agitators.

Advantages and disadvantages of gaseous fuels:

Gaseous fuel is becoming popular because of following advantages:
(1) Excess air require is very less for complete combustion'
(2) Good fuel economy and more efficiency of furnace operation'
(3) Combustion control is better.
(4) No problem of storage if the supply is available from public supply line.
(5) Easy to distribute with the help of pipe lines.
(6) Gaseous fuels produces higher temperatures and economical to produce same amount of heat.

Disadvantages
(1) They are very highly inflammable.
(2) Gas is more difficult to transport by pipe line compared to liquid fuel.
(3) Liquefied gases require high pressure/ low temperature insulated expensive tanks

LPG (Liquefied Petroleum Gas):

LPG is a colorless petroleum gas. It is natural derivative of both natural gas and crude oil. The main component gases of LPG are propane and butane or a combination of these two constituents. The gas is liquefied by moderate compression at normal temperature and is stored in tanks and cylinders. The liquefaction is necessary to provide a reduction in volume and produce acceptable energy densities. The calorific value of LPG is about 45,360 kJ/kg. The use of LPG is widespread. LPG is a fuel used for coo king. Also, LPG is a fuel which can run engines of cars, buses and lorries.LPG is best suited for light vehicles such as cars and small vans which normally run on petrol. LPG can be used in vehicles after conversion of

vehicle for LPG or modification in engine. It seems that conversion is practically applicable to petrol vehicles only, not diesel vehicles because diesel engines need significant modification. Normally modified engine can be run on either LPG or petrol at the flick of a switch, even while motoring.

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

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

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

fuel utilization

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

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

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

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

Nuclear Fuel and utilization

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

The fission process is used in all nuclear power plants, because fusion cannot be controlled. The tremendous amount of heat energy is liberated by fission of nuclear disintegration of nuclear fuel (uranium and other similar fissionable materials). It is estimated that I kg of nuclear fuel is equivalent to about 2.5x106 kg of coal. The heat energy so liberated in atomic

reactors is extracted by pumping fluid or molten metal like liquid sodium or gas through the pipe. The heated metal or gas is then allowed to exchange its heat to the heat exchanger by circulation. In the heat exchanger the gas is heated or steam is generated which is utilized to drive gas or steam turbines coupled to alternators thereby generating electrical energy.

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

Hydraulic or Water Energy

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

Solar Energy

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

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

Wind Energy

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

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

Bio-fuel

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

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

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

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

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

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

Advantages of using bio-fuel in vehicles:

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

Increases national energy security.

Limitations of bio-fuels:

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

Some of the bio-fuels are described below:

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

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

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

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

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

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

Hydrogen (H_2) Gas

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

Hydrogen can be mixed with natural gas to create an alternative fuel for vehicle that uses certain types of internal combustion engine is called hydrogen ICE vehicle. Hydrogen internal combustion engine is simple a modified version of traditional gasoline powered internal combustion engine. Hydrogen is also used in fuel cell a vehicle that run on electricity

produced by the petrochemical reaction that occurs when hydrogen and oxygen are combined in the fuel stack is known as hydrogen fuel cell vehicle

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

Global warming

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

Cause of global warming

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

years. Earth has warmed at a rate higher than that of previous time over the last hundred years and particularly over the last two decades.

Mitigation of global warming:

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

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

Ozone Depletion

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

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

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

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

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

Carbon Tetrachloride - it is used in solvents and some fire extinguishers. Chlorofluorocarbons (CFCs) are main substance causing ozone depletion, accounting 80% of total stratospheric ozone depletion. CFCs are not destroyed in reactions with chemicals or washed back to Earth by rain. They simply do not break down in the lower and they can remain in the atmosphere from 20to l2 years or more. Finally, they into the stratosphere where they broke down by ultra violet (UV) rays from, releasing free chlorine. The chlorine becomes

actively involved in the process of destruction of ozone. The net result is that two molecules of ozone are replaced by three of molecular oxygen, leaving the chlorine free to repeat the process. Ozone is converted to oxygen, leaving the chlorine atom free to repeat the process up to 100,000 times, resulting in reduced level of ozone.

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

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

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

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

Introduction of Energy Conservation Act 2001

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

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

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

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

Direct consumers to prepare and implement schemes for efficient use of energy. The EC Act was amended in 2010 and the main amendments of the Act are given below:

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

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Electricity Act 2003

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

The main/features of the act are as follows:

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

Properties of GasesVapour:

It can be defined as that state of the substance in which the evaporation from its liquid state is not complete. A Vapour consists of a mixture of the pure gaseous form and liquid particles in suspension. Example: Steam contains water particles. With the changes in temperature and pressure, a vapour can undergo condensation or evaporation. Vapour may be in three conditions, wet, dry and superheated. Superheated vapour behaves like a perfect gas. By changing temperature conditions can be changed**Gas:**

It is the state of a substance in which the evaporation from the liquid state is complete. Within the limits of temperature and pressure in thermodynamics, the substance like O_2, H_2, air, N_2 are taken as gases.

Perfect Gas:

A gas which strictly obeys all the gas laws under all conditions of temperature and pressure is called a perfect gas. There is no gas which is perfect, but many gases like O_2, N_2, H_2, and air tend to behave like perfect gases. They are known as real gases.

Gas laws:

1. Boyle's law:

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

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

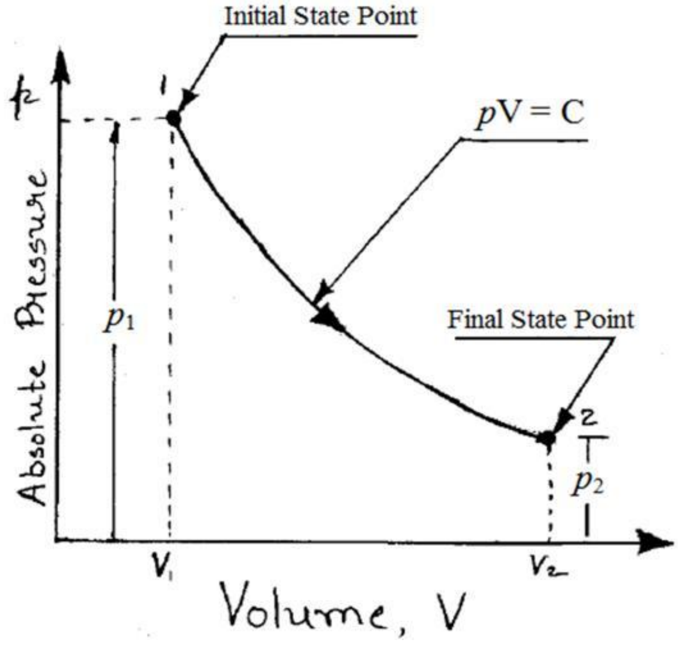
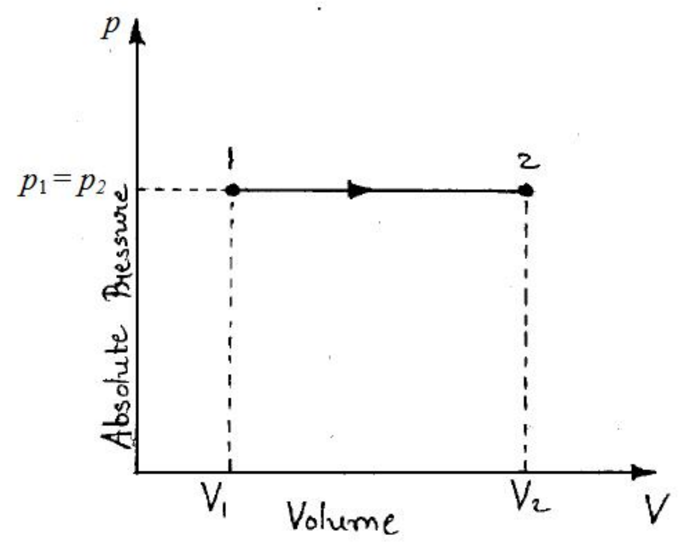


Fig. 1 Boyle's law

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."



p
$p_1 = p_2$
1
2
Absolute Pressure
V_1
Volume
V_2
V

Referring to fig. 2,

Fig. 2 Charles law 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 above equation

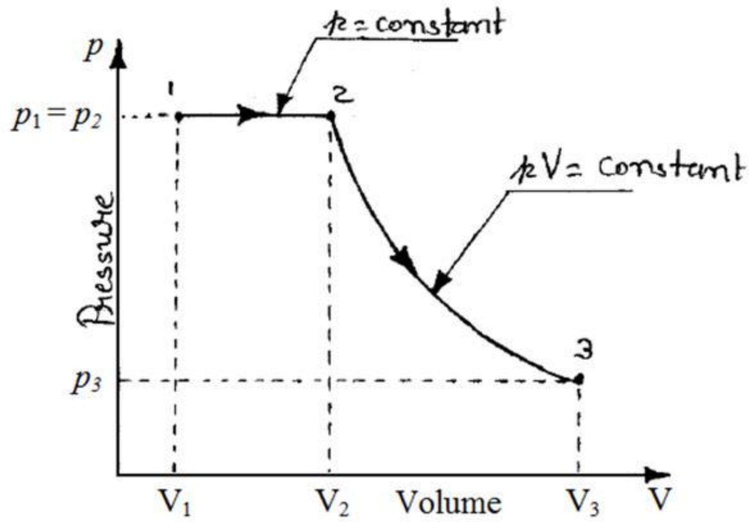


Fig. 3 Combined gas law

Non flow processes:

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

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

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

Constant Volume Process

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

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

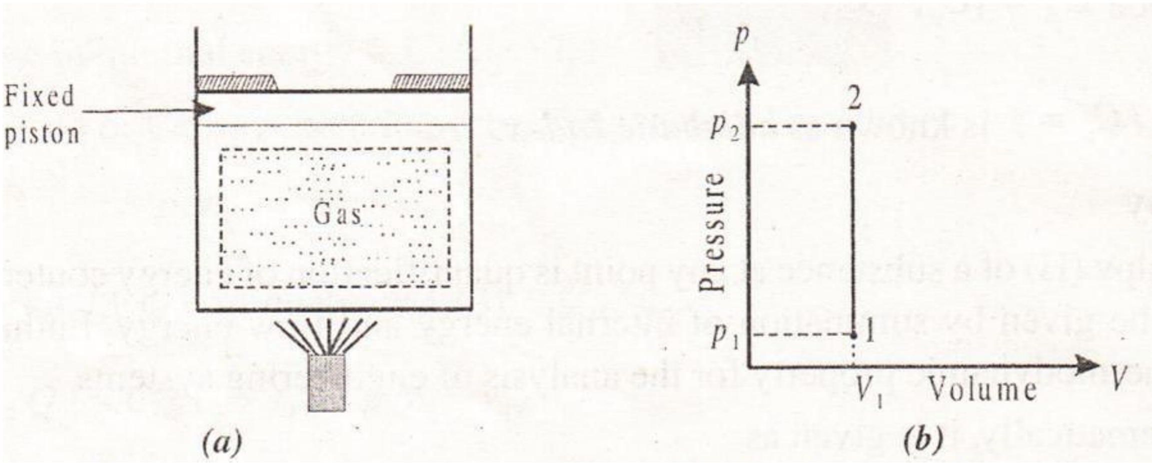


Fig. 3.1 Constant volume process

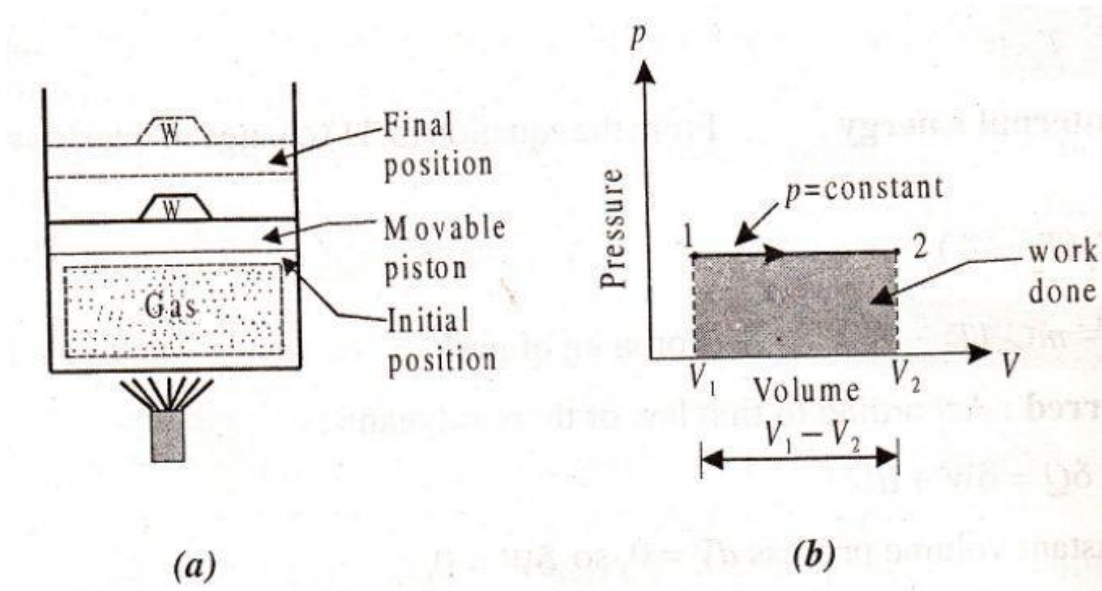


Fig. 3.2 Constant pressure process

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Isothermal Process

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

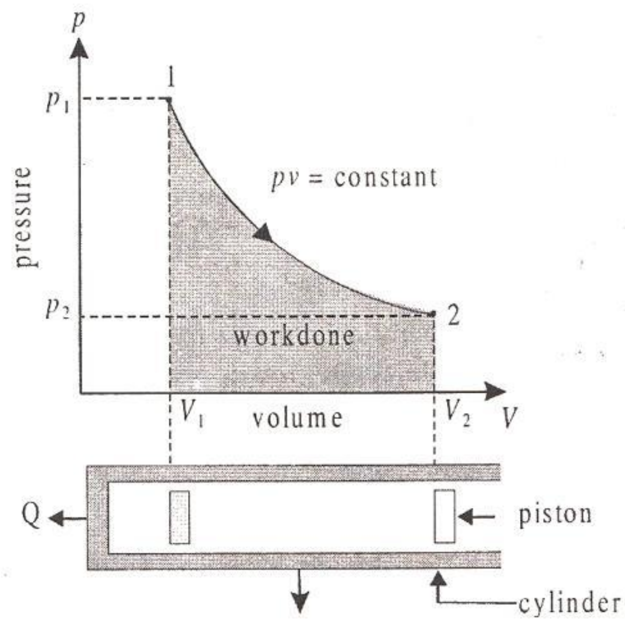


Fig. 3.3 Isothermal process

Adiabatic Process

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

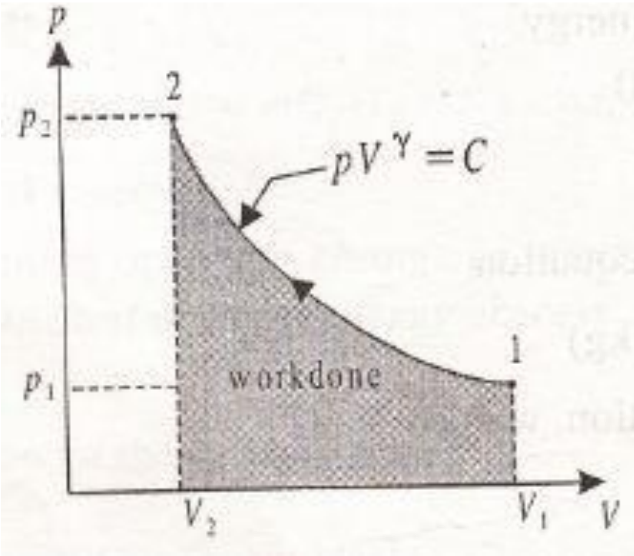


Fig. 3.4 Adiabatic process

Change in internal energy:

According to first law of thermodynamics, $\delta Q = \delta W + \delta U$
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:

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

Polytropic Process

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

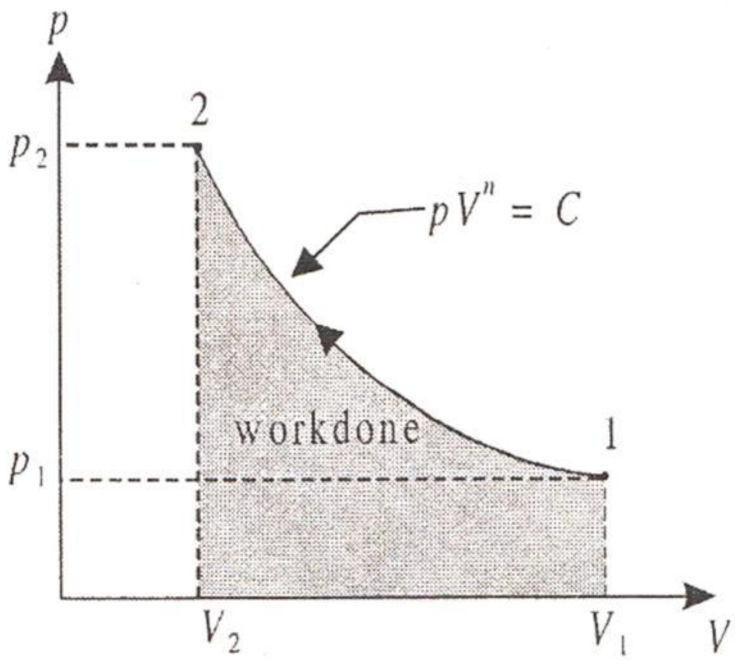


Fig. 3.5 Polytropic process

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

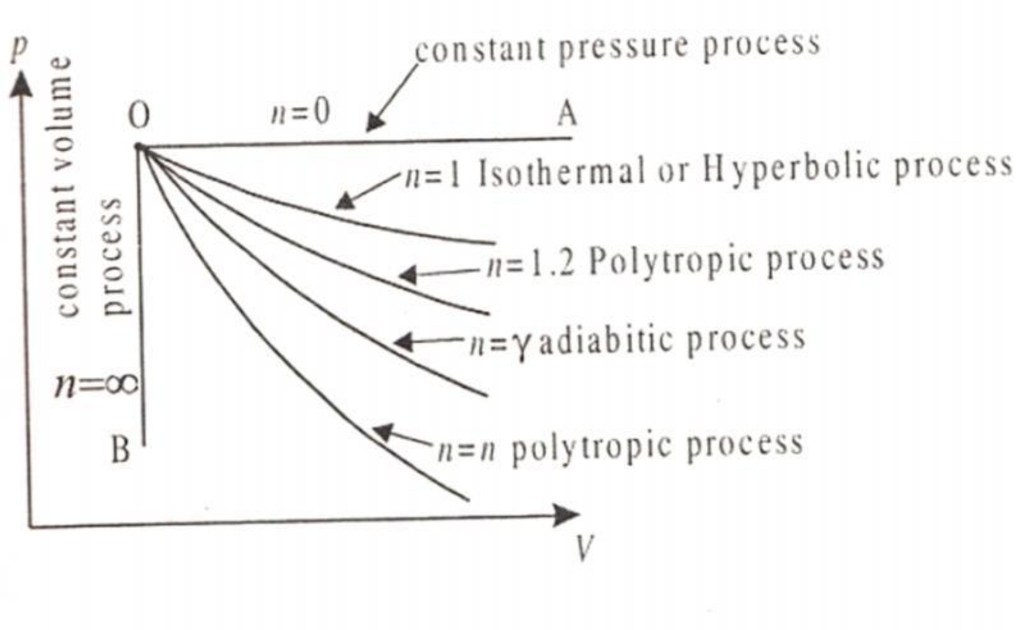


Fig. 3.6 Polytropic processes on p – V diagram

UNIT-II
STEAM TURBINES, HYDRAULIC MACHINES

Properties of Steam

Difference between Steam and Gas:

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

Steam Formation:

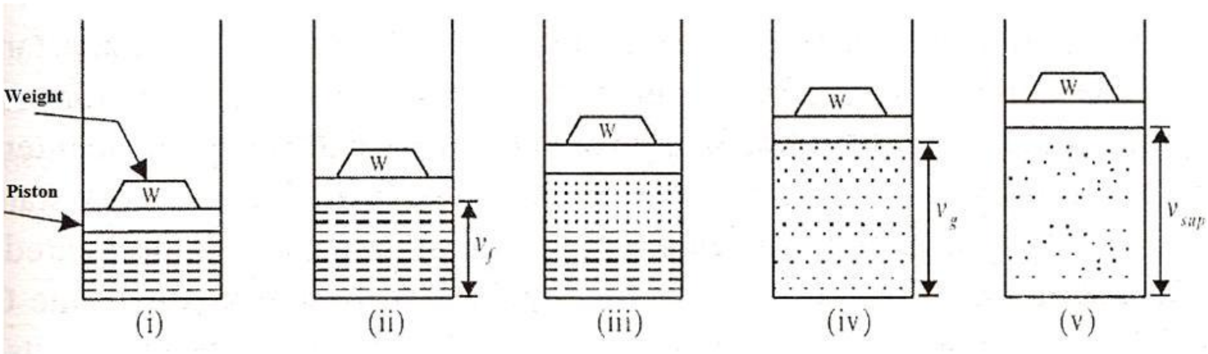


Fig. 4.1 Formation of steam

Fig. 4.2 Temperature – Enthalpy diagram

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

Now, if supply of heat to water is continued it will eliminate the evaporation of water while the temperature remains at the saturation temperature T_s because the water will be saturated with heat and any further addition of heat changes only the phase from the liquid phase to the gaseous phase.

This evaporation will be continued at the same saturation temperature T_s until the whole of the water is completely into steam as shown in Fig. 4.1 (iv). This point is represented by the **point C** on the graph.

This constant pressure and constant temperature heat addition is represented by the horizontal **line BC** on the graph. The heat being supplied does not show any rise of temperature but changes water into vapor state (steam) and is called **latent heat** or **hidden heat** or **enthalpy of evaporation**. It is denoted by h_{fg}. If the steam is in contact with water, it is called **wet steam** (Fig. 4.1 (iii)).

Again, if supply of heat to the saturated steam is continued at constant pressure there will be increase in temperature and volume of steam. The temperature of the steam above the saturation temperature at a given pressure is called **superheated temperature**.

During this process of heating, the dry steam will be heated from its dry state, and the process of heating is called **superheating.** The steam when superheated is called **superheated steam.** This superheating is represented by the inclined **line CD** on the graph.

The amount of heat required to raise the temperature of dry steam from its saturation temperature to any required higher temperature at the given constant pressure is called **amount of superheat** or **enthalpy of superheat.** The difference between the superheated temperature and the saturation temperature is known as **degree of superheat**.

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.

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

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.

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

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)

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

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})

Degree of superheat: It is defined as the difference between the temperature of superheated steam and dry saturated steam at the given pressure. Mathematically, Degree of superheat = (T_{sup} – T_{sat})

Amount of superheat: It is defined as the amount of heat added during superheating of steam. It is also known as heat of superheat.

Mathematically, Amount of superheat = C_{ps} (T_{sup} – T_{sat})

Specific Volume of Steam:

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

Specific Volume of Saturated Water (v_f): It is defined as the volume occupied by 1 kg of water at the saturation temperature at a given pressure. See Fig. 4.1 (ii).

Specific Volume of Dry Saturated Steam (v_g): It is defined as the volume occupied by 1 kg of dry saturated steam at a given pressure. See Fig. 4.1 (iv). **Specific Volume of Wet Steam (v)**: It is defined as the volume occupied by 1 kg of steam with dryness fraction *x* which contains some dry steam as well as water molecules suspended in it at a given pressure.

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

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

$v = x\,v_g + (1 - x)\,v_f$ Generally $(1 - x)\,v_f$ is very low and often is neglected. Therefore, $v = x\,v_g$ m^3/kg

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

The superheated steam behaves like a perfect gas; therefore its specific

volume is determined approximately applying Charle's law.

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.

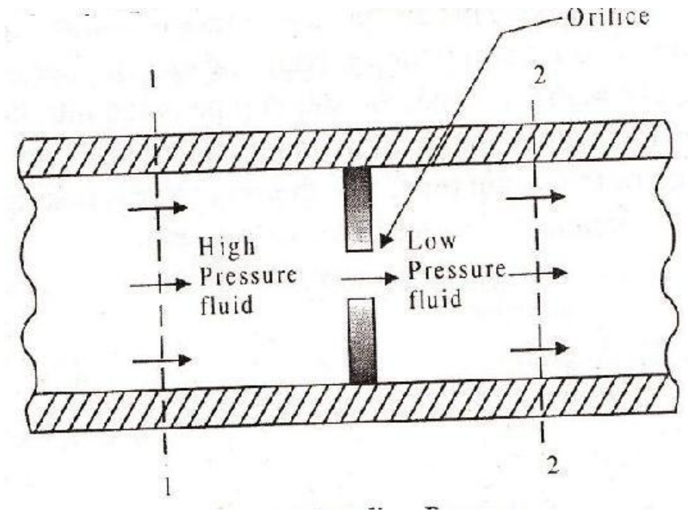


Fig. 4.3 Throttling Process

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.

Measurement of Dryness Fraction:

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

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

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.

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

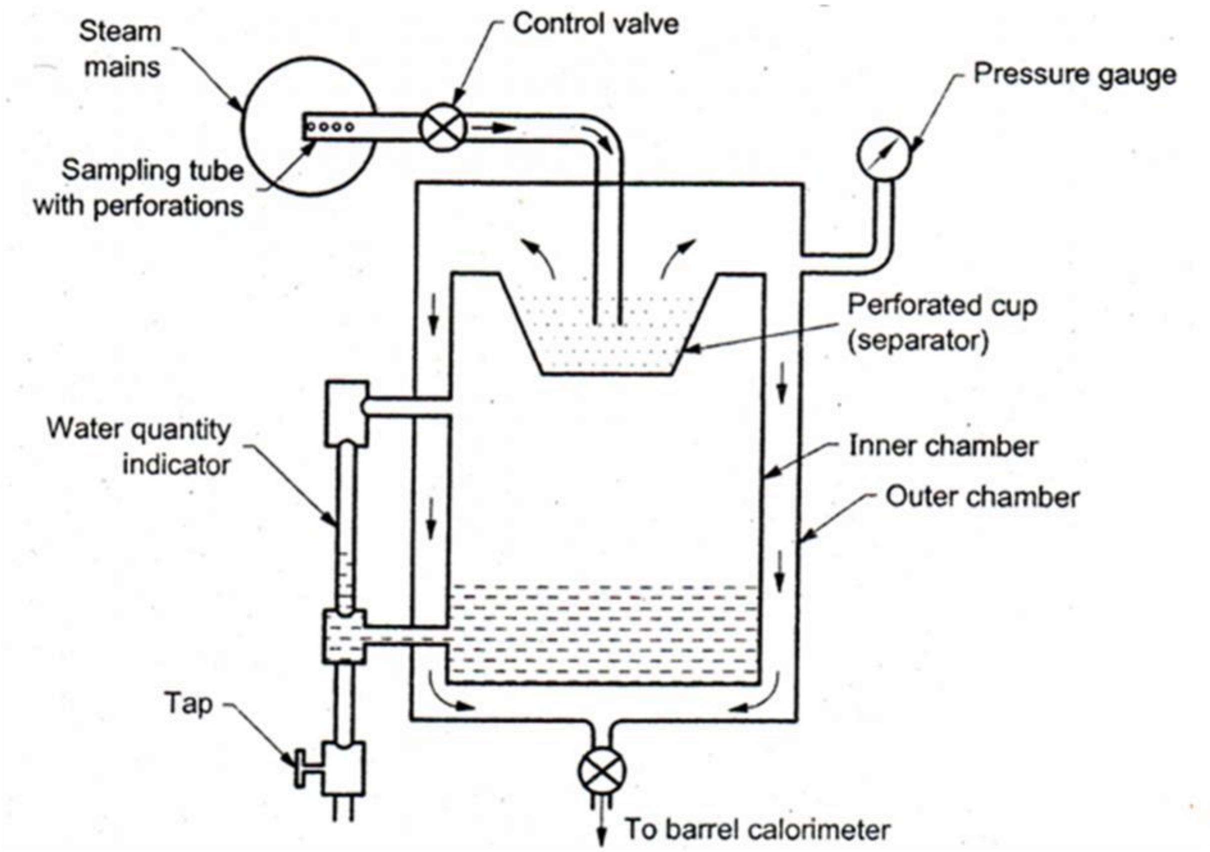


Fig. 4.5 Separating Calorimeter

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 (p1) and temperature after throttling is to be measured.

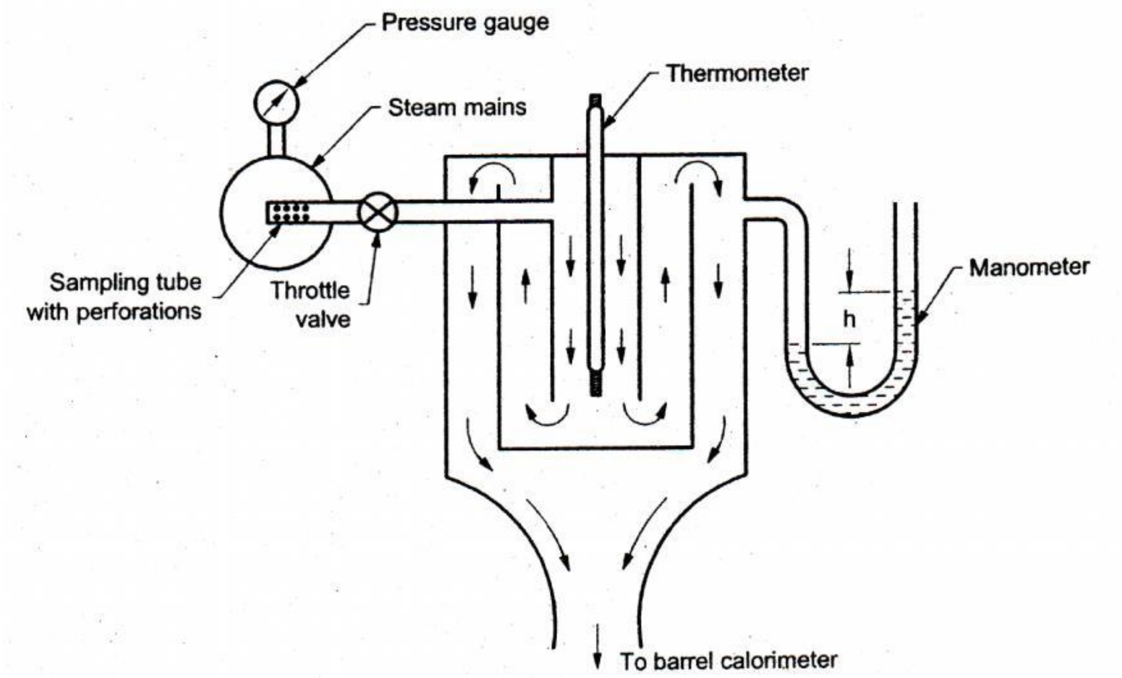


Fig. 4.5 Throttling calorimeter

Calculation

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

Limitation

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

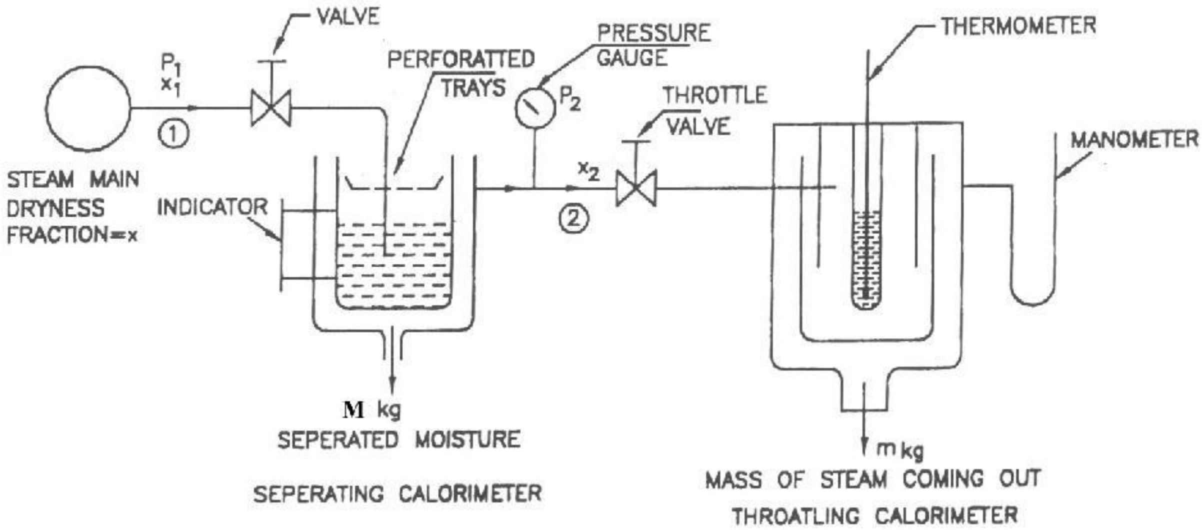


Fig. Combined separating and throttling calorimeter

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.

UNIT-III

INTERNAL COMBSUTION ENGINES, REFRIGERATION AND AIR-CONDITIONING

HEAT ENGINES

Thermal prime movers:

The thermal prime mover is a prime mover that is made to utilize the heat energy for conversion into mechanical work. Thermal prime movers are widely used for performing various functions, for example, to run vehicles, to run household appliances; to run machines etc. this is the most important of all the prime movers. Thermal prime movers have played very important role in the field of transportation and communication on land, on sea and in the space. Internal combustion engines, steam turbines, gas turbines, rockets etc. are examples ofthermal prime movers.

Sources of Energy (Heat):

The industrial progress of any country is based on the per capita consumption of electrical power. This electrical power can be generated by using different forms of energy in prime movers.
The sources of energy can be of two types –
(a). Renewable or Non-conventional energy
(b). Non-renewable or conventional energy
The following table lists theses energy sources.

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

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.***

Classification of Heat Engine:

Heat engine are divided into two broad classes:

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

1. External Combustion Engine:

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

2. Internal Combustion (IC) Engine:

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

Advantages of Heat Engines:

The advantages of internal combustion engines are:

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

The advantage of external combustion engines are:

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

DEFINITIONS:

Working substance:

When a gas or mixture of gases or a vapour is used in engine for transferring heat, it is known as working fluid or working substance.Working fluids are able to absorb heat, store within them and give up heat when required. During the process of absorbing and giving up heat, its pressure, volume, and temperature changes accordingly. Working fluid is never destroyed or reduced in quantity during the process.

Converting machines:

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

Reciprocating machine:

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

Rotary machine:

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

Jet machine:

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

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

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

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

HEAT ENGINE CYCLES:

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

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

Carnot cycle Processes:

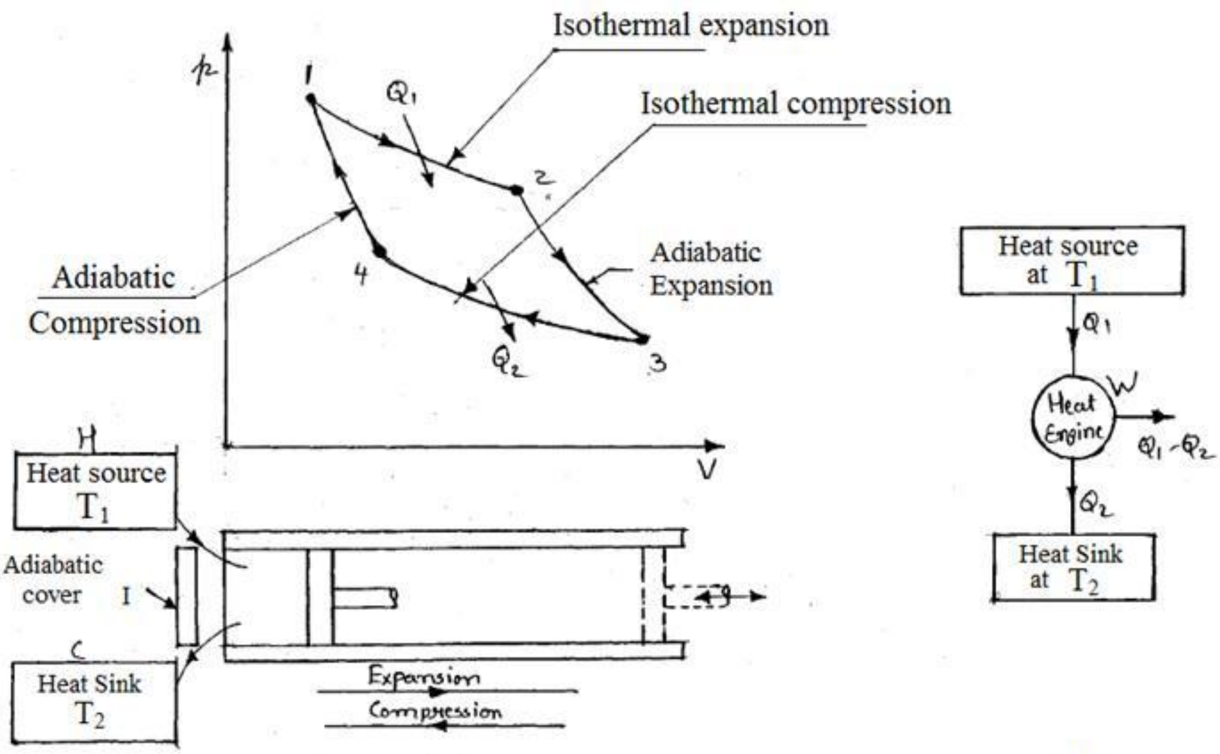
This cycle consists of four processes in the following order.

(1) Isothermal expansion,

(2) Adiabatic expansion,

(3) Isothermal compression,

(4) Adiabatic compression.



(a)Fig. 2 Carnot cycle. **(b)**

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

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

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

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

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

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

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

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

Assumptions made in the working of the Carnot Engine:

- The piston moving in a cylinder does not develop any frictioduring motion. The walls of piston and cylinder are considered as perfect insulators of heat. The cylinder head is so arranged that it can be a perfect heat conductor or perfect heat insulator.
- The transfer of heat does not change the temperature of source or sink.

CARNOT VAPOUR CYCLE:

In the Carnot Vapour Cycle, steam or any other vapour is used as working substance in place of a perfect gas. Components and arrangement of Carnot vapour cycle is shown in fig.(3) and same is represented on p-V diagram

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

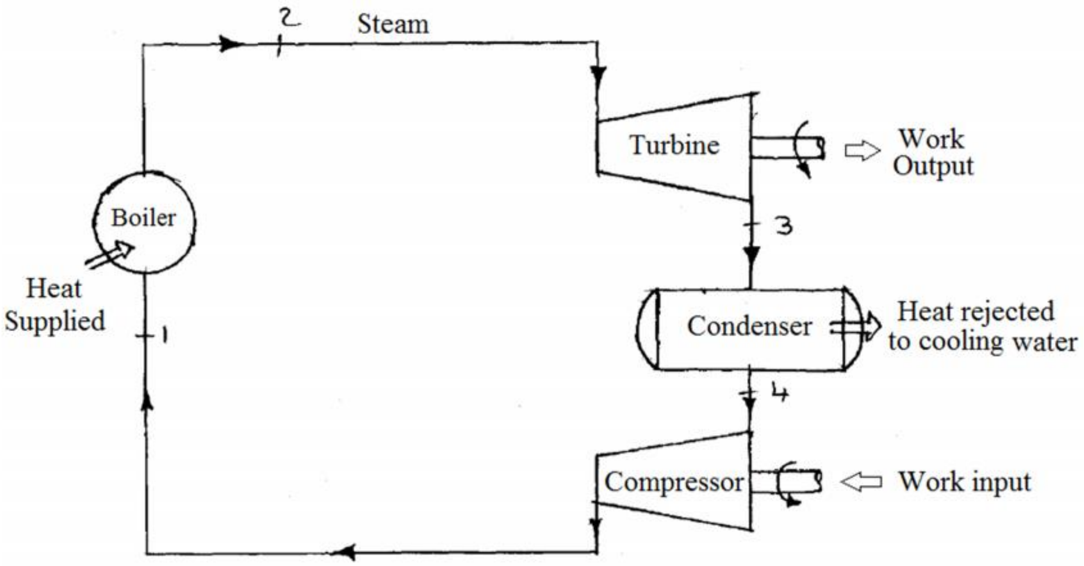


Fig. 3 Arrangement of Carnot vapour cycle

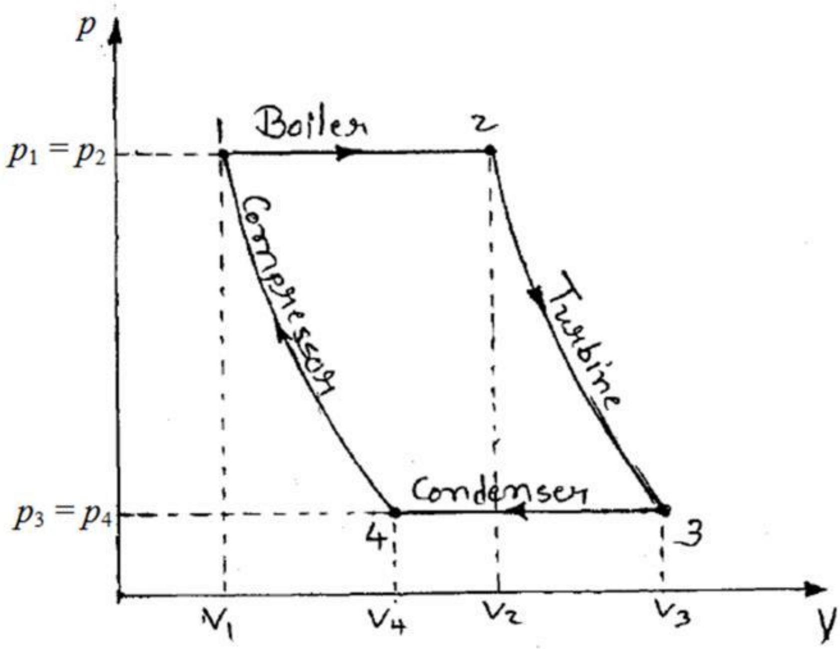


Fig. 4 p-V diagram of Carnot vapour cycle

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

Process (3-4): This is the heat rejection process in the condenser. The expanded steam enters the condenser at condition (3) changing condition from (3) to (4). The process 3-4is at constant pressure and temperature as shown in p-V diagram.

Process (4-1): At (4) steam and water enter the compressor in which reversible adiabatic/isentropic compression will take place. The pressure will increase from P_2 to P_1 by compression. Compressor consumes power W_C. This completes the cycle.

RANKINE CYCLE:

It is very difficult to pump mixture of vapour and liquid as in case of Carnot vapour cycle. This difficulty is eliminated in Rankine cycle by complete condensation of vapour in condenser and then pumping the water isentropically to the boiler at boiler pressure. The heat energy of the fuel is converted into mechanical work or power in steam turbine power plants. The flow diagram and (p-V) diagram of Rankine cycle are shown in fig.

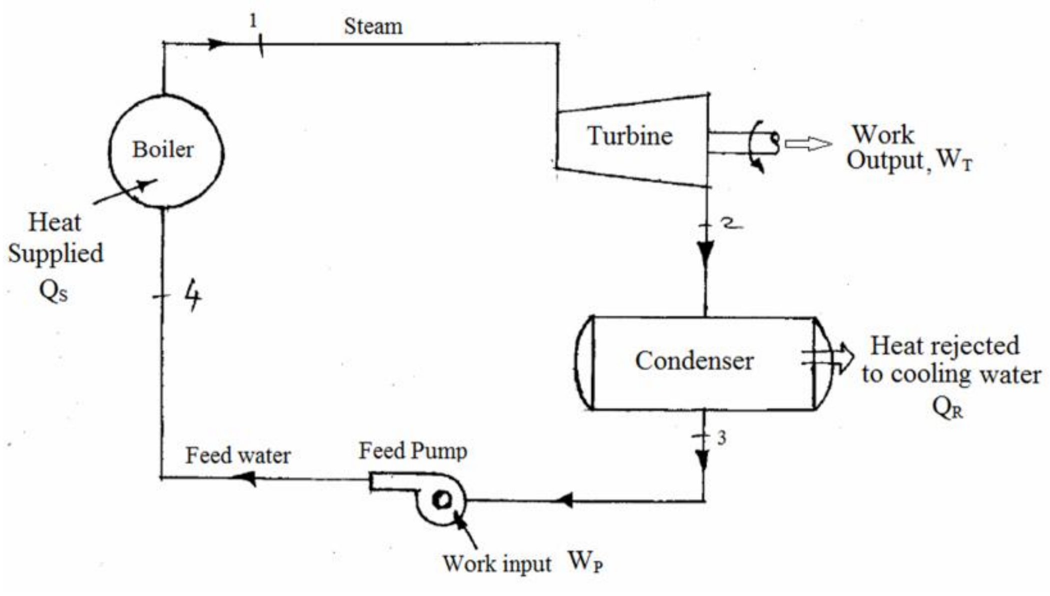


Fig. 5 Flow diagram of Rankine cycle

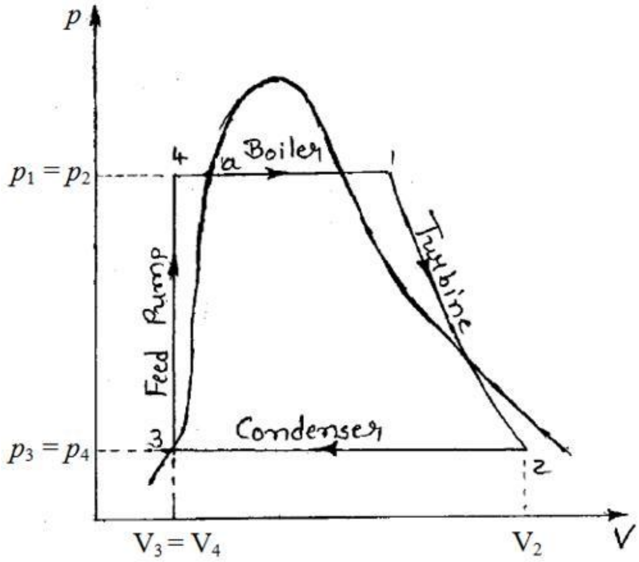


Fig. 6 p-V diagram of Rankine cycle.

The four main components of cycle are:

(1) Boiler, (2) Turbine, (3) Condenser, (4) Feed pump.

Process (1-2): High pressure and high temperature superheated, dry saturated or wet steam generated in the boiler at p_1 and T_1 is supplied to the steam turbine. This steam expands isentropically into steam turbine up to the condenser pressure. Steam turbine develops mechanical work, W_T due to expansion of steam.

Process (2-3): The exhaust steam from turbine enters into condenser, where it is condensed at constant pressure by circulating cooling water in the tubes. The heat rejected by exhaust steam is Q_R.

Process (3-4): The condensed water coming from condenser is pumped to boiler at boiler pressure with the help of feed pump. To do so work, W_P is supplied to feed pump.

Process (4-1): The water is heated at constant pressure p_1 in the boiler until the saturation temperature is reached (process (4-a)), Saturated water is converted into saturated steam at constant pressure (process (a-b)). During process (b-1) steam is superheated in superheater.

Difference between Rankine cycle and Carnot cycle:

(1) The exhaust steam from the turbine is not completely condensed in condenser in case of Carnot cycle; while in case of Rankine cycle it is completely condensed.

(2) The compressor is used in Carnot cycle to handle mixture of water and steam. In Rankine cycle pump is used in place of compressor, it has to handle only liquid.

(3) Superheating of steam is very difficult to achieve in Carnot cycle but there is a possibility of superheating of steam in Rankine cycle.

OTTO CYCLE:

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

Air standard efficiency:

The efficiency of engine in which air is used as working substance is known as ***air standard efficiency.***

The air standard efficiency is always greater than the actual efficiency of cycle. Otto cycle is also one of the air standard cycle.

Assumptions made for analysis of Air standard cycle:

(1) The working fluid is air.

(2) In the cycle, all the processes are reversible.

(3) The air behaves as an ideal gas and its specific heat is constant at all temperatures.

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Processes of Otto cycle:

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

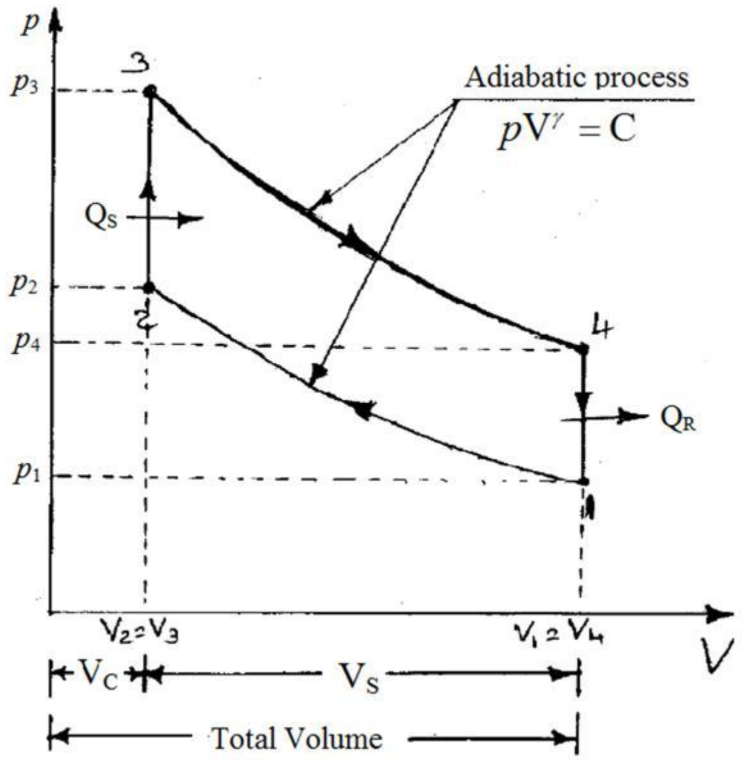


Fig. 7 p-V diagram for Otto cycle.

Consider 'm' kg of air in the cylinder.

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

Process (3-4): Reversible adiabatic or isentropic expansion of air from state-3 to state-4. Work is developed during this process. Pressure and temperature of air decreases.

Process (4-1): Constant volume heat rejection is carried out during this process. Hence pressure and temperature of air decreases to initial value. This way, a cycle is completed.

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.

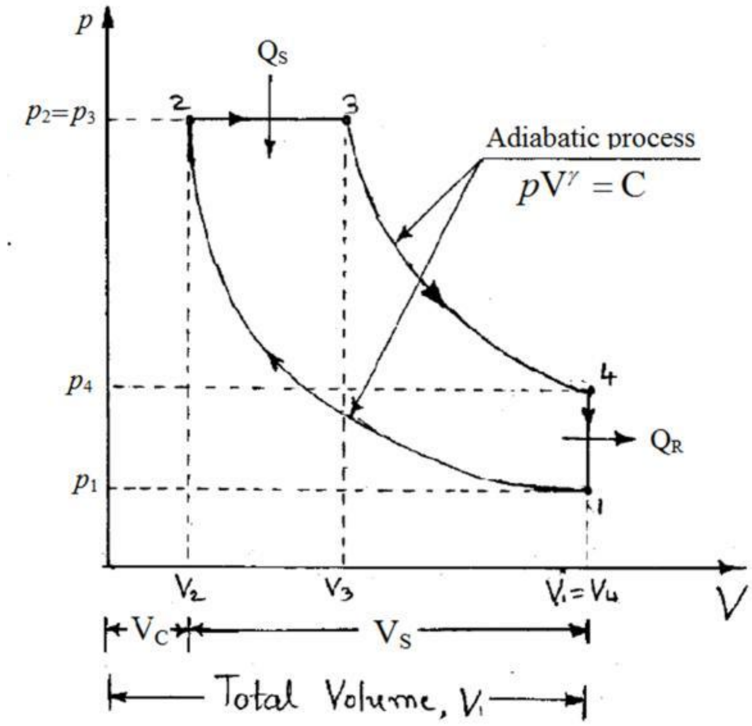


Fig. 9 p-V diagram for diesel cycle

It is clear from the above equation that the efficiency of diesel cycle depends upon compression ratio (r), ratio of specific heat (γ), and cut-off ratio ρ.

Cut-off ratio ρ is always greater than 1 and γ = 1.4 for air, the quantity in bracket is always greater than one.

The efficiency of Diesel cycle is always less than Otto cycle for same compression ratio due to above reason.

Heat is added at constant volume in Otto cycle while heat is added at constant pressure in Diesel cycle.

From the eq. (16) it is clear that the efficiency of Diesel cycle increases with the increase of compression ratio and with the decreases of cut-off ratio.

Introduction

STEAM BOILERS

Steam boiler may be defined as " A closed pressure vessel in which steam is generated with capacity exceeding 25 litres,gauge pressure greater than or equal to 1 kg/cm2 , and water Is heated at 100®C or above. The steam produced may be supplied:

1) For generating power in steam Engine or steam turbines.
2) At low pressures for industrial process work in cotton mills, sugar factories, etc., and
3) For producing hot water for supply of hot water and for heating the buildings in cold whether

Classification of Steam Boilers

According to relative position of water and hot gases.

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

According to the axis of the shell

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

According to the method of firing

Externally fired boilers – furnace is located outside the shell.

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

According to the Method of Water circulation

Forced Circulation boilers - water is circulated by pumps which is driven by motor and

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

According to the Pressure of steam

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

According to the mobility of boiler

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

According to the number of tubes in the boiler

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

Comparison between fire-tube and water tube boilers

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

General terms used in Steam Boiler

Cylindrical shell

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

Combustion chamber

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

Grate

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

Furnace

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

Fire Hole

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

Ash Pit (ash pan)
It is the area in which the ash of burnt coal is collected.

Smoke chamber (smoke box)
The waste gases are collected here and then releases to the chimney and then to atmosphere.

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

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

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

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

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

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

Cochran Boiler (Vertical multi-tubes boiler)
Characteristics of boiler:
A vertical, multi tubes, fire tube, internally fired, natural circulated boiler.

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

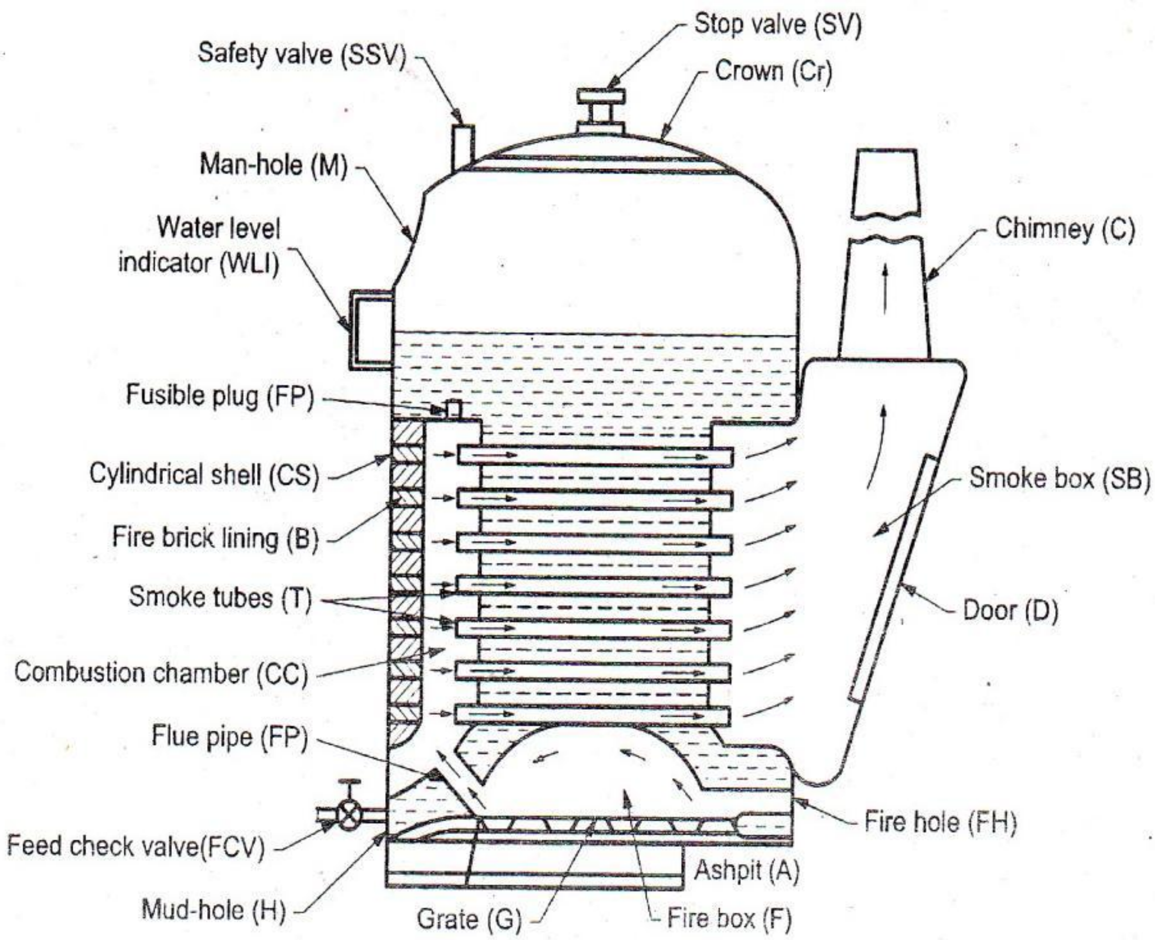


Fig. Cochran Boiler

Working

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

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)

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.

Babcock and Wilcox water tube Boiler

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

Construction

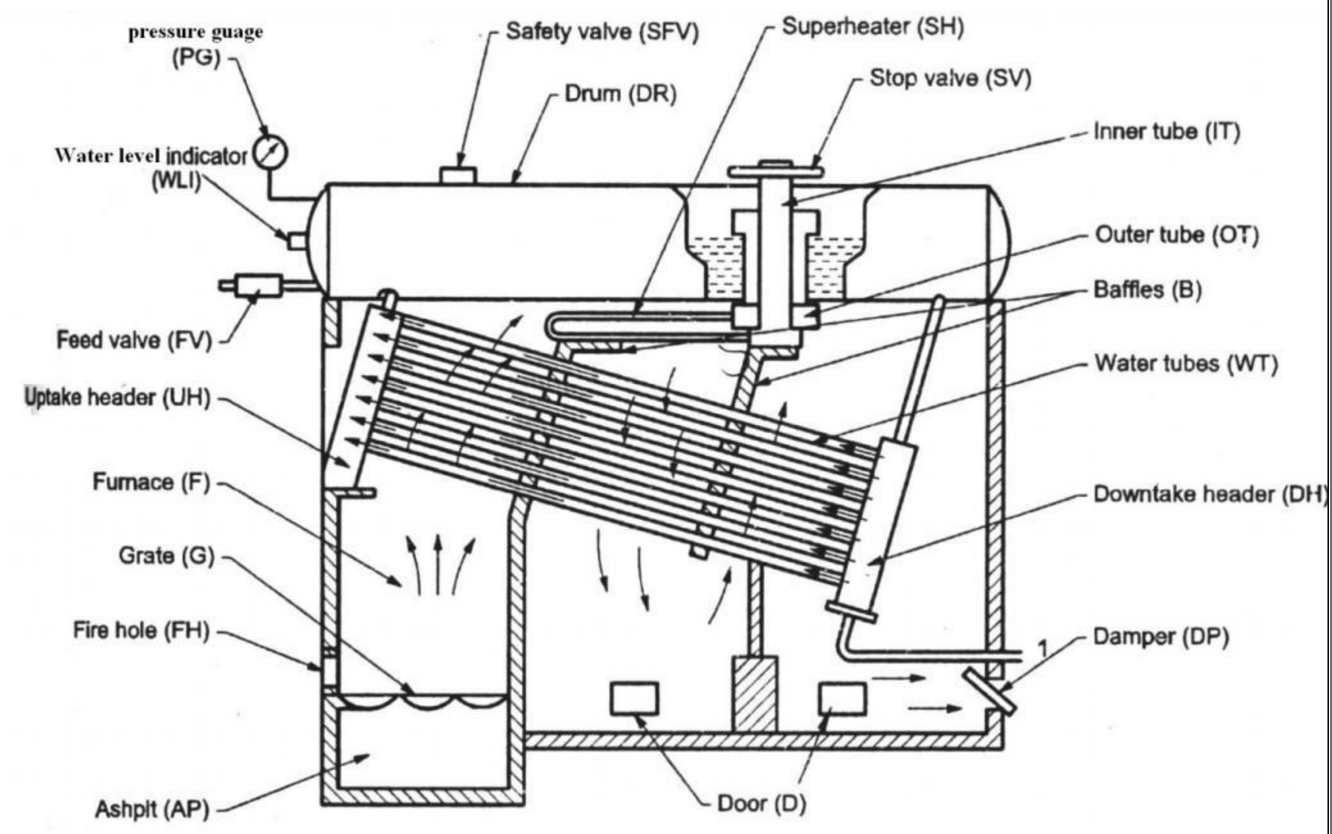


Fig. Babcock Wilcox Boiler

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

Working

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

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

Boiler Mountings & Accessories
List of Boiler Mountings & Accessories

According to IBR the following **mountings** should be fitted to the boilers'1) Two Safety valves

2) Two water level indicators
3) A pressure gauge
4) A Steam stop valve
5) A feed check valve
6) A blow off cock
7) An attachment of inspector's test gauge
8) A man hole
9) Mud holes or sight holes

Commonly used boiler **accessories** are as1) Feed pumps

2) Injector
3) Economiser
4) Air preheater
5) Superheater
6) Steam separator
7) Steam trap

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.

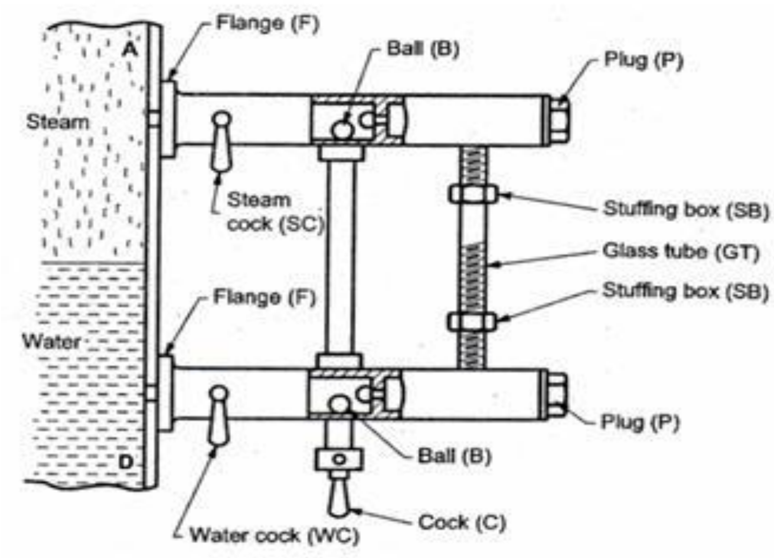


Fig. 6.3 Water Level Indicator

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. 6.4. This bent up tube is called Bourdon’s tube. One end of the gauge is fixed and connected to the steam space in boiler .The other end is attached by links and pins to a toothed quadrant. This quadrant meshes with a small pinion on the central spindle.

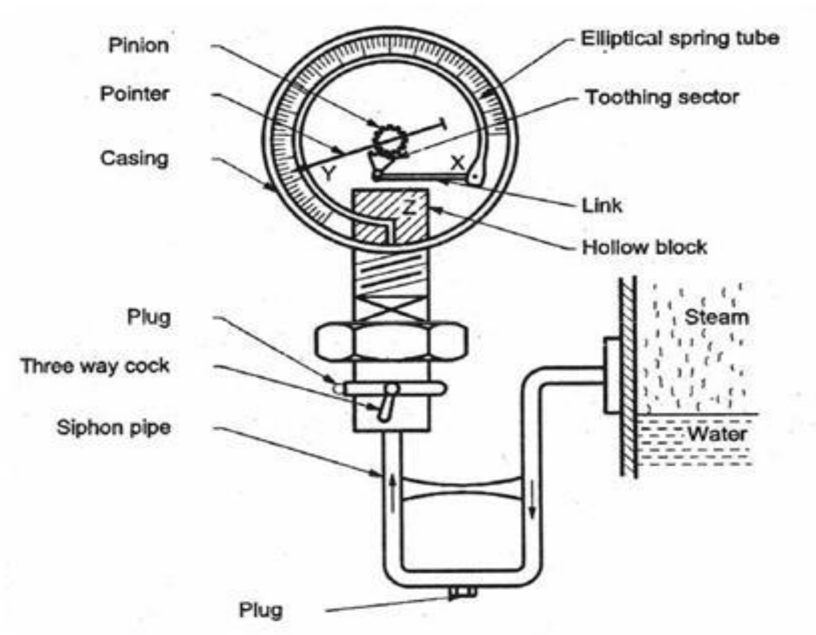


Fig 6.4 pressure gauge

Working

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

Safety Valves

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

Lever Safety Valve

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

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

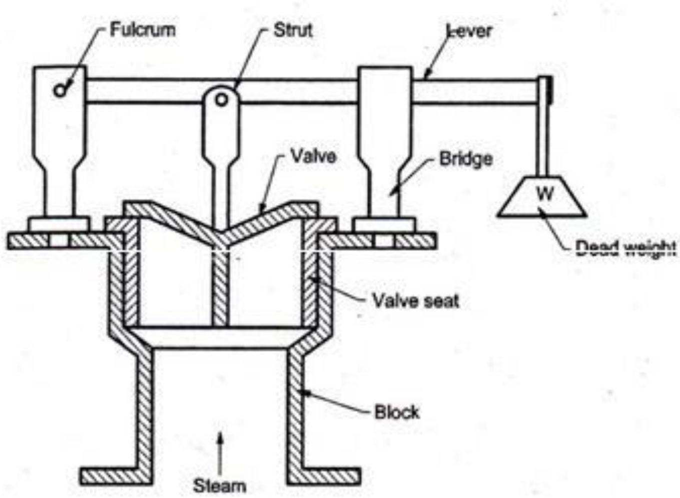


Fig 6.5 lever safety valve

Dead weight safety valve

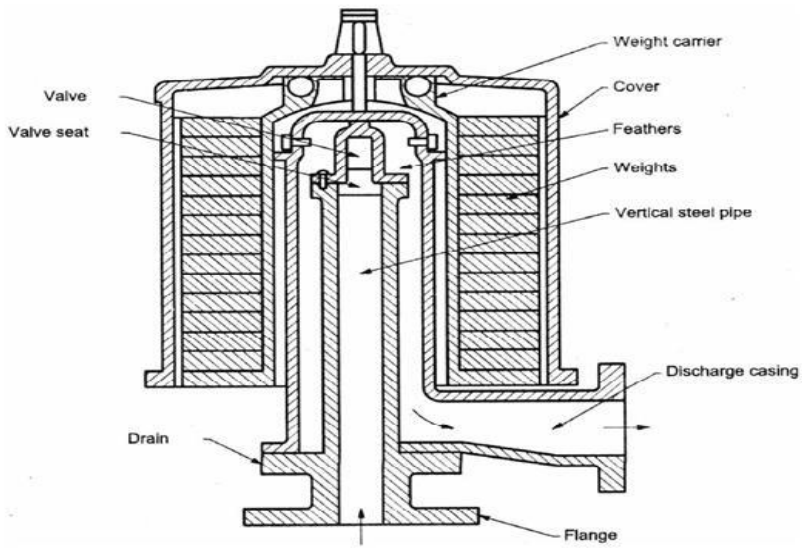


Fig 6.6 Dead weight safety valve

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

High steam low water safety valve

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

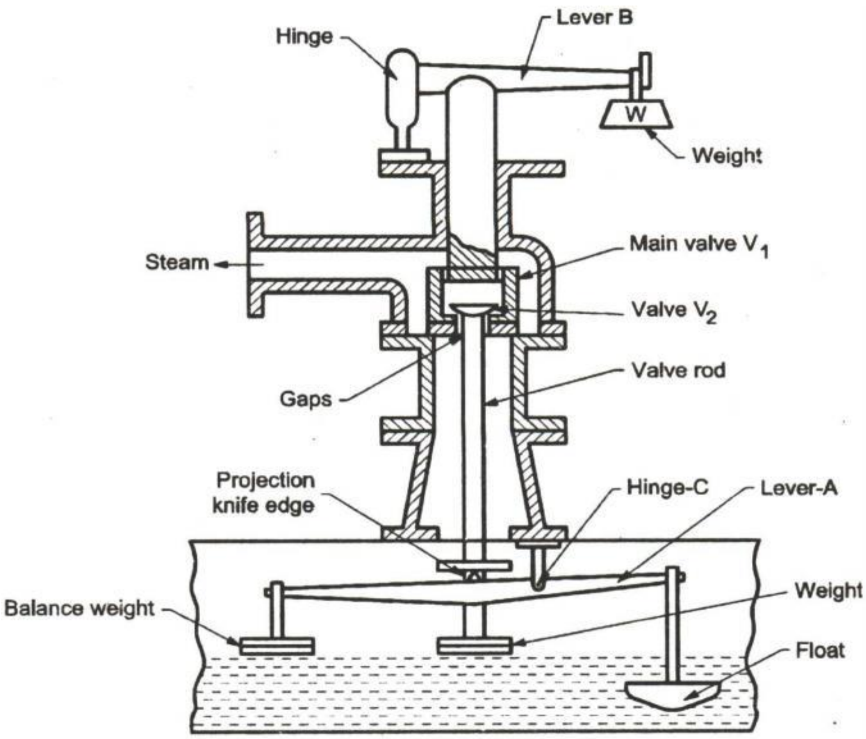


Fig. 6.7 high stem low water safety valve

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

Spring Loaded safety valve

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

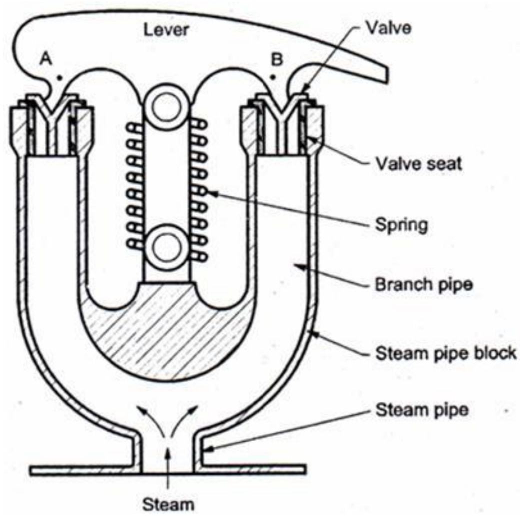


Fig. 6.8 Spring Loaded Safety valve

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

Steam stop valve

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. Whenthe 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.

Blow off cock

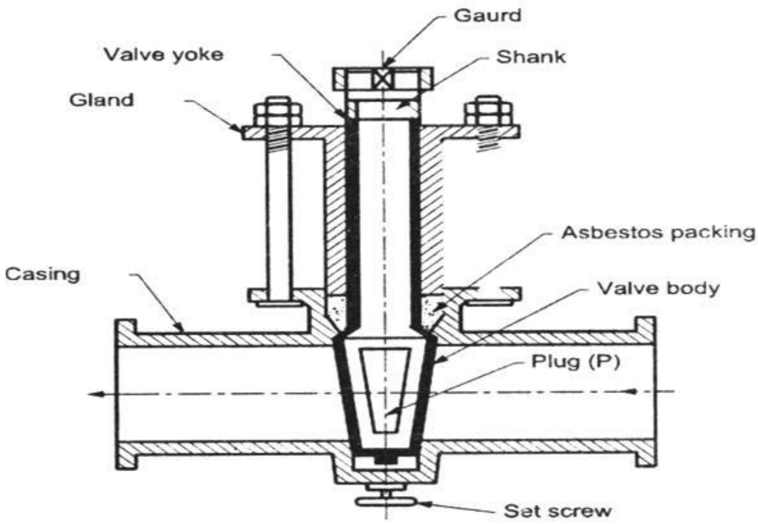


Fig. 6.11 Blow off Cock

A common type of blow-off cock is shown in fig. 6.11 A conical plug is fitted accurately into a similar casing. The plug has a rectangular opening.

In the position shown in fig. 6.11 the plug slot is perpendicular to the flow passage. When the plug slot is brought in line with the flow passage of body by rotating the plug, the water from boiler comes out with a great force. If sediments are to be removed, the blow-off cock is operated when the boiler is on. This forces the sediments quickly out of boiler.

Fusible Plug

Function

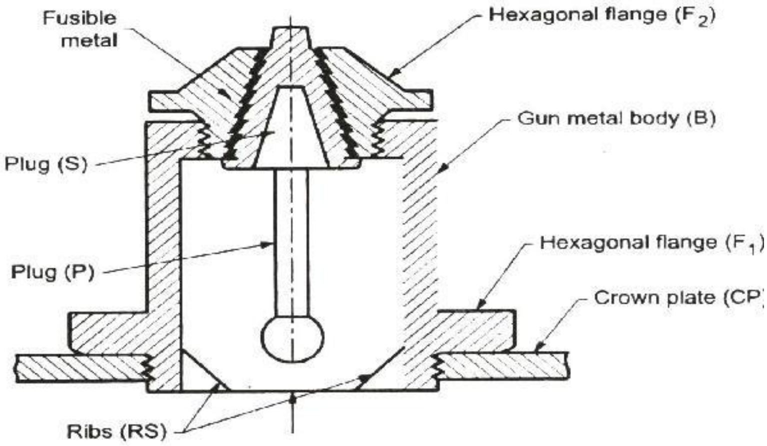


Fig. 6.12 Fusible Plug

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

Construction

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

Working

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

Boiler Accessories

Economiser

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

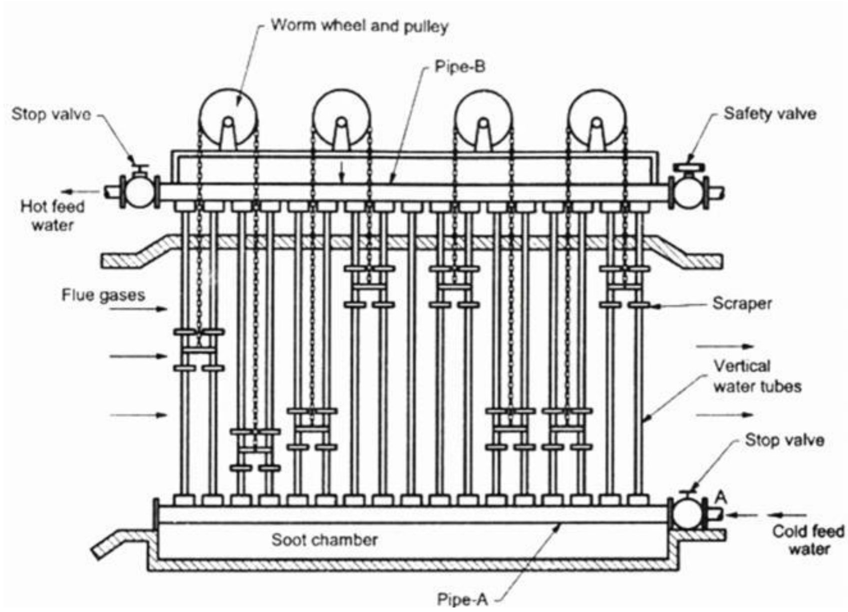


Fig. 6.13
Economiser

Construction and working

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 reducesthe efficiency of economizer. To prevent the soot deposit, the scrapers S move up and down to keep the external surface of pipe clean.By-pass arrangement of flue gases enables to isolate or include the economizer in the path of flue gases.The action of the superheater is as follows: The stop valve A is closed and stop valves B and C are in open position. The wet steam from boiler flows into right hand header via stop valve C. After superheating of steam in the tubes, it flows into the left hand header, from where it is withdrawn through the stop valve B. If the superheated steam is not needed, the stop valves B and C are closed and the wet steam is directly taken out from the boiler through stop valve A.

Internal Combustion Engine

Introduction

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

Diesel in the year 1892.

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

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

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

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

Classification of I.C. Engines

I.C. Engines may be classified according to,

a) Type of the fuel used as :

(1) Petrol engine (2) Diesel engine

(3) Gas engine (4) Bi-fuel engine (Two fuel engine)

b) Nature of thermodynamic cycle as :

(1) Otto cycle engine (2) Diesel cycle engine

(3) Duel or mixed cycle engine

c) Number of strokes per cycle as :

(1) Four stroke engine (2) Two stroke engine

d) Method of ignition as :

(1) Spark ignition engine (S.I. engine)

Mixture of air and fuel is ignited by electric spark. (2) Compression ignition engine (C.I. engine)

The fuel is ignited as it comes in contact with hot compressed air.

e) Method of cooling as :

(1) Air cooled engine (2) Water cooled engine

f) Speed of the engine as :

(1) Low speed (2) Medium speed

(3) High speed

Petrol engine are high speed engines and diesel engines are low to medium speed engines

g) Number of cylinder as :

(1) Single cylinder engine (2) Multi cylinder engine

h) Position of the cylinder as :

(1) Inline engines (2) V – engines

(3) Radial engines (4) Opposed cylinder engine

(5) Opposed piston engine

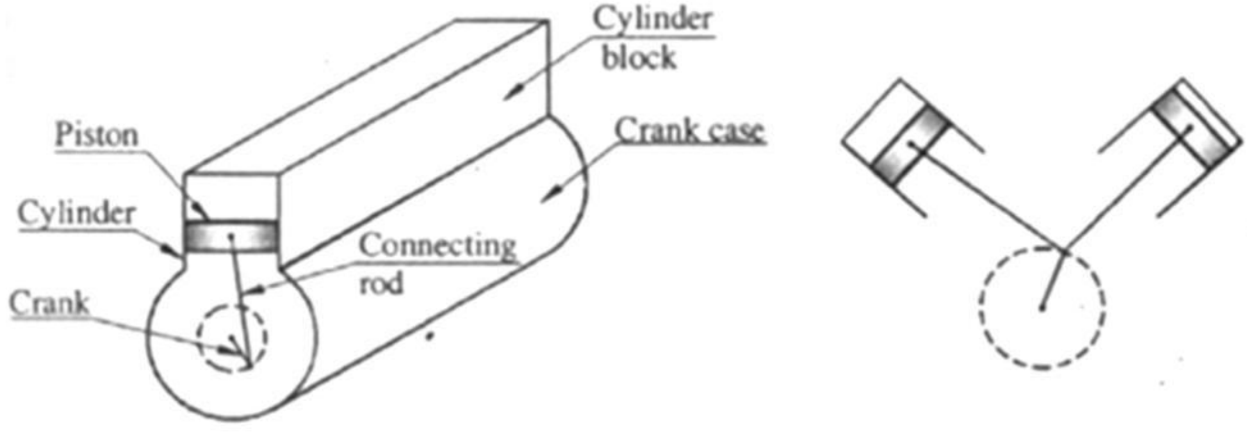


Fig. In line engine and V – engine

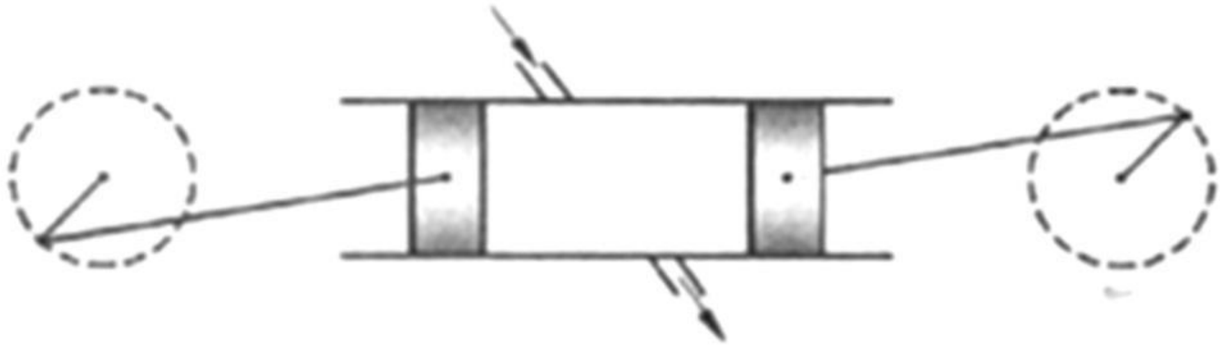


Fig. 7.2 Opposed piston engine

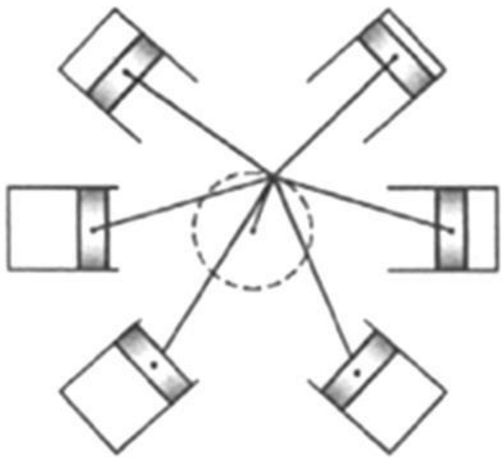


Fig. 7.3 Radial engine Fig. 7.4 Opposed cylinder engine

Engine details

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

Cylinder

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

Cylinder head

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

Piston

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

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.

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.

Connecting Rod

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

Crank and Crankshaft

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

Valves

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

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.

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.

Carburetor

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

Fuel pump

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

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

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

(ii) Compression stroke

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

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

(iii)Power or Expansion stroke

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

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

(iv)Exhaust Stroke

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

Diesel four stroke cycle <u>OR</u> Four stroke Diesel engine <u>OR</u> Four stroke compression ignition (C.I) engine.

The diesel engines work on the principle of Diesel cycle, also called constant pressure heat addition cycle shown in Fig. The four stroke diesel engine cycle also consists of suction, compression, power, and exhaust strokes. Fig. 10 shows the working and construction of a four stroke diesel engine.
The basic construction of a four stroke diesel engine is same as that of four stroke petrol engine, except instead of spark plug, a fuel injector is mounted in its place as shown in Fig. 10. A fuel pump supplies the fuel oil to the injector at higher pressure.

(i) Suction Stroke

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

(ii) Compression stroke

During this stroke, both inlet valve and exhaust valve remain closed. The piston moves from BDC to IDC. As this stroke is being performed, the air in the cylinder will be compressed, so pressure and temperature of air increases.
The compression ratio of this engine is higher than petrol engine. Due to higher compression ratio, air will have attained a higher temperature than self ignition temperature of the diesel fuel.

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

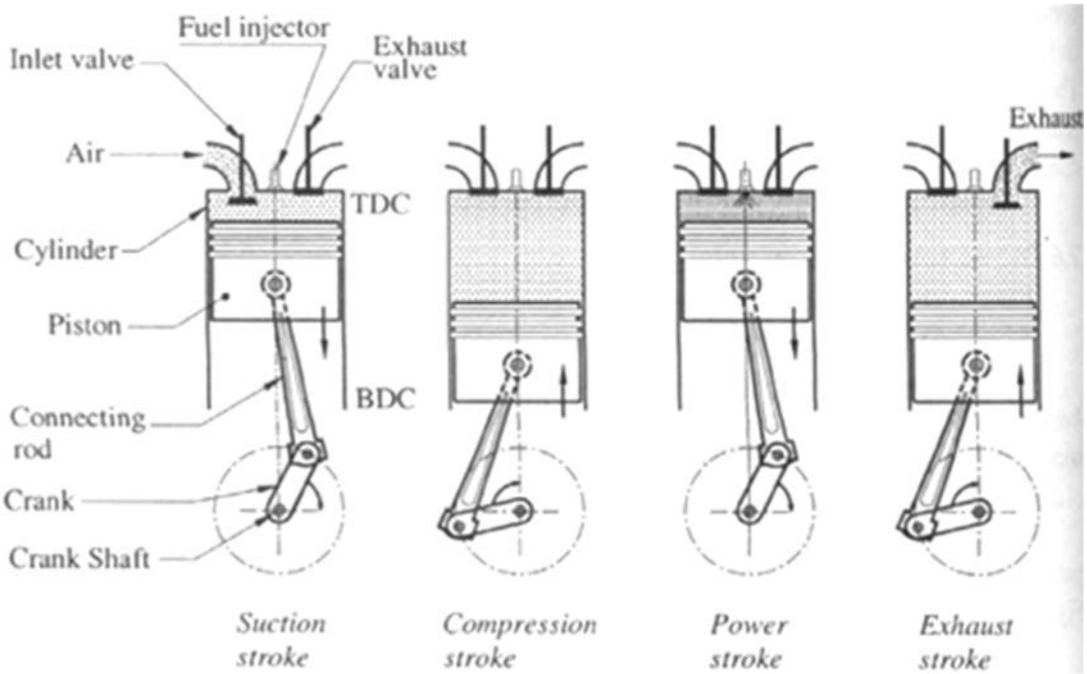


Fig. 7.9 Four stroke diesel engine

(iii) Power or Expansion stroke

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

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

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

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

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

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

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.

Difference between two stroke and four stroke cycle engines

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

Pumps

Introduction

The pump is a mechanical device which conveys liquid from one place to another place. It can be defined as machines which converts the mechanical energy of motor or engine in to kinetic energy, potential energy and thermal energy.

Applications

(1)Thermal engineering

To feed water into the boiler

To circulate the water in condenser

To circulate lubricating oil in the proper place

(2) Agriculture and irrigation

To lift water from deep well

To convey water from one place to another

(3) Chemical industries:

To convey liquid chemical from one place to another

(4) Municipal water works and drainage system

(5) Hydraulic control system.

Classification of pumps

The pump can be classified according to principle by which the energy is added to the fluid and their design feature as shown below.

(A) Positive displacement pumps

These pumps operate on the principle of a definite quantity of liquid is discharged or displaced due to the positive, or real displacement of working elements (i.e. piston, gear, vane, screw)

(1) Reciprocating pump

(i) Piston pumps

Single cylinder - single acting, double acting

Double cylinder - single acting, double acting

(ii) Plunger pump

(iii) Bucket pump - Hand pump

(2) Rotary pump (positive displacement with circular motion)

(B) Roto dynamic pump

These pumps operate on the principle of the rise in pressure energy of liquid by dynamic action of liquid. The dynamic action of liquid is carried out by revolving wheel which has curved vanes on it. This wheel is known as impeller.

(1) Centrifugal pump

Single stage

Multi stage

(2) Propeller (Axial flow) pump

(3) Mixed flow pump

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.

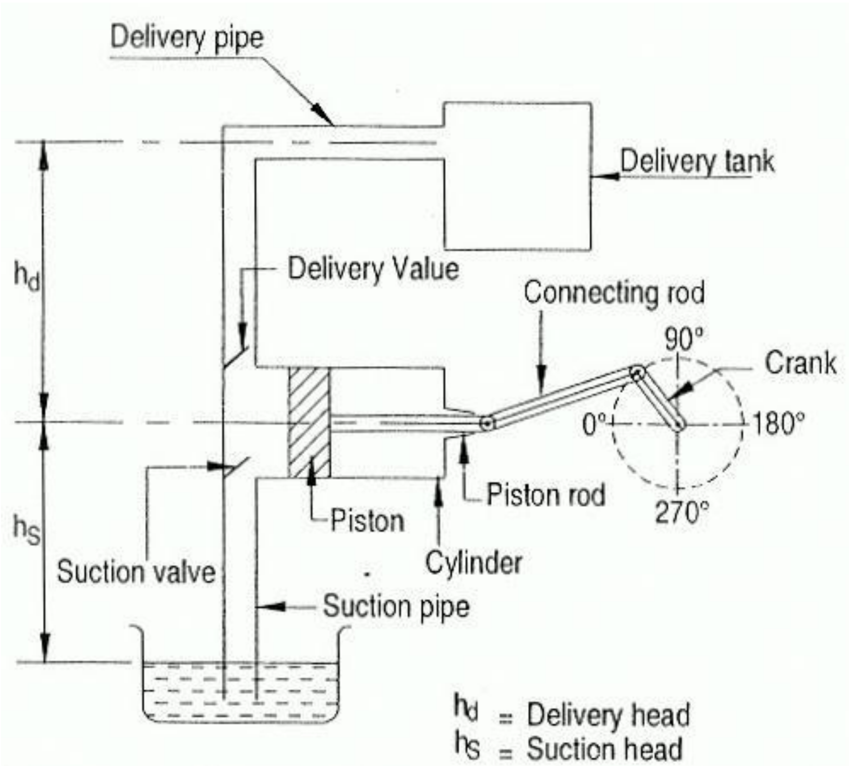


Fig1 Single acting reciprocating pump

Working

Forward stroke (Sctuion stroke):

The piston moves towards right, crank moves from 0° to 180", shown in Fig 8.1. This creates vacuum in the cylinder on the left side of piston causing the suction valve to open. The liquid enters the cylinder and fills it.

Reverse stroke (delivery stroke):

The piston moves towards left, crank moves from 180" to 360°. This causes increase of pressure in the left side of cylinder. The delivery valve open and the liquid are forced to delivery pipe. The suction and delivery valves are non-return valve, they opens or closes automatically according to pressure difference across them.

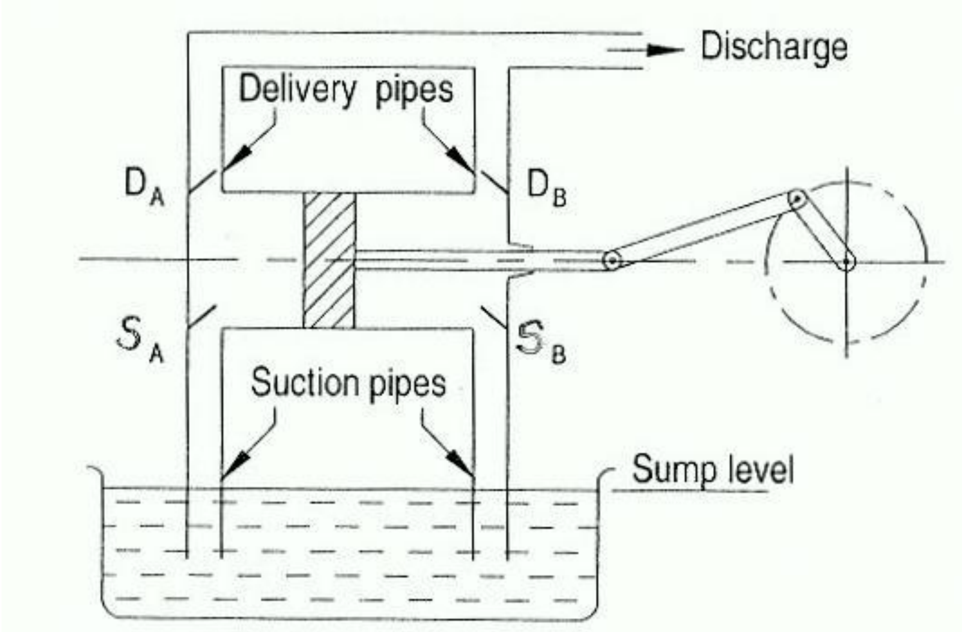
Operation of double acting reciprocating pump

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 SA as shown in Figure. At this moment, the liquid on right side of piston is compressed, the delivery valve DB 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.

(B) Plunger pump

Construction

A hand operated plunger pump consists of plunger, stuffing box, suction valve, delivery valve and handle as shown in fig. 8.3. The pump is operated by handle. In order to prevent leakage of the liquid, the stuffing box, gland and pickings are used. Non-return valves fitted at the suction nd 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.

a

Discharge stroke: Plunger moves down, suction valve closes and delivery valve open through which high pressure liquid is delivered to the delivery pipe.

(C) Bucket pump

Construction

A bucket pump is single acting vertical reciprocating pump. It consists of an open cylinder and a piston with bucket type valve as shown in fig. 8.4. A bucket type valve works as a non return valve, packing, Stuffing box, glide bush.

Intake stroke:

Piston moves up the bucket valve remains closed. During this stroke liquid enters into the cylinder through suction valve. Simultaneously, the liquid above the bucket is forces into delivery pipe through delivery valve.

Discharge stroke:

Piston moves down, the bucket valve open. In this stroke neither suction nor delivery of water takes place, but the water which previously sucked in cylinder moves on upper side of piston.

Priming of centrifugal pump

When a pump is first put into service, its passageways (suction pipe, casing, delivery pipe) are filled with air. If pump is running with air, pressure head generated is in terms of meter of air. If pump is running with water the pressure head generated in terms of meter of water. But density of air is very low, therefore pressure head generated by pump with air is negligible compared to pressure head generated by pump with water. Hence, initially water may not be sucked by pump from sump. Therefore, to avoid this, before first time start the pump air must removed from passageways.

The priming is operation of filling passage ways (suction pipe, casing and delivery pipe up to delivery valve) from outside source with the liquid to be raised before starting the pump. Thus the air from passageways is removed and filled with the liquid to be pumped.

Types of priming

1. Priming by hand
2. Priming with vacuum pump
3. Priming with jet pump
4. Priming with separator

(1) Priming by hand

For small pump priming is done by pouring liquid directly in the casing through funnel air vent cock open provided on the casing. When all air is evacuated from the casing, suction pipe and portion of delivery pipe, the system is filled with liquid. The cocks are closed and pump started.

(2) Self priming

When the pump is idle and liquid level in the pump remains full in the suction pipe & casing the pump can removed the air by their own pumping action. This is called self priming.
The pumps can be primed by any of the following methods.

Main parts of centrifugal pump

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

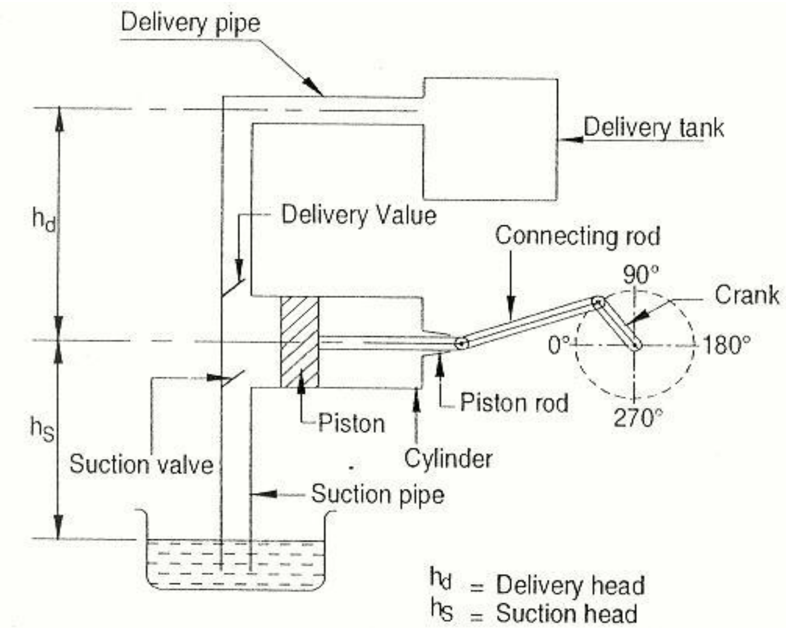


Figure 8.6 Centrifugal pump

1. Impeller: It is rotating part of a centrifugal pump and increases kinetic energy of liquid. It consists of a series of backward curved vanes. The impeller is mounted on a shaft which is connected to the shaft of an electric motor.
2. Casing: It is an airtight passage surrounding the impeller and is designed in such a way that the kinetic energy of the liquid discharged at the outlet of impeller is converted into pressure energy before the delivery pipe.
3. Suction pipe: It is a pipe whose one end is connected to the inlet of the pump and other end is into liquid in a sump.
4. Foot valve: It is a non-return valve or one way type valve. It is fitted at the lower end of suction pipe. The foot valve is essential for all types of roto dynamic pumps. It helps in allow the liquid to enter into pump in upward direction only and does not allow the liquid to flow downwards.
5. Strainer: The strainer is essential for all types of pumps. It protect pump against foreign material which passes through the pump. Without strainer pump may be chocked.
6. Delivery pipe: A pipe whose one end is connected to the outlet of the pump and other end extend to deliver the liquid at a required height is known as delivery pipe.
There are three types of the casing are used in centrifugal ump as shown below:

Classification of centrifugal pump

(A) According to type of casing,

a. Volute or spiral casing type pump
b. Vortex or whirlpool chamber type pump
c. Diffuser type (casing with guide blades) pump

(a) Volute type pump

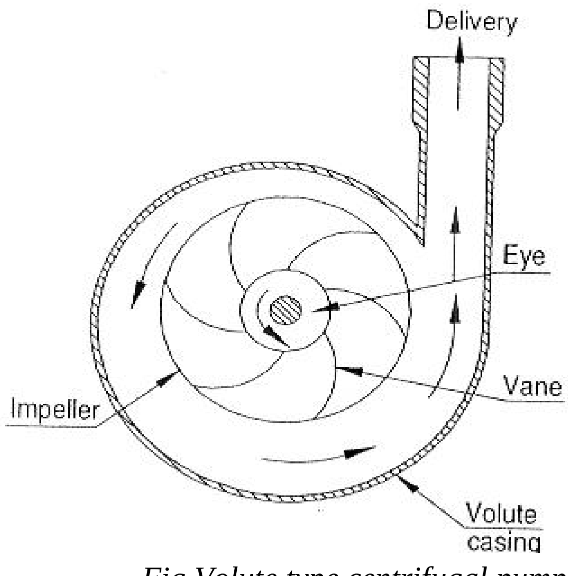


Fig Volute type centrifugal pump

In this type of centrifugal pump, impeller is surrounded by the spiral casing known volute chamber as shown in figure. Volute chamber provides a gradual increase in area to the discharge pipe. The liquid leaving the impeller enters the volute chamber with high velocity, then gradually reduced and pressure increases due to gradually increasing area of casing. This volute casing useful for effective conversion of kinetic energy of water in to pressure energy.

Disadvantage

Volute casing has greater eddy losses which decrease overall efficiency.

Vortex type pump

This vortex type of pump is modified type of volute casing. In this casing, circular chamber (annular space) is inserted between the impeller and volute chamber and is formed a combination of spiral and circular chamber as shown in fig. 8.8. This chamber is known as vortex or whirlpool chamber.

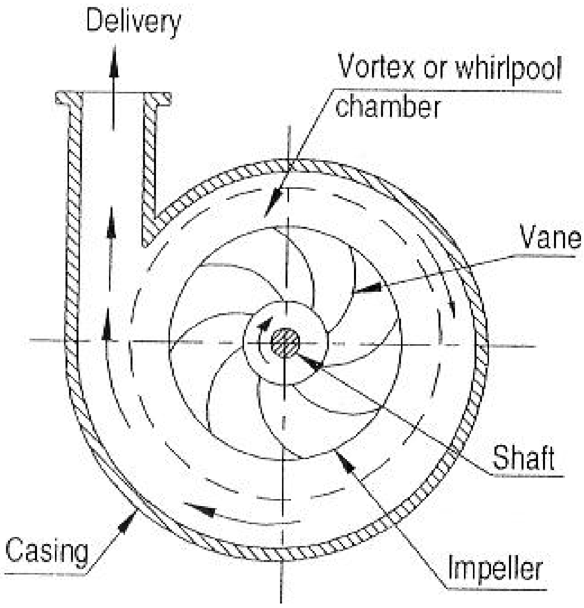


Fig. Vortex type centrifugal pump

The water leaving the impeller moves freely in this vortex chamber and its velocity head is gradually converted into pressure head and afterwards the liquid is collected in the volute chamber and is discharged through the discharge pipe. This arrangement reduces eddies to a considerable extent and improves the performance of the pump.

(a) Single stage centrifugal pump

If the pump has only one impeller then the pump is called a single stage pump. A single stage cannot produce sufficient high pressure head efficiently. It is mostly used for lower head and lower discharge.

(b) Multi-stage centrifugal pump

Impeller in series

If the pump has more than one impeller and all the impellers are keyed to a single shaft, arranged serially one after the other and enclosed in the same casing is known as multistage pump of impellers in series.
Use: for high working pressure head.

Impellers in parallel

Impellers are arranged in parallel. One impeller on each shaft and keeping the shafts parallel to one other.
Use: for high discharge.

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,

a. Gear pump
b. Vane pump c.
Screw pump

(a) Gear pump

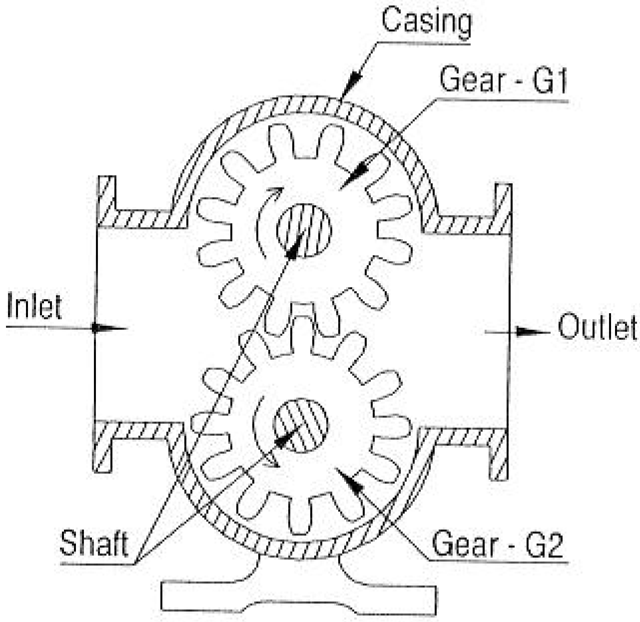


Figure 8.10 Gear pump

Construction & Working

Gear pump are consist of two or more gears which mesh each other. The rotation of these gears provides pumping action. Spur, helical, herringbone type of gear may use for the purpose but spur gears are most commonly used. Two spur gears are in mesh with each other and one of the gears is driving gear and other driven gear. The mechanical contact between the gears teeth and casing seal space between the teeth of gears at suction side. With the rotation of gears entrapped liquid between teeth and casing is carried to the discharge side and squeezed to discharge side.

Air compressors

Introduction

The machines which take in air or any other gas at low pressure and compress it to high pressure are called compressors. Compressors are driven by electric motors, I.C. engines gas turbines.

A compressor is used for increasing the pressure of air is called air compressor. Following are the uses of compressed air,

1. Operating pneumatic tools like drill, hammers, riveting machine etc.
2. Filling the air in automobile tyres.
3. Spray painting.
4. Increasing inlet pressure of I.C. Engine.
5. To operate air motor in mines where fire risks are more.
6. Pumping of water.
7. Gas turbine power plant.
8. Conveying the materials like sand and concrete along a pipe line.
9. For sand blasting.
10. Operating blast furnaces.
11. Operating air brakes used in buses, trucks, trains etc.

Classification of compressors

The compressors may be classified according to,

According to method of compression

Reciprocating compressor:

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

Rotary Compressor:

In a rotary compressor, air or gas is compressed due to the rotation of impeller or blades inside a casing similar to a rotary pump.

Centrifugal compressor:

A machine in which compression of air to desired pressure is carried out by a rotating impeller as well as centrifugal action of air.

(2) According to method delivery pressure Low pressure - up to 1.1 bar Medium pressure - 1.1. to 8 bar High pressure – 8 to 10 bar Very high pressure - above 10bar

(3) According to principle of operation

(a) Positive displacement

In this type pressure of air is increased by reducing the volume of it. Here air is compressed by positive displacement of air with piston or with rotating element.

Example: Reciprocating compressor, Root Blower etc.

(b) Roto dynamic or steady flow compressor

In this type compression of air is carried out by a rotating element imparting velocity to the flowing air and developed desired pressure. Here compression is achieved by dynamic action of rotor.

Examples: Centrifugal, Axial flow, etc.

(4) According to the number of stages

Single stage compressor - pressure up to 5 bar

Multistage compressor - pressure above 5 bar

(5) According to method the number of cylinder

Single cylinder

Multi cylinder

(6) According to method the pressure limit

Fans - pressure ratio 1 to 1.1
Blowers - pressure ratio 1.1 to 2.5
Compressor - pressure ratio above 2.5

(7) According to volume of air delivered

Low capacity - volume flow rate up to 9 m^3/min
Medium capacity - volume flow rate 10 m^3/min to 300 m^3/min
High capacity: Volume flow rate above 300 m^3/min.

(8) According to fluid to be compressed

Air compressor
Gas compressor
Vapour compressor

Reciprocating air compressor

Construction

It consists of the cylinder in which a piston reciprocates. The piston is driven by crank through connecting rod. The crank is mounted in a crankcase. The valves are generally pressure differential type. Thus they operate automatically by the difference of pressure across the valve.

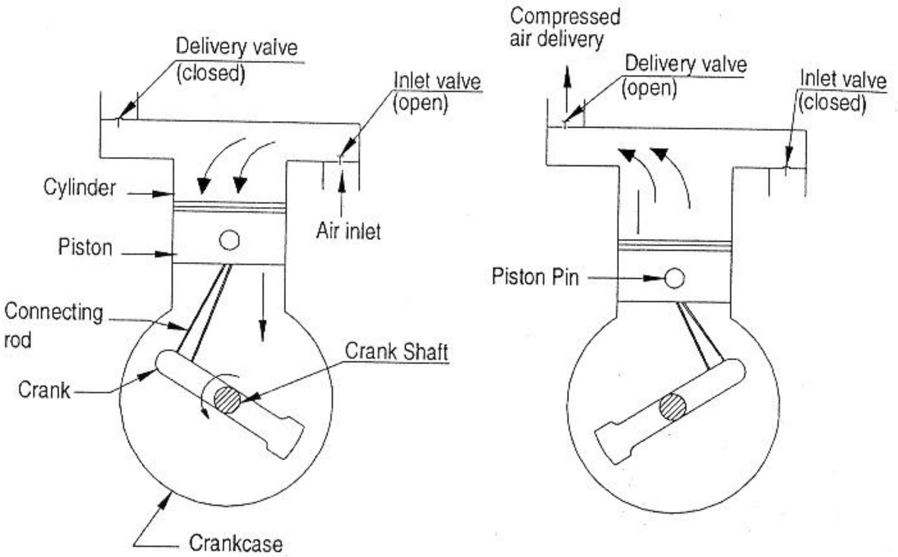


Figure 9.1 Reciprocating air compressor

Operation of a compressor

Case- (1) Operation without clearance

It is assumed that in an ideal compressor there is no clearance volume at the end of the stroke. In this type of compressor, when piston is moving away from IDC, pressure inside cylinder will decrease and volume will increase. Hence pressure difference across the valve is created. The spring operated inlet valve will be opened automatically for intake of air. Therefore the atmospheric air enters into the cylinder at constant pressure P_1 with increase in volume. This process is shown by (4-1) on p- V diagram.

compressed air becomes equal to the pressure of receiver in which the air is delivered, the

spring operated delivery valve opens automatically and the air is forced into the receiver at constant pressure P_2 from the cylinder. This process is shown by horizontal line 2-3.
Again piston moves away from TDC.

Case- (2) Operation with clearance

In actual compressor there is always clearance volume at the end of stroke. The small clearance is required because of,

(1) Preventing striking of piston at cylinder head,

(2) Thermal expansion due to high temperature at the end of compression,

(3) Maintaining machine tolerance.

(A) If the compression is follow

The clearance volume is denoted by V_C or V_3.The residual compressed air at a pressure $P_2 = P_3$ is filled in clearance volume at the end of upward stroke of piston. So during the suction stroke this residual compressed air expands and denoted by the curve (3-4) on p-V diagram in figure.

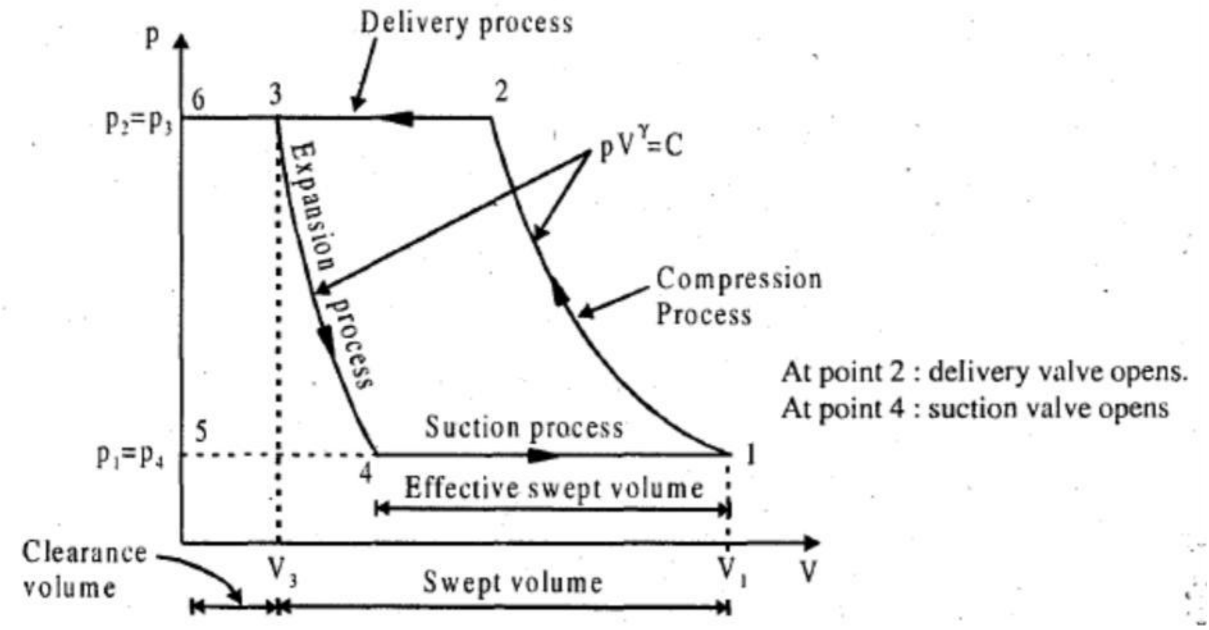


Figure 9.3 Compression with clearance volume

This expansion will reduce pressure from $P_2 = P_3$ to intake pressure $P_4 = P_1$. Due to this reduction in pressure the in valve will begin to open. This will permit the intake of a fresh air. The volume (V_1 - V_4) known as suction volume or effective swept volume or free air delivery at suction condition.

The work required to drive compressor per cycle is represented by area (4-1-2-3). At point 4 suction valve opens, at point 2 delivery valve opens.

Factors are responsible for reduction in volumetric efficiency,

1. The presence of clearance volume,
2. The throttling of the air when it passes through the inlet and outlet valves,
3. Heating of the incoming air, and leakages.

Multistage reciprocating compressors

In a single stage compressor, if the pressure ratio is increased, the volumetric efficiency decreases. When the pressure ratio is increase maximum, the volumetric efficiency becomes zero, thus multistage compression is needed.

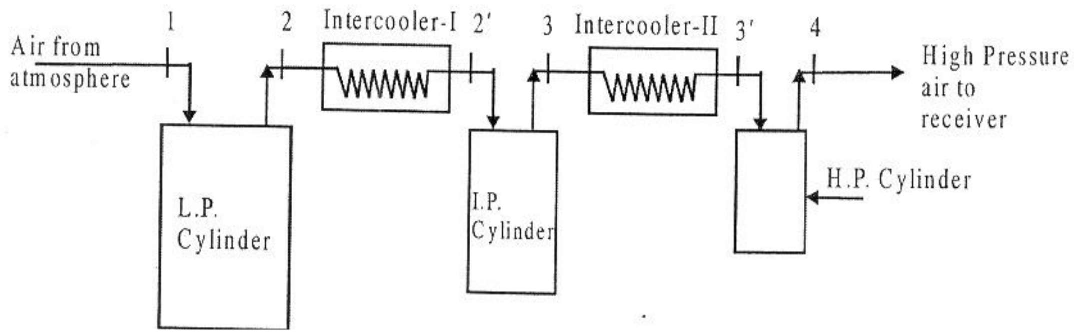


Figure 9.2 Multistage stage reciprocating compression

Problems with single stage compression are,

1. The higher the delivery pressure, the higher will be delivery temperature. This increase in temperature causes increase in specific volume and energy loss. So compressor has to handle more volume of air at higher temperature.
2. The increase in temperature of air causes reduction in density of air, hence the mass flow through compressor decreases.
3. The operation at high pressure and temperature will need heavy working parts.

Working

In low pressure (L.P.) cylinder, air is compressed adiabatically from point 1 to 2. This compressed air is passed through intercooler-l where it is cooled from 2 to 2'. The air coming from intercooler-l is then admitted into the intermediate pressure (J.P.) cylinder where it is compressed adiabatically from 2' to 3. The compressed air from J.P. cylinder is cooled from 3 to 3' in the intercooler-2. Finally air enters into high pressure (H.P.) cylinder for getting higher pressure.

**Advantage
s**

1. Without intercooling, the curve of compression will follow the path (1- 4"), hence the saving in work input due to intercooling.
2. Volumetric efficiency is increased due to the smaller pressure range, as the effect of expansion of air in the clearance volume is less.
3. Less shaft power is required for a given pressure ratio due to the saving in work input.
4. Due to smaller working temperature, better lubricating effect is provided.
5. Better mechanical balance and smoother torque-angle diagram is obtained.
6. In a multistage compressor, the low pressure cylinder is lighter.
7. There is less leakage problems due to less pressure difference for each stage.

Introduction

In heat engine, heat flow from hot body to cold body and produce useful work.

If it operates in the reverse direction, it takes heat from a cold body and rejects it to a hot body by the external mechanical work known as reversed heat engine. This principle is used in two devices.

(1) Heat pump

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

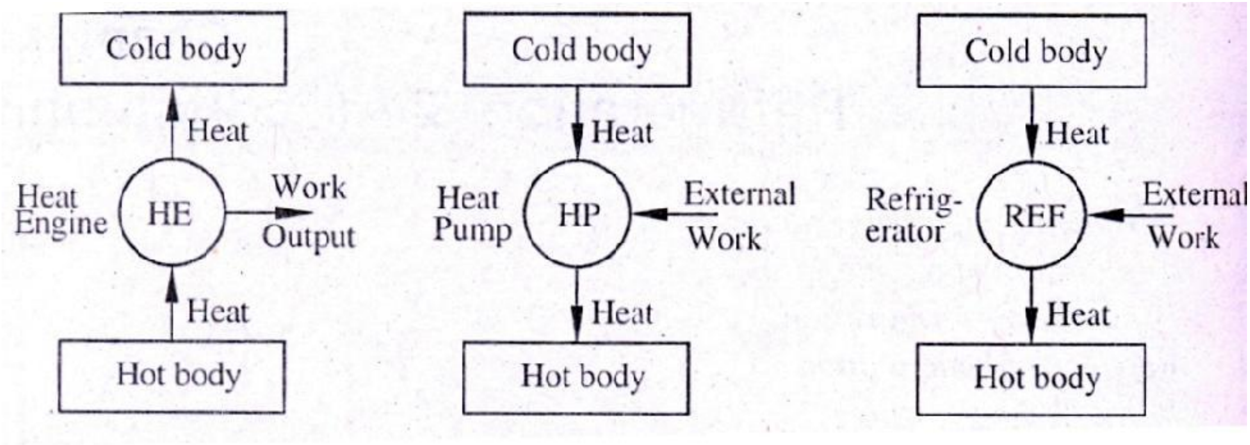


Figure 10.1 Heat engine, Heat pump and Refrigerator

(2) Refrigerator

It is a device which removes heat from cold body and reject to hot body (surrounding) and maintains low temperature for useful purr this device, external work is required to convey heat from cold body to hot body.

"It is a device or system used to maintain the low temperature below the atmosphere temperature within required space.”

Application of refrigeration

Storage and transportation of food stuffs as dairy products, fruits, vegetables, meat, fishes etc.

Preservation of medicines and syrups.

Manufacturing of ice, photographic films, rubber products.. Processing of petroleum and other chemical products. Liquefaction of gases like N_2, O_2, H_2 etc.

Cooling water

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).

Properties of a good refrigerant are,

1. High latent heat of evaporation and low specific volume.
2. Good thermal conductivity for rapid heat transfer.
3. Non-toxic, non-flammable and non-corrosive.
4. Low specific heat in liquid state and high specific heat in vapour state.
5. Low saturation pressure.
6. High co-efficient of performance.
7. Economical in initial cost and maintenance cost.

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 f refrigeration.

A ton of refrigeration

It is defined as "refrigerating effect produced by melting of 1 ton of ice from and at 0°C in 24 hours."

In actual practice, 1 ton = 900 kg considered for calculation of 1 ton of refrigeration, **Co-efficient of performance**

It is defined as the ratio of refrigerating effect to work required compressing the refrigerant in the compressor. It is the reciprocal of the efficiency of a heat engine. Thus the value of COP is greater than unity.

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

Types of refrigerators

The refrigerator can be classified as follows.

(A) Natural refrigerator

In natural refrigerator, the cooling effect produced by evaporation of liquid or sublimation of solids. When liquid evaporate, it absorbs heat from surrounding and produces cooling. Similarly, in sublimation (melting) of solid, it absorbs heat from surrounding and produces cooling effect.

(B) Mechanical refrigerator

In mechanical refrigerator, refrigeration effect produced by, external source of mechanical energy or heat energy.

It is further classified as,

1. Vapour compression refrigerator
2. Vapour absorption refrigerator
3. Air refrigerator

Vapour Compression Refrigeration system (VCR)

Construction

This system consist of (l) Evaporator (2) compressor (3) condenser and (4) expansion device. In vapour compression refrigerator, vapour used as the refrigerant. It is circulated in system in which it alternately evaporates (liquid to vapour) and condenses (vapour to liquid) thus it undergoes a change of phase. In the evaporation it absorbs the latent heat from the space to be cooled. In the condensing or cooling, it rejects heat to atmosphere.

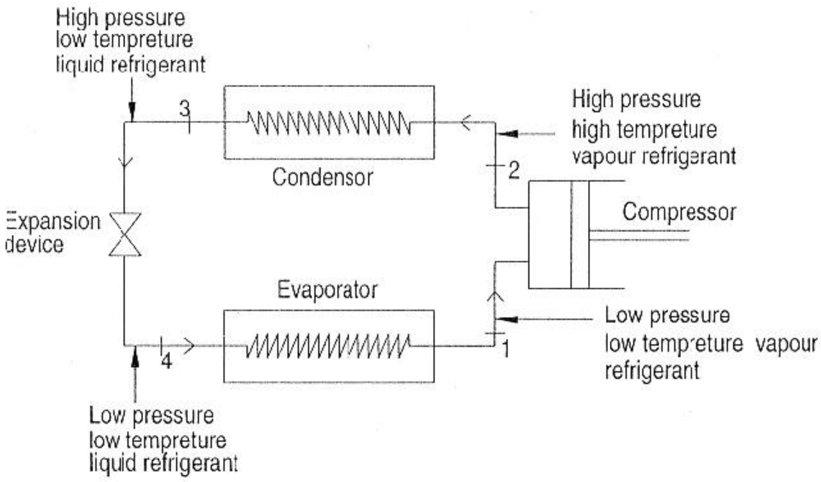


Figure 10.2 Vapour Compression Refrigeration system

Functions of main parts of vapour compression system are,

(1) Compressor

Function of compressor is to remove the vapour from the evaporator and increases its pressure and temperature up to it can be condensed in the condenser. Pressure of refrigerant coming from compressor should be such that the saturation temperature of vapour (corresponding to this pressure of vapour) is higher than the temperature of cooling medium in condenser. So that high pressure vapour can reject heat to cooling medium in the condenser.

(2) Condenser

The function of condenser is to facilitate a heat transfer surface through which heat transfer takes place from the hot refrigerant vapour to the condensing medium. In domestic refrigerator condensing medium is atmospheric air.

(3) Expansion valve or device

The function of expansion valve is to meter the proper amount of liquid refrigerant and reduces pressure of liquid refrigerant entering the evaporator. Hence liquid will vaporize in the evaporator at the desired low temperature and absorb heat from the space.

(4) Evaporator

An evaporator provides a heat transfer surface through which low temperature liquid refrigerant can absorb heat from space and it vaporized.

Working

Process 1-2: Inlet of compressor (at point 1), low pressure and low temperature vapour enters the compressor. Compressor compresses the vapour at high temperature and pressure. The condition of refrigerant at exit to compressor (at point 2) is high pressure and high temperature vapour.

Process 2-3: High pressure, high temperature vapour coming from compressor condenses in the condenser by the rejecting heat to cooling medium. Cooling medium is usually air or water. The condition of refrigerant at exit to condenser (at point 3) is low temperature saturated liquid.

Process 3-4: The saturated liquid coming from condenser passes through expansion device (throttling valve) where pressure of saturated liquid decreases from condenser pressure to evaporator pressure. The condition of refrigerant after throttling is low temperature and low pressure liquid.

Process 4-1: Liquid refrigerant coming from expansion device enters into evaporator where it absorbs latent heat of evaporation from space to be cooled (refrigerator compartment). Due to absorption of heat liquid refrigerant converted into saturated vapor or superheated vapour at low pressure and low temperature. Again this vapour enters into compressor and the cycle is repeated.

Domestic vapour compression refrigerator

Construction

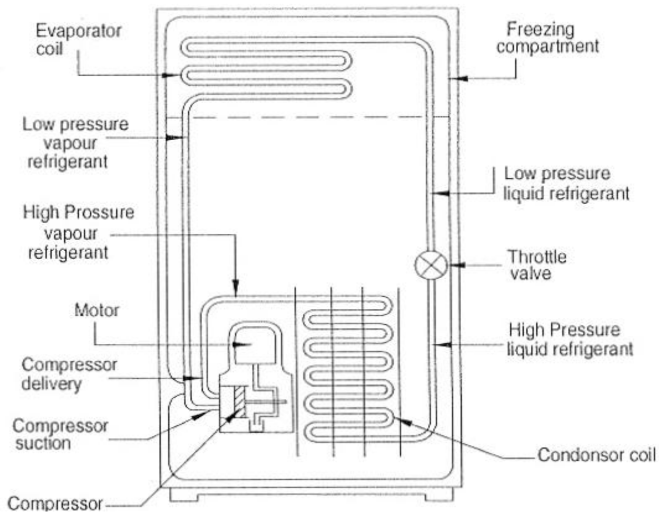


Figure 10.3 Domestic vapour compression refrigerator

It consists of an evaporator installed in the freezing compartment of the refrigerator. One end of evaporator connected to the suction side of the compressor and other end connected to condenser through throttle valve. Normally condenser installed at the backside of refrigerator. The delivery side of compressor is connected to a condenser.

Examples…available in capacities of 65 liters, 100 liters, 165 liters, 275Iitres,1000 liters.

Vapour Absorption Refrigeration System (VAR)

Construction

This system is shown in figure consists of (i) evaporator, (ii) condenser, (iii) generator, (iv) absorber, (v) pump and (vi) expansion device.

In this system the refrigerant coming from evaporator is absorbed by absorber. The absorbing medium may be solid or liquid. In VAR system, the compressor is replaced by an absorber and generator.

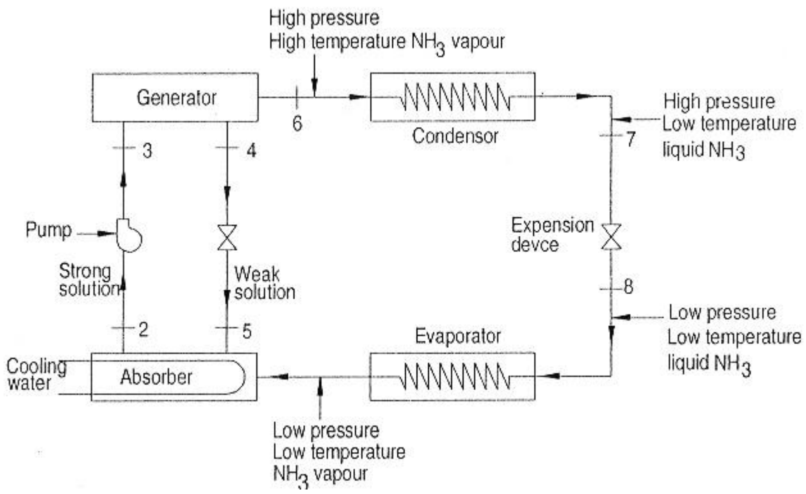


Figure 10.4 Vapour Absorption Refrigeration system

Ammonia is refrigerant has characteristic as it is easily absorbed by water at low pressure and temperature, but at high pressure and temperature, the solubility of ammonia in water is reduced. Therefore when mixture of water and ammonia is heated by generator, the ammonia vapour is separated from water. This principle is used in the vapour absorption refrigeration system. Here the ammonia is refrigerant and water is absorbent.

Working

Low pressure and low temperature vapour ammonia coming from evaporator enters in the absorber where ammonia is absorbed by weak solution coming from generator through throttle valve at point 5. Due to absorption of NH3 in water, solution becomes strong. [In the mixture of NH3 and water, if amount of NH3 is less than water is called weak solution and if amount of NH3 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 NH3 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 NH3 vapour coming from evaporator.

NH3 vapour coming from generator (at point 6) passes through condenser and condensed in condenser and reject heat to cooling medium. Then liquid NH3 (at point 7) throttled through expansion device and it enters into evaporator (point 8). In the evaporator NH3 evaporates by absorbing latent heat of evaporation to produce refrigerating effect. Thus the cycle is completed.

Air refrigerator

Construction

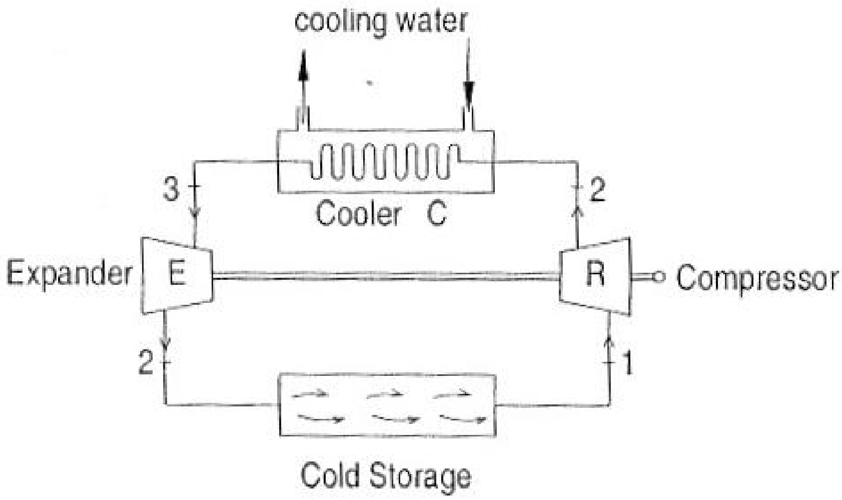


Figure 10.5 Air refrigerator

The Air refrigerator is one of the oldest types of refrigerator. In this system air is used as refrigerant and operates on Bell Coleman cycle. It consists of (1) compressor (R) (2) expander (E) (3) Cooler (C) and (4) Cold storage as shown in figure.

Working

Process 1-2: Air from cold storage is sucked by air compressor. Air is compressed isentropically in compressor, pressure and temperature of air increases.

Process 2-3: The hot air from the compressor is cooled at constant pressure in the cooler. The temperature of air is reduced.

Process 3-4: High pressure and low temperature air is expanded isentropically in the expander. Temperature and pressure of air decreases. During the expansion of air work is produced. This work is utilized to run compressor. But this work is not sufficient for compressor and so extra work to compressor.

Process 4-1: The cold air from the expander passes into the cold storage where the air sorbs heat from the bodies that is required to be cooled. Then it again enters into the compressor, cycle is completed and it is repeated again and again.

Advantages

1. Air is freely available from the nature.
2. As compared to the other refrigerator, weight of air refrigerator per ton of refrigeration capacity is low. Therefore it is used in air crafts and missiles cooling.

Disadvantages

1. COP is very low
2. Requires large power
3. Requires more space.
4. The volume of air required to be circulated is more compared to refrigerant is in other refrigerator. Thus it cannot be used for large capacity plants.

Air conditioning

The basic function of air conditioning system is,

Cooling or heating of air.

Addition of moisture in air (Humidification) or removal of moisture from (dehumidification).

Purification, control movement or distribution of air and addition of fresh air from outside.

Definition

It is the simultaneous control of temperature, air humidity, air movement and air cleanliness.

Applications

For Human comfort:

To provide cooling or heating and conditioning of air as per comfort of human being. This is known as comfort air conditioning.

For commercial use:

To provide cooling or heating and conditioning air as per required in some engineering manufacturing and processing. This is known as industrial air conditioning.

The comfort air conditioning means conditioning of air in such a way that the human being can feel good.

Standard comfort conditions for human being are,

Temperature of air: Dry bulb temperature (DBT) 17° to 25° C

Moisture level: Relative humidity (RH) 30 to 70 %

Velocity of air 0.1 m/s to 0.25 m/s

Principle of air conditioning

In air conditioning system, the device or unit provides air conditioning is called air conditioner. This device continuously draws air from an indoors space which is required to cool, it cools in refrigeration system and discharge back into the same indoor space. This continuous cyclic process of drawing, cooling, and recirculation of the cooled air maintains indoor space cool at the required lower temperature which is required for comfort cooling or industrial cooling.

The basic components of air-conditioning system are,

1. Fans: For circulation of air
2. Filters: For cleaning air
3. Heating element: Heating of air (It may be electric heater, steam, hot water)
4. Control system: It regulates automatically the amount of cooling or heating.
5. Grille: It adjusts the direction of conditioned air to the room.
6. Tray: It collects condensed water

Classification of Air conditioning system

(A) According to arrangement of equipments

(1)Unitary system

In this system different component of air conditioning system is manufactured and assembled as unit in a factory. This unit is installed in or near to space to be conditioned.

1. Window air conditioner
2. Split air conditioner
3. Packaged air conditioner

(2) Central system

In this system different components are manufactured in factory and assembled at the site. This type of system is used for conditioning of air in theatres, cinemas, restaurants, exhibition halls, big factory space etc.

(B) According to the purpose

1. Comfort air conditioning system
2. Industrial air conditioning system

(C) According to season of year

1. Winter air conditioning system: Air is heated and humidified
2. Summer air conditioning system: Air is cooled and dehumidified

Window air conditioner

Basic function

It mainly used for conditioning of air in the room. The basic function of window air conditioner is to provide comfort cooling, dehumidification, filtering and circulation of air.

Construction

Refrigerating unit: evaporator/cooling coil, condenser, compressor, and expansion device (throttle valve or capillary tube).Air circulation fan each for evaporator and condenser.

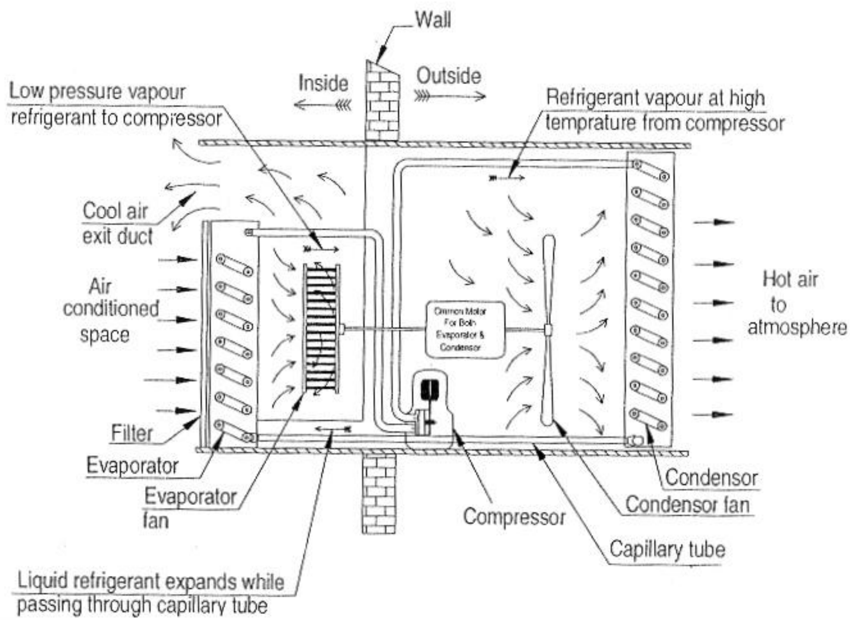


Fig Window air conditioner

Working

The hot air coming from room is flowing on the evaporator (cooling coil), the cooling coil absorbs heat from air. The moisture of air gets removed on the cooling coil surface by process of condensation of air. Thus the air is cooled and dehumidified to meet the requirement comfort air conditioning in the room. The filter clean the air coming from room before passes through the cooling coil. The tray is provided below the cooling coil (evaporator) to collect moisture which condenses from recirculation of air.

The flow of hot air (from room) and cooled air (to room) is taking place by the evaporator blower. The refrigerating unit provides cooling effect at evaporator. The condenser fan circulates air on outside of condenser tubes, the refrigerant in condenser reject heat to outside atmospheric air. Necessary fresh air is allowed to mix with the recalculated room air to meet the ventilation requirement. Ventilation air is controlled by ventilation damper. The room -temperature is controlled by a thermostat using on-off power supply to compressor motor.

It available in size up to 2 tons capacity.

Limitations

1. It produce noise in the room because of compressor is very near to the room.
2. The evaporator and condenser are enclosed in single unit. Therefore evaporator cannot be used as an interior of room because condenser requires outside air for cooling.
3. It requires appropriate size of window or hole in wall to fit the conditioner.
4. Most of window A/C doesn't provide heating for winter.
5. No provision for humidification is possible in window AC.
6. It has no control over humidity through it carries out dehumidification.

Split air conditioner

It is modification of window air conditioner.

Construction

This unit differs from window air conditioner. In terms of split of unit into two parts. In split air conditioner, the window air conditioner divided (split) into two parts.

First part: Includes the evaporator, filter, evaporator fan and grille (cooling coil). They placed inside the room.

Second part: Includes condenser, condenser fan, and compressor. This placed outside the room.

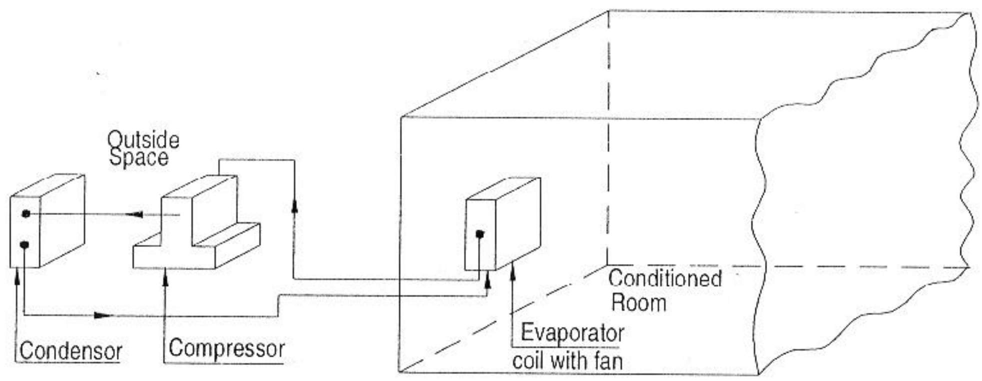


Figure 10.7 Split air conditioner

First part (inside of room) and second part (outside of room) is connected by small diameter tubes. Therefore, small hole required in wall for installation of split air conditioner.

The advantages of split air conditioner over window air conditioner

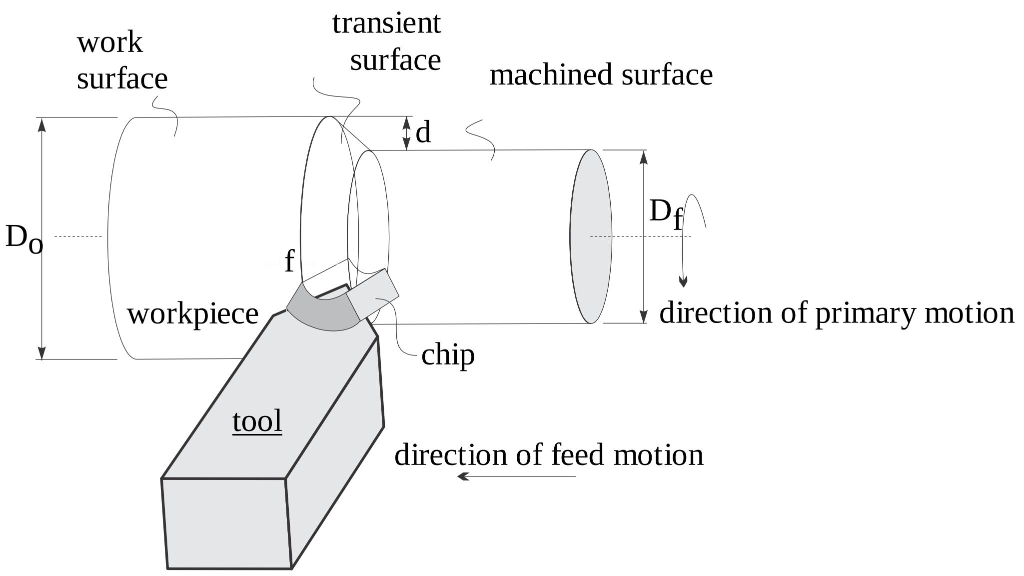
1. The compressor is outside of room, therefore no compressor noise in the room.
2. No window opening and fixing needed.
3. The first part can be located in the room with decorative display. The first unit can be mounted on floor, ceiling, and wall or behind a decorative structure.

UNIT-IV
MACHINE TOOLS AND AUTOMATION

MACHINE TOOL OPERATIONS

TURNING

Turning is a machining process to produce parts round in shape by a single point tool on *lathes*. The tool is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the workpiece, or along a specified path to produce complex rotational shapes. The *primary* motion of cutting in turning is the rotation of the workpiece, and the *secondary* motion of cutting is the feed motion.



Turning operation

Cutting conditions in turning

Cutting speed in turning V in m/s is related to the rotational speed of the workpiece by the equation: $V = \pi DN$

where D is the diameter of the workpiece, m; N is the rotational speed of the workpiece, rev/s.

One should remember that cutting speed V is always a linear vector. In the process planning of a turning operation, cutting speed V is first selected from appropriate reference sources or calculated as discussed in *Section 5.10 Selection of Cutting Conditions*, and the rotational speed N is calculated taking into account the workpiece diameter D. Rotational speed, not cutting speed, is then used to adjust lathe setting levers.

Feed in turning is generally expressed in mm tr^{-1} (millimetres per revolution).

The turning operation reduces the diameter of the workpiece from the initial diameter D_o to the final diameter D_f. The change in diameter is actually two times *depth of cut*, d:

$$2d = D_o - D_f$$

The volumetric rate of material removal (so-called *material removal rate*, *mrr*) is defined by mrr = Vfd

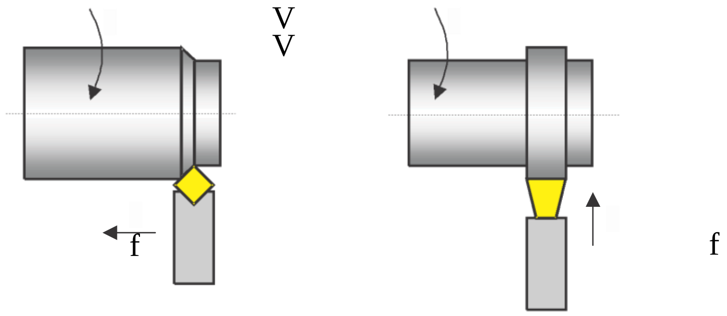
When using this equation, care must be exercised to assure that the units for V are consistent with those for f and d.

Operations in turning

Turning is not a single process but class of many and different operations performed on a lathe.

Turning of cylindrical surfaces

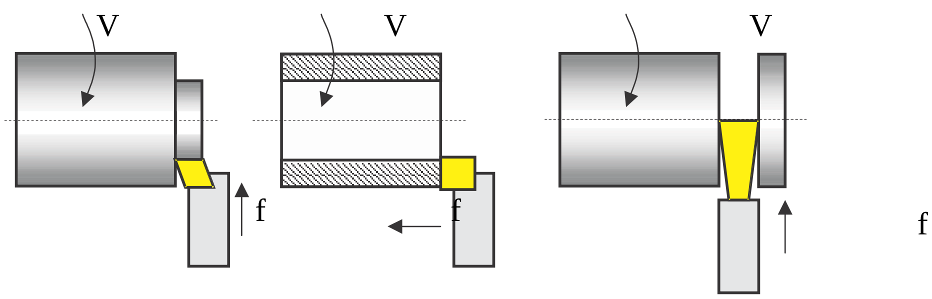
The lathe can be used to reduce the diameter of a part to a desired dimension. The resulting machined surface is cylindrical.



straight turning plunge turning

Turning of flat surfaces

A lathe can be used to create a smooth, flat face very accurately perpendicular to the axis of a cylindrical part. Tool is fed radially or axially to create a flat machined surface.

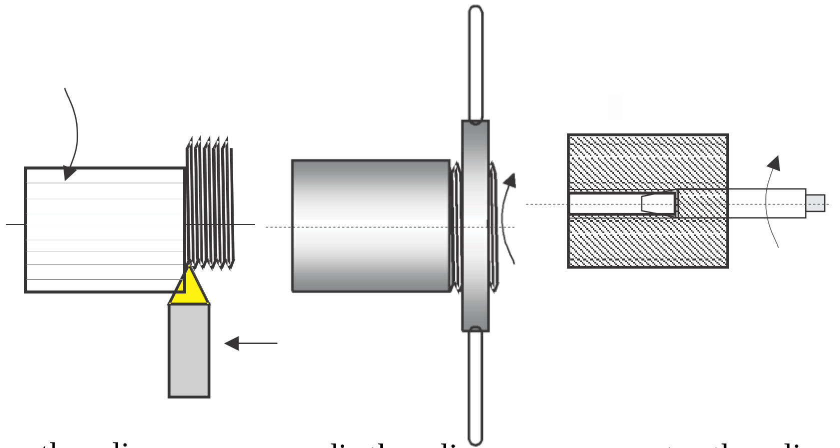


facing tube turning parting (cutting-off)

Threading

Different possibilities are available to produce a thread on a lathe. Threads are cut using lathes by advancing the cutting tool at a feed exactly equal to the thread pitch. The single-point cutting tool cuts in a helical band, which is actually a thread. The procedure calls for correct settings of the machine, and also that the helix be restarted at the same location each time if multiple passes are required to cut the entire depth of thread. The tool point must be ground so that it has the same profile as the thread to be cut.

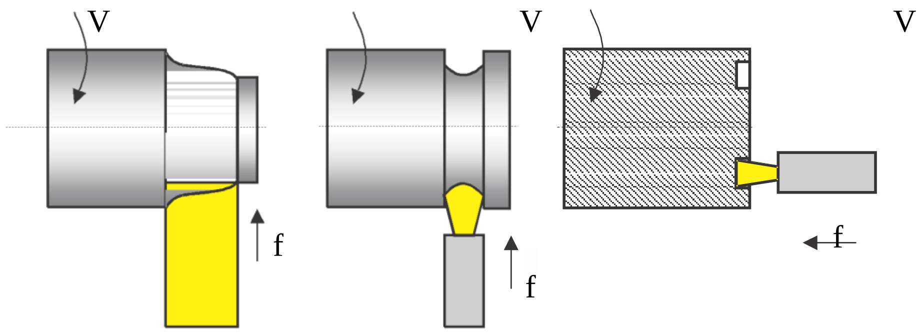
Another possibility is to cut threads by means of a *thread die* (external threads), or a *tap* (internal threads). These operations are generally performed manually for smal thread diameters.



threading   die threading   tap threading

Form turning

Cutting tool has a shape that is imparted to the workpiece by plunging the tool into the workpiece. In form turning, cutting tool is complex and expensive but feed is linear and does not require special machine tools or devices.



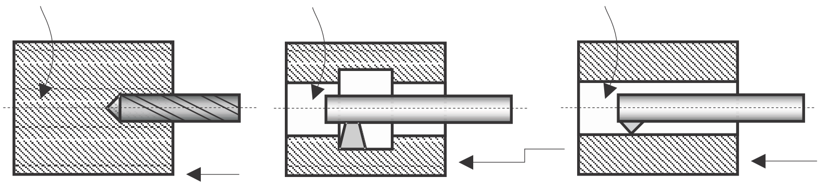
forming   plunge grooving   face grooving

Contour turning (profiling)

Cutting tool has a simple shape, but the feed motion is complex; cutting tool is fed along a contour thus creating a contoured shape on the workpiece. For profiling, special lathes or devices are required.

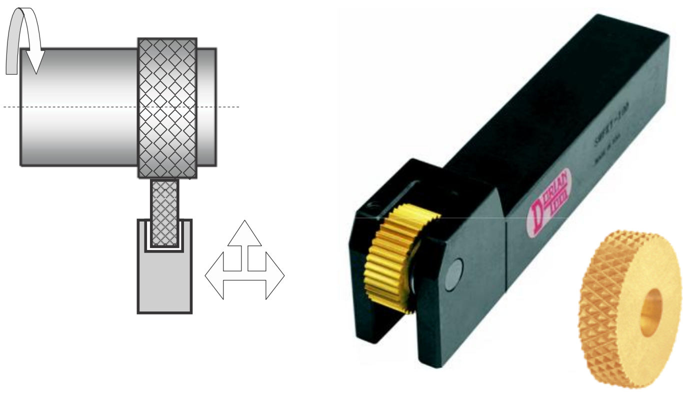
Miscellaneous operations

Some other operations, which do not use the single-point cutting tool can be performed on a lathe, making turning one of the most versatile machining processes.



Knurling

This is not a machining operation at all, because it does not involve material removal. Instead, it is a metal forming operation used to produce a regular crosshatched pattern in the work surface.



(*Left*) Knurling operation; (*Right*) Knurling tool and knurling wheel. Wheels with different patterns are easily available.

Lathes

A lathe is a machine tool that rotates the workpiece against a tool whose position it controls. The *spindle*
(see picture in the next page) is the part of the lathe that rotates. Various work holding attachments such as *three jaw chucks*, *collets*, and *centers* can be held in the spindle. The spindle is driven by an electric motor through a system of belt drives and gear trains. Spindle rotational speed is controlled by
varying the geometry of the drive train.

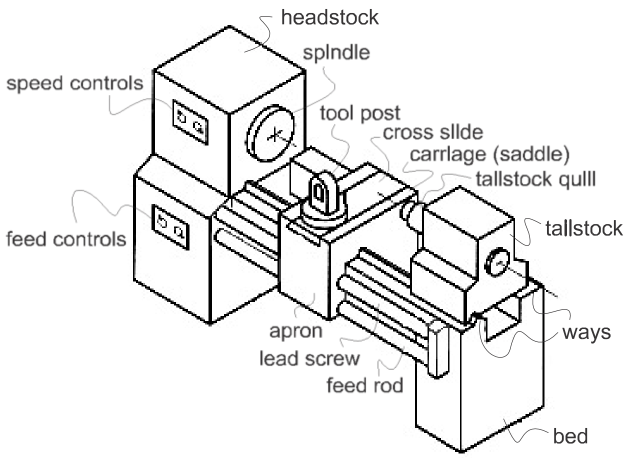
The *tailstock* can be used to support the end of the workpiece with a *center*, or to hold tools for drilling, reaming, threading, or cutting tapers. It can be adjusted in position along the *ways* to accommodate different length workpieces. The *tailstock barrel* can be fed along the axis of rotation with the *tailstock hand wheel*.

The *carriage* controls and supports the cutting tool. It consists of:

- a *saddle* that slides along the *ways*;
- an *apron* that controls the feed mechanisms;

Engine lathes

The basic, simplest and most versatile lathe. This machine tool is manually operated that is why it requires skilled operators. Suitable for low and medium production, and for repair works.



The principal components of an engine lathe

There are two tool feed mechanism in the engine lathes. These cause the cutting tool to move when engaged.

The *lead screw* will cause the apron and cutting tool to advance quickly. This is used for cutting threads, and for moving the tool quickly.
The *feed rod* will move the apron and cutting tool slowly forward. This is largely used for most of the turning operations.

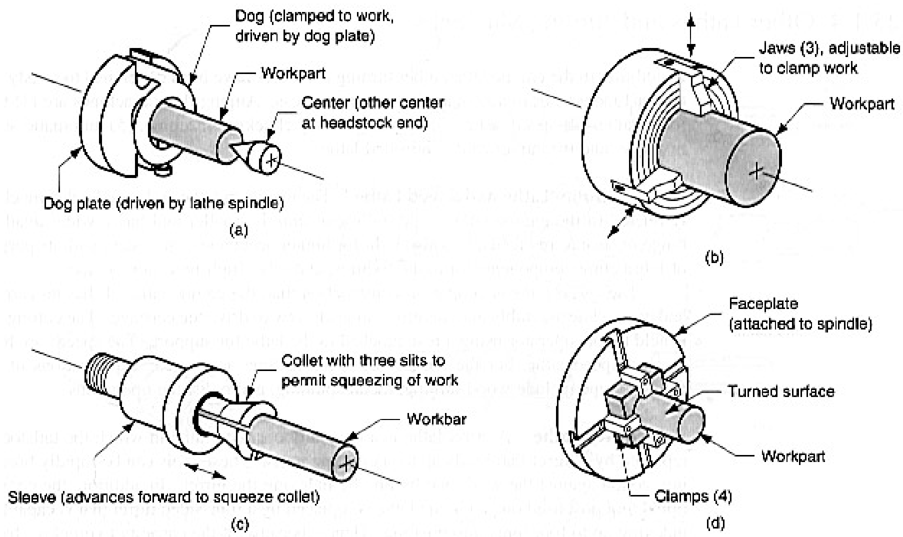
Work is held in the lathe with a number of methods,

Between two *centres*. The workpiece is driven by a device called a *dog*; The method is suitable for parts with high *length-to-diameter ratio*.

A *3 jaw self-centering chuck* is used for most operations on cylindrical workparts. For parts with high *length-to-diameter ratio* the part is supported by center on the other end.

Collet consists of tubular bushing with longitudinal slits. Collets are used to grasp and hold barstock. A collet of exact diameter is required to match any barstock diameter.

A *face plate* is a device used to grasp parts with irregular shapes:



Four work holding methods used in lathes: (a) mounting the work between centers using a dog, (b) three-jaw chuck, (c)collet, and (d) face plate for noncylindrical workparts.

Turning tapers on engine lathes

A taper is a conical shape. Tapers can be cut with lathes quite easily. There are some common methods for turning tapers on an engine lathe,

Using a *form tool*: This type of tool is specifically designed for one cut, at a certain taper angle. The tool is plunged at one location, and never moved along the lathe slides.

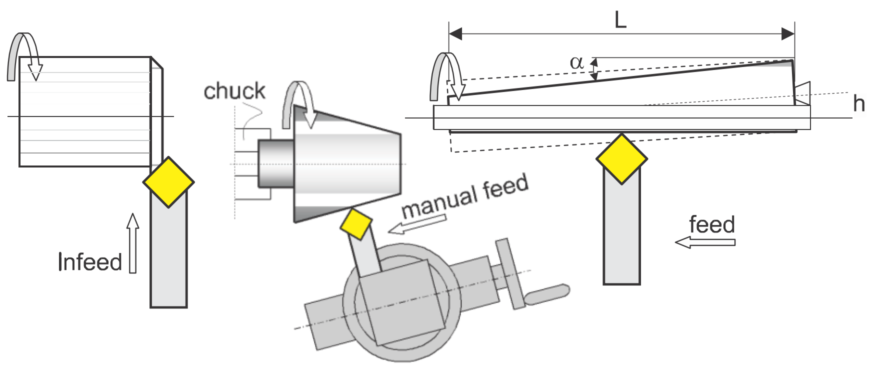
Compound Slide Method: The compound slide is set to travel at half of the taper angle. The tool is then fed across the work by hand, cutting the taper as it goes.

Off-Set Tail Stock: In this method the normal rotating part of the lathe still drives the workpiece (mounted between centres), but the centre at the tailstock is offset towards/away from the cutting tool. Then, as the cutting tool passes over, the part is cut in a conical shape. This method is limited to small tapers over long lengths.

The tailstock offset h is defined by

$$h = L\sin\alpha$$

where L is the length of workpiece, and α is the half of the taper angle.

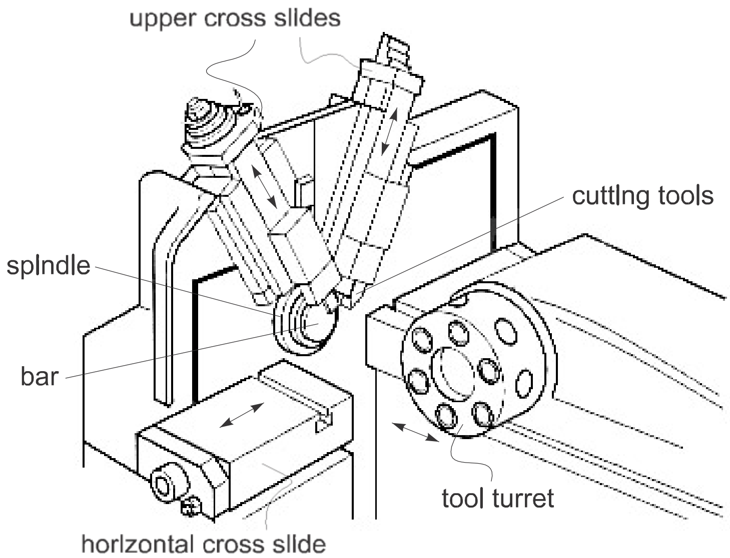


(a) (b) (c)

Three methods for turning tapers on an engine lathe: (a) using a form tool, (b) the compound slide method, and (c) offsetting tailstock.

Single-spindle and multi-spindle bar machines

In these machines, instead of a chuck, a collet is used, which permits long bar stock to be fed through the headstock into position. At the end of each machining cycle, a cutoff operation separates the new part. Owing to the high level of automation, the term *automatic bar machine* is often used for these machines. Bar machines can be classified as single spindle or multiple spindle. The *single-spindle bar machine* is sometimes referred to as *swiss automatics*.



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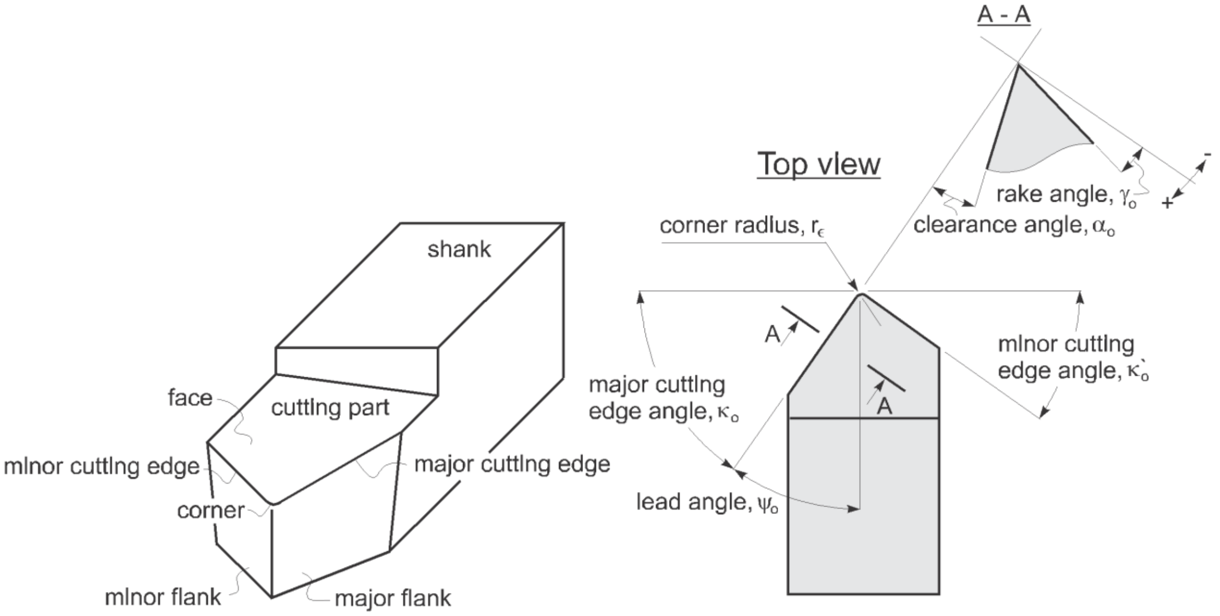
The *single-spindle bar machine* has up to six upper cross slides and two horizontal cross slides with cut- ting tools, which move radially inwards. All operations on the machine are controlled by appropriately shaped cams. The machine is usually equipped with three-spindle drilling/threading turret, or with a multi-position turret. More recent machines are numerically but not cam controlled.

To increase production rate, *multiple-spindle bar machines* are available. A spindle carrier in which four to eight spindles feed and rotate as many bars replaces the headstock of the lathe. A tetra-, hexa-, or octagonal axial tool slide on which tool holders are mounted replaces the tailstock. Additional tools
are engaged radially, mounted on lower cross slides. So, multiple parts are machined simultaneously by multiple tools. At the end of each machining cycle, the spindles are indexed to the next set of cutting tools. A single part is completed at each indexing of the spindle carrier.

Cutting tools

The geometry and nomenclature of cutting tools used in turning is standardized by ISO 3002/1-1982:



Cutting edges, surfaces and angles on the cutting part of a turning tool

The figure shows only the most important geometrical features of a turning cutting tool. Recommenda- tions for proper selection of the cutting tool geometry are available in the reference materials.

Process capabilities and process planning in turning

If the workpart has a central hole, the hole is drilled starting with a centre drill, and increasing drill diameters gradually. Finally, boring is applied (*Section 6.5*) to achieve the final diameter of the hole. Machining of the internal features is scheduled after rough cuts and before special operations (after step 1 in the general plan).

Drilling is a process of producing round holes in a solid material or enlarging existing holes with the use of multi- tooth cutting tools called drills or drill bits. Various cutting tools are available for drilling, but the most common is

the twist drill.

Reaming is a process of improving the quality of already drilled holes by means of cutting tools called *reamers*. Drilling and reaming are performed on a *drilling press,* although other machine tools can also perform this operation, for instance lathes, milling machines, machining centers.

In drilling and reaming, the primary motion is the rotation of the cutting tool held in the spindle. Drills and reamers execute also the secondary feed motion. Some finishing reaming operations are manual.

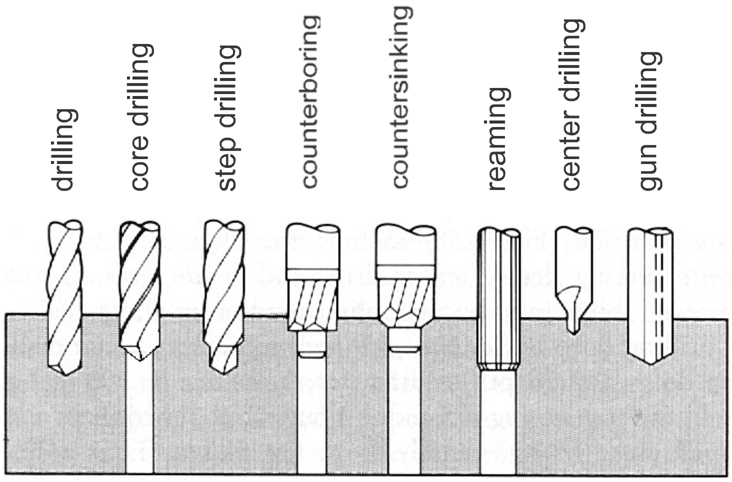
Cutting velocity V in drilling is not a constant along the major cutting edge as opposed to the other machining operations. It is zero at the center of the twist drill, and has a maximum value at the drill corner. The maximum cutting speed is given by

$$V = \pi DN$$

where D is the drill diameter, and N is the rotational speed of the drill.

Drilling and reaming operations

Several operation are related to drilling, most of them illustrated in the figure:



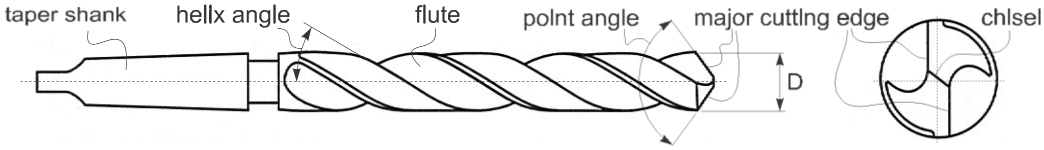
Drilling and reaming operations.

Upright drill press. Bench drill press.

Drills and reamers

Twist drill

The twist drill does most of the cutting with the tip of the bit. It has two flutes to carry the chips up from the cutting edges to the top of the hole where they are cast off. The standard drill geometry is shown in the figure:



Standard geometry of a twist drill.

The typical helix angle of a general purpose twist drill is 18~30^{o} while the point angle (which equals two times the major cutting edge angle, see page 101) for the same drill is 118^{o}.

Some standard drill types are,

- v straight shank: this type has a cylindrical shank and is held in a
- v taper shank: his type is held directly in the drilling machine spindle

Drills are normally made of HSS but carbide-tipped drills, and drills with mechanically attached carbide inserts are commonly used in many operations, especially on CNC drilling machines:



Coated HSS twist drills.

Carbide-tipped twist drills.

Indexable inserts twist drills.

Reamers

The reamer has similar geometry. The difference in geometry between a reamer and a twist drill are:

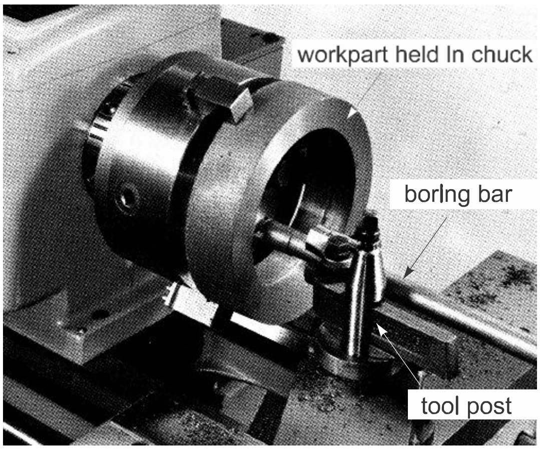
- The reamer contains four to eight straight or helical flutes, respectively cutting edges.
- The tip is very short and does not contain any cutting edges.


Straight-flute reamer with taper shank. Helical-flute reamer with taper shank.

6.5 BORING

Introduction

Boring is a process of producing circular internal profiles on a hole made by drilling or another process. It uses single point cutting tool called a *boring bar*. In boring, the boring bar can be rotated, or the workpart can be rotated. Machine tools which rotate the boring bar against a stationary workpiece are called *boring machines* (also *boring mills*). Boring can be accomplished on a turning machine with a stationary boring bar positioned in the tool post and rotating workpiece held in the lathe chuck as illustrated in the figure. In this section, we will consider only boring on boring machines.



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NUMERICAL CONTROL OF MACHINE TOOLS

Definitions

Numerical Control (NC) refers to the method of controlling the manufacturing operation by means of directly inserted coded numerical instructions into the machine tool. It is important to realize that
NC is not a machining method, rather, it is a concept of machine control. Although the most popular
applications of NC are in machining, NC can be applied to many other operations, including welding,
sheet metalworking, riveting, etc.

Because of the introductory character of this chapter, we will restrict our discussion only to two- dimensional machining operations (e.g. turning), which are among the most simple applications of NC. Nevertheless, most of the principles and conclusions here are also valid for more advanced NC applications.

The major advantages of NC over conventional methods of machine control are as follows:

higher precision:NC machine tool are capable of machining at very close tolerances, in some operations as small as 0.005 mm;

Types of NC systems

Machine controls are divided into three groups,

traditional numerical control (NC);
computer numerical control (CNC);
distributed numerical control (DNC).

The original numerical control machines were referred to as NC machine tool. They have "hardwired" control, whereby control is accomplished through the use of punched paper (or plastic) tapes or cards. Tapes tend to wear, and become dirty, thus causing misreading's. Many other problems arise from the use of NC tapes, for example the need to manual reload the NC tapes for each new part and the lack of program editing abilities, which increases the lead time. The end of NC tapes was the result of two competing developments, CNC and DNC.

CNC refers to a system that has a local computer to store all required numerical data. While CNC
was used to enhance tapes for a while, they eventually allowed the use of other storage media, magnetic tapes and hard disks. The advantages of CNC systems include but are not limited to the possibility to store and execute a number of large programs (especially if a three or more-dimensional machining of complex shapes is considered), to allow editing of programs, to execute cycles of machining commands,etc.

The development of CNC over many years, along with the development of local area networking,
has evolved in the modern concept of DNC. Distributed numerical control is similar to CNC, except
a remote computer is used to control a number of machines. An off-site mainframe host computer

holds programs for all parts to be produced in the DNC facility. Programs are downloaded from the
mainframe computer, and then the local controller feeds instructions to the hardwired NC machine.
The recent developments use a central computer which communicates with local CNC computers (also called *Direct Numerical Control*)

Controlled axes

NC system can be classified on the number of directions of motion they are capable to control simultaneously on a machine tool. Each free body has six degree of freedom, three positive or negative translations along x, y, and z-axis, and three rotations clockwise or counter clockwise about these axes. Commercial NC system are capable of controlling simultaneously two, two and half, three, four and five degrees of freedom, or axes. The NC systems which control three linear translations (3-axis systems), or three linear translations and one rotation of the worktable (4-axis systems) are the most common.

UNIT-V
ENGINEERING MATERIALS, JOINING PROCESS

ENGINEERING MATERIALS

Introduction

Materials play an important role for our existence, for our day to day needs, and even for our survival. In the stone age the naturally accessible materials were stone, wood, bone, fur etc *Gold was the 1st metal used by the mankind followed by copper.* In the bronze age Copper and its alloy like bronze was used and in the iron age they discovered Iron (sponge iron & later pig iron).

1960's Engineering Materials

Design Choice of Material New

Materials New Products Number of

Materials 40 – 80,000! General

Definition of Material

According to Webster's dictionary, materials are defined as *'substances of which something is composed or made'*

Engineering Material: Part of inanimate matter, which is useful to engineer in the practice of his profession (used to produce products according to the needs and demand of society)

Material Science: Primarily concerned with the search for basic knowledge about internal structure, properties and processing of materials and their complex interactions/relationships

Material Engineering: Mainly concerned with the use of fundamental and applied knowledge of materials, so that they may be converted into products, as needed or desired by the society (bridges materials knowledge from basic sciences to engineering disciplines)

Material Science & Engineering important to technologists

Examples:

- Mechanical engineers search for high temp material so that gas turbines, jet engines etc can operate more efficiently and wear resistance materials to manufacture bearing materials
- Electrical engineers search for materials by which electrical devices or machines can be operated at a faster rate with minimum power losses
- Aerospace & automobile engineers search for materials having high strength-to-weight ratio

- Electronic engineers search for material that are useful in the fabrication & miniaturization of electronic devices
- Chemical engineers search for highly corrosion-resistant materials

Note: All these demands may be fulfilled when the internal structure and engineering properties are known to an engineer or technologist

Classification

It is the systematic arrangement or division of materials into groups on the basis of some common characteristic

1. According to General Properties

2. According to Nature of Materials

3. According to Applications

1. According to General Properties

(a). Metals (*e.g.* iron, aluminium, copper, zinc, lead, etc)

Iron as the base metal and range from plain carbon (> 98 % Fe) to *(i). Ferrous:* high alloy steel (< 50 % alloying elements), e.g. cast iron, wrought iron, steel, alloys like high-speed steel, spring steel, etc

(ii). Non-Ferrous: Rest of the all other metals and their alloys, e.g. copper, aluminium, zinc lead, alloys like brass, bronze, duralumin, etc

(b). Non-Metals (e.g. leather, rubber, asbestos, plastics, etc)

2. According to Nature of Materials

(a). Metals: e.g. Iron & Steel, Alloys &Superalloys, Intermetallic Compounds, etc

(b). Ceramics: e.g. Structural Ceramics (high-temperature load bearing), Refractories (corrosion-resistant, insulating), Whitewares (porcelains), Glass, Electrical Ceramics (capacitors, insulators, transducers), Chemically Bonded Ceramics (cement & concrete)

(c). Polymers: e.g. Plastics, Liquid Crystals, Adhesives

(d). Electronic Materials: e.g. Silicon, Germanium, Photonic materials (solid-state lasers, LEDs)

(e). Composites: e.g. Particulate composites (small particles embedded in a different material), Laminate composites (golf club shafts, tennis rackets), Fiber reinforced composites (fiberglass)

(f). Biomaterials: e.g. Man-made proteins (artificial bacterium), Biosensors, etc

(g). Advanced / Smart Materials: e.g. materials in computers (VCRs, CD Players, etc), fibreoptic systems, spacecrafts, aircrafts, rockets, shape-memory alloys, piezoelectric ceramics, magnetostrictive materials, optical fibres, microelectromechanical (MEMs) devices, electrorheological / magnetorheological fluids, Nanomaterials, etc

3. According to Applications

(a). Electrical Materials: e.g. conductors, insulators, dielectrics, etc

Difference between	Metals	Non-metals
Structure	Crystalline	Amorphic
State	Generally solids at room temp.	Gaseous & solid at ordinary temp.
Luster	Metallic luster	No metallic luster (except iodine & graphite)
Conductivity	Good conductors of heat & Electricity	Bad conductors
Malleability	Malleable	Not malleable
Ductility	Ductile	Not ductile
Hardness	Generally hard	Hardness varies
Electrolysis	Form anions	Form anioins
Excitation of valence electron by e.m.f.	Easy	Difficult
Density	High	Low

1. Material Properties

- *Physical:* e.g. appearance, shape, weight, boiling point, melting point, freezing point, density, glass transition temperature, permeability
- *Mechanical:* e.g. strength (tensile, compressive, shear, torsion, bending), elasticity, plasticity, ductility, malleability, rigidity, toughness, hardness, brittleness, impact, fatigue, creep, strain hardening, Bauschinger effect, strain rate effect, vibration

resistance, wear

- *Thermal:* e.g. thermal conductivity, expansion coefficient, resistivity, thermal shock resistance, thermal diffusivity

Types of Force / Stress System

- *Electrical:* e.g. conductivity, resistivity, dielectric strength, thermoelectricity, superconductivity, electric hysteresis

- *Magnetic:* e.g. ferromagnetism, paramagnetism, diamagnetism, magnetic permeability, coercive force, curie temperature, magnetic hysteresis

- *Chemical:* e.g. reactivity, corrosion resistance, polymerization, composition, acidity, alkalinity

- *Optical:* e.g. reflectivity, refractivity, absorptivity, transparency, opaqueness, colour, luster

Metallurgical: e.g. grain size, heat treatment done / required, anisotropy, hardenability

Imperfections in Crystals

Introduction to Crystal Geometry

¾ Materials may be classified as Crystalline or Non-Crystalline structures

¾ Crystalline solid can be either *Single Crystal Solid* (crystal lattice of entire sample is continuous and unbroken to edges of sample with no grain boundary) or *Poly Crystal Solid* (aggregate of many crystals separated by well-defined boundaries)

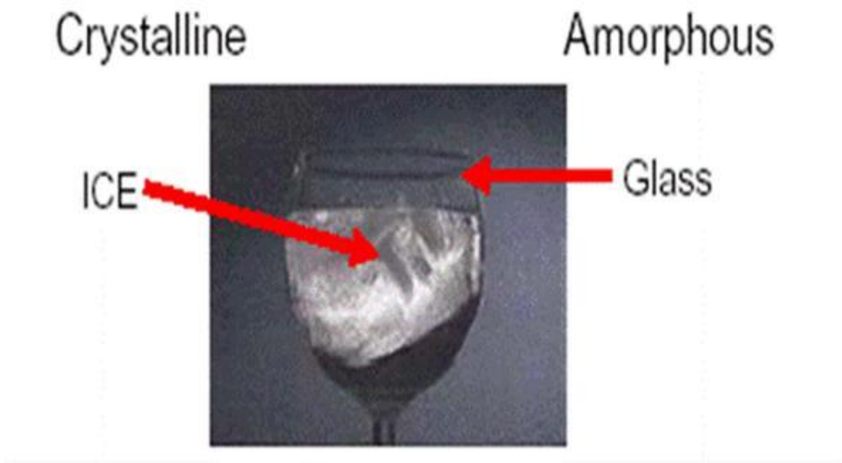
¾ Cluster of crystals with identical structure (same crystallographic planes & directions) are known as *Grains* separated by *Grain Boundaries*

¾ X-ray diffraction analysis shows that atoms in metal crystal are arranged in a regular, repeated 3-D Pattern known as *CrystallineStructure*

Example:

Ceramic: Inorganic non-metallic crystalline (regular internal Structure) materials

Glass: Inorganic non-metallic non-crystalline / amorphous (completely disordered form) material



¾ Arrangement of atoms can be most simply portrayed by *Crystal Lattice,* in which atoms are visualized as, *Hard Balls* located at particular locations

¾ Space Lattice / Lattice: Periodic arrangement of points in space with respect to three dimensional network of lines

¾ Each atom in lattice when replaced by a point is called *Lattice Point, which are the* intersections of above network of lines

¾ Arrangement of such points in 3-D space is called *Lattice Array* and 3-D space is called *Lattice Space*

¾ Tiny block formed by arrangement of small group of atoms is called *Unit Cell.* It is chosen to represent the symmetry of crystal structure, and may be defined as:

f Finite representation of infinite lattice

Small repeat entity

Basic structural unit

Building block of crystal structure

Can generate entire crystal by translation

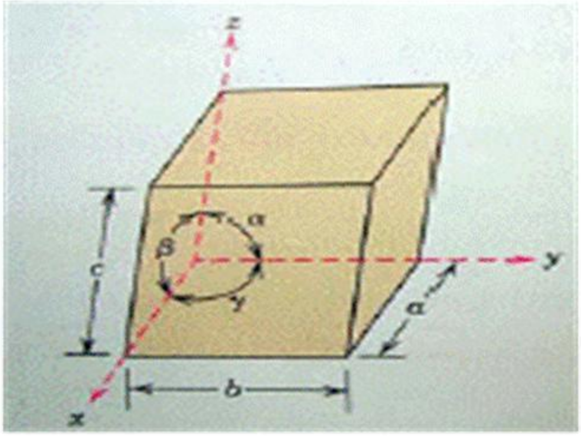
Lattice Parameters

¾ Six lattice parameters a, b, c, α, β, γ

¾ Typically in the order of few Angstroms (few tenths of nanometer)

¾ Example: Cubic structure has following lattice parameters:

$$a = b = c \text{ and } \alpha = \beta = \gamma = 90^{0}$$



Types of Crystal

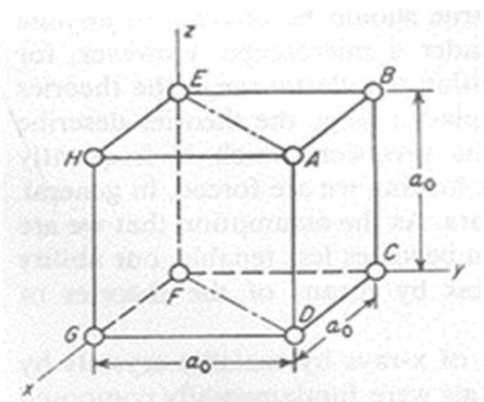
Cubic, Monoclinic, Triclinic, Tetragonal, Orthorhombic, Rhombohedral and Hexagonal

Principal Metal Crystal Structures

- *Simple Cubic Lattice Structure*
- *Body Centered Cubic (BCC) Structure*
- *Face Centered Cubic (FCC) Structure*

Simple Cubic Lattice

- Most elementary crystal structure with three mutually perpendicular axes arbitrarily placed through one of the corners of a cell
- Each corners occupied with one atom
- Example: alpha polonium



i). Aggregate of atoms (ii). Hard Sphere Unit Cell

Face Centered Cubic (FCC) Structure

- Atoms at each corner of cube, and in addition there is an atom at the center of each cube’s face

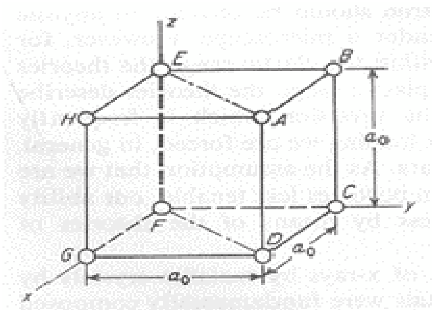
¾ Example: aluminium, copper, gold, lead, silver and nickel

ABC Stacking Sequence

Crystallographic Planes & Directions

¾ *Crystallographic Planes &Directions* are specified with respect to the reference axes in terms of ‘*Miller Indices*’, which is the system of notation of planes within a crystal of space lattice

¾ Example: SC structure is chosen for understanding



¾ *Crystallographic Plane* is specified in terms of length of its intercepts on three mutually perpendicular axes. To simplify it, reciprocals of these intercepts reduced to lowest common denominator (LCM) are used as miller indices,

e.g. plane ABCD in figure is parallel to x and z axes and intersects y-axis at one interatomic distance ‘a_0’, therefore miller indices of the plane are 1/∞, 1/ a_0, 1/∞ or (hkl) = (010)

¾ Plane EBCF is designated as (00) plane, where bar indicates that plane intersects the axis in negative direction

¾ *Crystallographic Directions* are indicated by integers in brackets like [uvw], where reciprocals are never used, e.g. direction ‘FD’ is obtained by moving out from origin, a distance ‘a_0’ along positive x-axis and moving same distance along positive y-axis also, therefore, the crystallographic direction will be given as [110]

¾ Example: Ionic crystals like NaCl, LiF (not for metals)

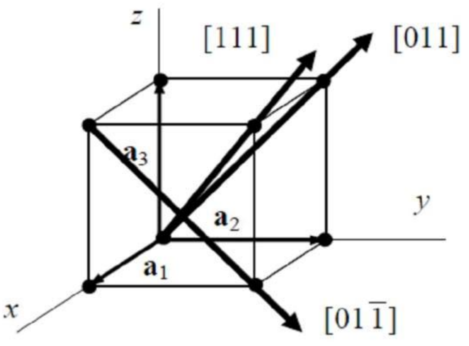
Note: For simple cubic lattice only, direction is always perpendicular the plane having same indices

Index system for crystal directions and planes

Crystal directions:

The direction is specified by the three integers [n1n2n3]. If the numbers n1n2n3 have a common factor, this factor is

removed. For example, [111] is used rather than [222], or [100], rather than [400]. When we speak
about directions, we mean a whole set of parallel lines, which are equivalent due to transnational
symmetry. Opposite orientation is denoted by the negative sign over a number. For example:



Crystal planes: The orientation of a plane in a lattice is specified by *Miller indices*. They are defined as follows. We find intercept of the plane with the axes along the primitive translation
vectors **a**1, **a**2 and **a**3. Let's these intercepts be *x*, *y*, and *z*, so that *x* is fractional multiple of a1,
y is a
fractional multiple of a2 and *z* is a fractional multiple of a3. Therefore we can measure *x*, *y*, and *z* in
units a1, a2 and a3 respectively. We have then a triplet of integers (*x y z*). Then we invert it (1/*x* 1/*y*
1/*z*) and reduce this set to a similar one having the smallest integers by multiplying by a common
factor. This set is called Miller indices of the plane (*hkl*). For example, if the plane intercepts *x*, *y*,
and *z* in points 1, 3, and 1, the index of this plane will be (313).

The orientation of a crystal plane is determined by three points in the plane, provided they are not
collinear. If each point lay on a different crystal axis, the plane could be specified by giving the coordinates

of the points in terms of the lattice constants *a, b, c*. A notation conventionally used to describe lattice points (sites), directions and planes is known as Miller Indices.
A crystal lattice may be considered as an assembly of equidistant parallel planes passing through the
lattice points and are called lattice planes. In order to specify the orientation one employs the so
called Miller indices.

.

How to find Miller Indices:
To determine the indices for the plane p in Figure 2,
-first we have to find the intercepts with the axes along the basis vector be x, y, z. We form the fractional triplet Let these intercepts
-Take reciprocal to this set.
-Then reduce this set to a similar one having the smallest integers multiplying by common factor.
To determine the Miller indices:
(i) Find the intercepts on the axes along the basis vector
→→→
cba ,, in terms of the lattice constants *a*,*b*
and *c*. The axes may be those of a primitive or nonprimitive cell. Let these intercepts be x, y, z. We form the fractional triplet
.
(ii) Take the reciprocals of these numbers.

(iii) Reduce the numbers to three smallest integers by multiplying the numbers with the same integral multipliers.

This last set is enclosed in parentheses (h k l), is called the index of the plane or Miller Indices.
The Miller indices specify not just one plane but an infinite set of equivalent planes. Note that for
cubic crystals the direction [hkl] is perpendicular to a plane (hkl) having the same indices, but this is
not generally true for other crystal systems. Examples of the planes in a cubic system:

Imperfection / Defects In Crystals

In actual crystals, imperfection or defects are always present, which are important to understand, as they influence the properties of material

Classifications of Defects

(i). Point Defects (Zero Dimensional Defects)

(a). Vacancy

(b). Schottky Imperfections

(c). Interstitialcy

(d). Frenkel Defect

(e). Compositional Defect

f Substitutional Defect

ƒ Interstitial Impurity

(f). Electronic Defect

(ii). Line Defects / Dislocations (One Dimensional Defects)

(a). Edge Dislocations

(b). Screw Dislocations

(iii). Surface / Plane Defects (Two Dimensional Defects)

(**a**). External Defects

(b). Internal Defects

ƒ Grain Boundary Defect

ƒ Tilt Boundary Defect

ƒ Twin Boundary Defect

ƒ Stacking Fault

(iv). Volume Defects (Three Dimensional Defects

(I). Point Defects (Zero Dimensional Defects)

¾ Imperfect point like regions in crystal (size is one or two atomic diameter)

¾ Completely local in effect, i.e. vacant lattice site

¾ Always present in crystals

¾ Created by thermal fluctuations, quenching (high rate of cooling), severe deformation of crystal lattice (hammering or rolling) or external bombardment by atoms / high energy particles

(e). Compositional Defect

Arises due to presence of impurity atom in crystal lattice of metal during original crystallization process (responsible for functioning of semi-conductor devices)

¾ *Substitutional Defect:* Original parent atom from its lattice is replaced

¾ *Interstitial Impurity:* Small impurity occupies interstitial spaces in lattice

(f). Electronic Defect

Errors in charge distribution in solids, e.g. diodes and transistors devices, where charges diffuse in opposite regions leading to change of their concentration in that region

(ii). <u>Line Defects (One Dimensional Defects)</u>

- ¾ Linear disturbance of atomic arrangement, which can move very easily on slip plane through crystal
- ¾ Occurs during recrystallization process or during slip
- ¾ Created along a line, which is also boundary between slipped and unslipped regions of crystals
- ¾ Defect is known as 'dislocation' and boundary is known as '*Dislocation Line*'
- ¾ Region near dislocation, where distortion is extremely large is called '*Core of Dislocation*' (very high local strain)

(a). <u>Edge Dislocation</u>

- ¾ Any extra plane of atoms within a crystal structure is edge dislocation
- ¾ Accompanied by zones of compression and tension and there is a net increase in energy along dislocation
- ¾ Displacement distance for atoms around dislocation is called '*Burger Vector*', which is at right angle to edge dislocation
- ¾ Berger vector is determined by drawing a rectangle in region by connecting an equal number of atoms on opposite sides (circuit fails to complete), i.e. PP' as shown in figure

(iii). <u>Surface / Plane Defects (Two Dimensional Defects)</u>

- ¾ Two-dimensional regions in crystal and arise from change in stacking of atomic planes on or across boundary

(a). <u>External Defects</u>

- ¾ Defects or imperfections represented by a boundary
- ¾ External surface of material itself is an imperfection because atomic bonds do not extend beyond it
- ¾ Surface atoms do not have neighboring atoms on one side (as compared to atoms inside the material) and thus, have high energy (in the order of 1 J/m2)

(b). <u>Internal Defects</u>

- ƒ ***<u>Grain Boundary Defect</u>***

¾ Imperfections, which separate crystals or grains of different orientation in polycrystalline aggregation during nucleation or crystallization

¾ Individual crystals with different orientation are called as '*Grains*', and boundary separating grains are called as '*Interface / Interface Boundary*'

Example: copper metal

¾ Atoms within a grain are arranged with one orientation and pattern, which does not aligns with orientation of atoms in neighboring grains

¾ Misalignment between adjacent grains may be of various degrees (small or high angle grain boundaries)

¾ Always a transition zones between two neighboring grains

¾ Leads to less efficient packing of atoms at boundary and thus, atoms at boundary have higher energy as compared to those at inside of grain boundaries

ƒ ***Tilt Boundary Defect***

¾ Series of aligned dislocations, which tend to anchor (fasten) dislocation movements normally contributing to plastic deformation

¾ Associated with little energy

¾ Orientation difference between two neighboring grains is less than 10^0, thus, it may be called as small / low angle grain boundary

ƒ

Stacking Fault

¾ Arise due to stacking of one atomic plane out of sequence on another, while lattice on either side of fault is perfect, i.e. one or more than one atomic plane may be missing from usual conventional style of stacking

(iv). Volume Defects (Three Dimensional Defects)

¾ Bulk defects, which includes pores, cracks, foreign inclusions or other phases

Slip by Dislocation Motion

¾ Slip is plastic deformation process produced by dislocation motion (Note: *Dislocations Can Move)*

¾ Dislocation motion is analogous to the mode of locomotion employed by caterpillar

¾ Caterpillar forms a hump near its posterior (later) end by pulling in its pair of legs unit leg distance and then this hump is propelled forward by repeating lifting and shifting of leg pairs

¾ When a hump moves forward, entire caterpillar moves forward by leg separation distance corresponding to extra half plane of atoms in its dislocation model of plastic deformation

Analogy between Caterpillar & Dislocation

Concept of Elastic & Plastic Deformation

Introduction:

¾ Change in dimensions of material under action of applied forces

¾ Caused by mechanical action or by various physical and physio-chemical processes

¾ Deformed components are superior to cast components in performance

¾ Types: Elastic & Plastic deformations

Classification of Deformation

Elastic Deformation

¾ Disappears, when load is removed & takes place before plastic deformation

¾ Strain is proportional to stress (*Hooke'sLaw*)

¾ Ratio of stress to strain is *Young'sModulusofElasticity (E)*, which is a material characteristic (magnitude depends upon force of attraction between atoms of metal)

¾ Shear stress produces shear strains and ratio of shear stress to shear strain is *Shear Modulus of Rigidity (G)*

¾ Ratio of volumetric stress to volumetric stain is *Bulk Modulus of Elasticity (K)*

¾ Perfect elastic material is one which regains back its original shape and size completely, after deforming force is removed

¾ During elastic deformation, material stores energy (strain or elastic energy), which is recovered, when load is removed

¾ Elastic strain energy is area under stress-strain curve (up to elastic limit)

¾ Materials subjected to tension shrink laterally & those subjected to compression, bulge

¾ Ratio of lateral and axial strains is called the Poisson's ratio (ν), which is a dimensionless quantity (sign shows that lateral strain is in opposite sense to longitudinal strain)

¾ Theoretical value is 0.25 & maximum value is 0.50 (typical value lies in between 0.24 to 0.30

Plastic Deformation

¾ Permanent deformation, which persists even when deforming load is removed (function of stress, temperature & rate of straining)

¾ Caused by loads exceeding elastic limit & occurs after elastic deformation

¾ Non-linear relation between stress and strain (nature varies with material & deformation condition)

¾ Exhibit yield point phenomenon (yield stress)

¾ Continued plastic deformation leads to fracture (instantaneous fracture for brittle material & necking followed by fracture for ductile material)

Yield Point Phenomenon

¾ Yielding starts at 1st higher point known as *UpperYieldPoint*and 2nd lower point is known as *LowerYieldPoint*

¾ Stress required to deform metal after yield point is always higher due to strain hardening, which causes curve to gradually rise upwards uptill ultimate tensile point (corresponding stress known as *Ultimate Tensile Strength*). After this specimen fails by fracture

Strain Hardening

¾ Increase in yield stress of material when loaded subsequently in same direction again and again below recrystallization temperature

¾ When material is loaded in any direction (say tensile direction), it experiences linear elastic deformation till elastic limit. If load is removed, material comes back to its original shape and size and curve will retrace back loading path

¾ If material is further loaded (beyond yield stress 'σ_0'), slight plastic deformation occurs leading to small permanent deformation. Now, if load is

removed, material will retail this small plastic / permanent deformation and curve will not retrace
original path, but will follow path parallel to original loading path

¾ If same material is loaded in same (tensile) direction again, it will start yielding at new yield stress '$\sigma_0^{/}$', which will be higher than initial yield stress of material 'σ_0'.

¾ This is because material becomes harder during plastic deformation by storing strain energy (some % of total deformation energy)

¾ Reduces ductility and plasticity of material

¾ At micro level, dislocation piles up during plastic deformation at slip planes, which interact with each other and create barriers to further motion / movement of dislocations through crystal lattice.

<u>BauschingerEffect / Elastic Hysteresis</u>

¾ Decrease in yield stress of material when loaded initially in one direction (tensile) and then subsequently in opposite direction (compressive) below recrystallization temperature

¾ When a material is loaded in any direction (say tensile direction), it experiences linear elastic deformation till elastic limit. If it is further loaded (beyond yield stress 'σ_0'), slight plastic deformation will occur leading to small permanent deformation

¾ Now, even if load is removed, material will retail this small plastic / permanent deformation and curve will not retrace original path, but will follow path parallel to
original loading path

Bauschinger Effect

¾ Further, loaded in opposite direction (compressive), it will start yielding at new yield stress '$\sigma_0^{/}$', which will be very less than initial yield stress of material 'σ_0'.

¾ This is because residual tensile stress stored in material during tensile loading need to be removed / compensated before elastic deformation in reversal (compressive) direction starts

¾ At micro level, dislocations piles up during tensile loading along at slip planes, which can be easily moved in opposite direction (compressive loading) by residual stresses

Anelasticity:

Time-dependent, recoverable low strain with linear behaviour and relatively low damping

Viscoelasticity:

Time-dependent, recoverable higher strains with nonlinear behaviour and higher damping

Viscoplasticity:

Time-dependent, non-recoverable strain with nonlinear behaviours and higher damping

JOINING

This chapter presents the fundamental approaches used in manufacturing namely casting, forming, welding and machining. Further, common methods of developing joint and selection of suitable methods have been described. Applications, advantages and limitations of welding as a fabrication technique have also been covered.

Keywords: Manufacturing process, election of joint, welding vs. manufacturing processes, selection of welding process, advantages, application and limitation of welding processes

Introduction

The manufacturing technology primarily involves sizing, shaping and imparting desired combination of the properties to the material so that the component or engineering system being produced to perform indented function for design life. A wide range of manufacturing processes have been developed in order to produce the engineering components ranging from simple to complex geometries using materials of different physical, chemical, mechanical and dimensional properties. There are four chief manufacturing processes i.e. casting, forming, machining and welding. Selection of suitable manufacturing process for a produce/component is dictated by complexity of geometry of the component, number of units to be produced, properties of the materials (physical, chemical, mechanical and dimensional properties) to be processed and economics. Based on the approach used for obtaining desired size and shape by different manufacturing processes.

Casting and forming are categorized as zero processes as they involve only shifting of metal in controlled (using heat and pressure singly or in combination) way from one region to another to get the required size and shape of product. Machining is considered as a negative process because unwanted material from the stock is removed in the form of small chips during machining for the shaping and sizing of a product purpose. During manufacturing, it is frequently required to join the simple shape components to get desired product. Since simple shape components are brought together by joining in order to obtain desired shape of end useable product therefore joining is categorized as a positive process. Schematic diagrams of few typical manufacturing processes are shown in Fig. 1.1.

Selection of Joint

The fabrication of engineering systems frequently needs joining of simple components and parts. Three types of joining methods namely mechanical joining (nuts & bolts, clamps, rivets), adhesive joining (epoxy resins, fevicol), welding (welding, brazing and soldering) are commonly used for manufacturing variety of engineering product/component. Each type of joint offers different load carrying capacity, reliability, compatibility in joining of similar or dissimilar materials besides their fitness for use in different environments and cost. It will be appropriate to consider following aspects while selecting type of joints for an application:

a) type of joint required for an application is temporary or permanent

b) Whether similar or dissimilar materials are to be joined in order to take care of the compatibility aspect as metallurgical incompatibility can be disastrous for performance of the joints

c) Physical, chemical metallurgical properties of materials to be joined

d) requirements of the service from the joint under special conditions of temperature, corrosion, environment, and reliability

e) type and nature of loading conditions (static and dynamic loading under tension, shear, compression, bending etc.)

f) economy or cost effectiveness is one most important factors influencing the selection of joint for manufacturing an engineering component

Welding and its comparison with other manufacturing processes

Welding is one of the most commonly used fabrication techniques for manufacturing engineering components for power, fertilizer, petro-chemical, automotive, food processing, and many other sectors. Welding generally uses localized heating during common fusion welding processes (shielded metal arc, submerged arc, gas metal arc welding etc.) for melting the faying surfaces and filler metal. However, localized and differential heating & cooling experienced by the metal during welding makes it significantly different from other manufacturing techniques:

1) Residual stresses are induced in welded components (development of tensile residual stresses adversely affects the tensile and fatigue properties of work piece)
2) Simple shape components to be joined are partially melted
3) Temperature of the base metal during welding in and around the weld varies as function of time (weld thermal cycle)
4) Chemical, metallurgical and mechanical properties of the weld are generally anisotropic
5) Reliability of weld joint is poor.
6) Little amount of metal is wasted in the form of spatter, run in and run off
7) Process capabilities of the welding in terms of dimensional accuracy, precision and finish are poor.
8) Weld joints for critical applications generally need post weld treatment such as heat treatment or mechanical working to get desired properties or reline residual stress.
9) Problem related with ductile to brittle transition behaviour of steel is more severe with weld joints under low temperature conditions.

1.4 **Selection of welding process**

A wide range of welding processes are available to choose. These were developed over a long period of time. Each process differs in respect of their ability to apply heat for fusion, protection of the weld pool and soundmen of welds joint the so performance of the weld joint. However, selection of a particular process for producing a weld joint is dictated by the size and shape of the component to be manufactured, the metal system to be welded, availability of consumables and machines, precision required and economy. Whatever process is selected for developing weld joint it must be able to perform the intended function for designed life. Welding processes with their field of applications are given below:

i. Resistance welding: Automobile
ii. Thermite welding: Rail joints in railways
iii. Tungsten inert gas welding: Aerospace and nuclear reactors
iv. Submerged arc welding: Heavy engineering, ship building.
v. Gas metal arc welding: Joining of metals (stainless steel, aluminium and magnesium) sensitive to atmospheric gases

1.5 Advantages and Limitation of Welding as a Fabrication Technique Welding is mainly used for the production of comparatively simple shape components. It is the process of joining the metallic components with or without application of heat, pressure and filler metal. Application of welding in fabrication offers many advantages, however; it suffers from few limitations also. Some of the advantage and limitations are given below.

Advantages of welding are enlisted below:

1. Permanent joint is produced, which becomes an integral part of work piece.
2. Joints can be stronger than the base metal if good quality filler metal is used.
3. Economical method of joining.
4. It is not restricted to the factory environment.

Disadvantages of welding are enlisted also below:

1. Labour cost is high as only skilled welder can produce sound and quality weld joint.
2. It produces a permanent joint which in turn creates the problem in dissembling if of sub-component required.
3. Hazardous fumes and vapours are generated during welding. This demands proper ventilation of welding area.
4. Weld joint itself is considered as a discontinuity owing to variation in its structure, composition and mechanical properties; therefore welding is not commonly recommended for critical application where there is a danger of life.

Applications of welding

General applications

The welding is widely used for fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications besides shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations.

Specific components need welding for fabrication includes

1. Transport tankers for transporting oil, water, milk etc.
2. Welding of tubes and pipes, chains, LPG cylinders and other items.
3. Fabrication of Steel furniture, gates, doors and door frames, and body
4. Manufacturing white goods such as refrigerators, washing machines, microwave ovens and many other items of general applications

3. Tank body fabrication, joining of turret mounting to main body of tanks are typical examples of applications of welding in defense industry.

Electronic industry

4. Electronic industry uses welding to limited extent e.g. joining leads of special transistors but other joining processes such as brazing and soldering are widely used.
5. Soldering is used for joining electronic components to printed circuit boards (PCBs).
6. Robotic soldering is very common for joining of parts to printed circuit boards of computers, television, communication equipment and other control equipment etc.

Electrical Industry

7. Components of both hydro and steam power generation system, such as penstocks, water control gates, condensers, electrical transmission towers and distribution system equipment are fabricated by welding. Turbine blades and cooling fins are also joined by welding.

Surface transport

8. Railway: Railway uses welding extensively for fabrication of coaches and wagons, repair of wheel, laying of new railway tracks by mobile flash butt welding machines and repair of cracked/damaged tracks by thermite welding.
9. Automobiles: Production of automobile components like chassis, body and its structure, fuel tanks and joining of door hinges require welding.

Aerospace Industry

10. Aircraft and Spacecraft: Similar to ships, aircrafts were produced by riveting in early days but with the introduction of jet engines welding is widely used for aircraft structure and for joining of skin sheet to body.
11. Space vehicles which have to encounter frictional heat as well as low temperatures require outer skin and other parts of special materials. These materials are welded with full success for achieving safety and reliability.

Ship Industry

12. Ships were produced earlier by riveting. Welding found its place in ship building around 1920 and presently all welded ships are widely used. Similarly, submarines are also produced by welding.

Construction industry

13. Arc welding is used for construction of steel building structures leading to considerable savings in steel and money.

INTRODUCTION TO COMPOSITES

The use of composites is an in exhaustive list. In the following we cite some important applications.

applications of the composite materials

The applications of the composites are given in the following as per the area of application.

Aerospace:

- Aircraft, spacecraft, satellites, space telescopes, space shuttle, space station, missiles, boosters rockets, helicopters (due to high specific strength and stiffness) fatigue life, dimensional stability.
- All composite voyager aircraft flew nonstop around the world
- with refueling. Carbon/carbon composite is used on the leading edges nose cone of the shuttle.
- B2 bomber - both fiber glass and graphite fibers are used with epoxy matrix and polyimide matrix.
- The indigenous Light Combat Aircraft (LCA - Tejas) has Kevlar composite in nose cone, Glass composites in tail fin and carbon composites form almost all part of the fuselage and wings, except the control surfaces of the wing.
- Further, the indigenous Light Combat Helicopter (LCH – Dhruvh) has carbon composites for its main rotor blades. The other composites are used in tail rotor, vertical fin, stabilizer, cowling, radome, doors, cockpit, side shells, etc.

Missile:

- Rocket motor cases
- Nozzles
- Igniter
- Inter stage structure Equipment section Aerodynamic fairings

***Launch Vehicle*:**

- Rocket motor case
- Interstage structure
- Payload fairings and dispensers
- High temperature Nozzle
- Nose cone
- Control surfaces

***Composite Railway Carrier*:**

- Composite railway auto carrier
- Bodies of Railway Bogeys Seats

- Driver's Cabin
- Stabilization of Ballasted Rail Tracks
- Doors

- Sleepers for Railway Girder Bridges
- Gear Case
- Pantographs

Sports Equipments

- Tennis rockets, golf clubs, base-ball bats, helmets, skis, hockey sticks, fishing rods, boat hulls, wind surfing boards, water skis, sails, canoes and racing shells, paddles, yachting rope, speed boat, scuba diving tanks, race cars reduced weight, maintenance, corrosion resistance.

Automotive

- Lower weight and greater durability, corrosion resistance, fatigue life, wear and impact resistance.
- Drive shafts, fan blades and shrouds, springs, bumpers, interior panels, tires, brake shoes, clutch plates, gaskets, hoses, belts and engine parts.
- Carbon and glass fiber composites pultruted over on aluminum cylinder to
- create drive shaft. Fuel saving –braking energy can be stored in to a carbon fiber super flywheels.
- Other applications include: mirror housings, radiator end caps, air filter housing, accelerating pedals, rear view mirrors, head-lamp housings, and intake manifolds, fuel tanks.

***Infrastructure Structures*:**

- Corrosion is a major design consideration such as in the chemical and on off-shore oil plate forms
- Skeletal Structures
- Walls and Panels
- Doors, Windows, Ladders, Staircases
- Chemical and Water Tanks
- Cooling Towers
- Bridge Decks
- Antenna Dishes
- Bridge enclosures
- Aerodynamic fairings

Industrial:

- Drive,
- conveyer belts, hoses,
- tear and puncture resistant
- fabrics, rotor vanes,
- mandrels, ropes, cables.

Medical:

- Wheelchairs, Crutches,
- Hip joints,
- Heat valves,
- Dentistry,
- Surgical equipments

Electronic:

- Chips in electronic computing devices are laminated hybrid systems composed of a number of layers (materials) which serve different functions.
- Chip must have good heat transfer properties and must be able to withstand induced thermal stresses without delaminating.
- The composite finds a vast usage in electronic packaging materials. The Styrofoam, particle bonded materials formed from paper pulp, air-bubble cushioned plastic sheets, etc. are some of the popular materials used in the packing.

Military:

- Helmets,
- bullet proof vests,
- impact resistant vehicles,
- lighter and less
- detectable ships,
- portable bridges.

Marine:

The Glass reinforced fibre plastics are used in:

- Ship and Boat Hulls
- Masts
- Instrument Panels Hydrofoils Hovercrafts
- Propellers Propulsion shafts Rudders

- Heat exchangers
- Flywheel
- Piping
- Ventilation ducts
- Engine and equipment foundations

***Wind Power Engineering*:**

- Rotor blades including blade shell, integral webs, spars or
- box structure. Mast
- Generator housing

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