As per Revised Syllabus of

# Visvesvaraya Technological University

# Elements of Mechanical Engineering

## Anup Goel

B.E. Mechanical &
Post Graduation in Tool Design with CAD/CAM

®

### TECHNICAL
**PUBLICATIONS**
*An Up-Thrust for Knowledge*

# Elements of Mechanical Engineering

Semester - I / II (Common to All Branches)

**First Edition : September 2014**

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**Price :₹ 225/-**
**ISBN 978-93-5099-824-3**

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The importance of **Elements of Mechanical Engineering** is well known in various engineering fields. Overwhelming response to my books on various subjects inspired me to write this book. The book is structured to cover the key aspects of the subject **Elements of Mechanical Engineering**.

The book uses plain, lucid language to explain fundamentals of this subject. The book provides logical method of explaining various complicated concepts and stepwise methods to explain the important topics. Each chapter is well supported with necessary illustrations, practical examples and solved problems. All the chapters in the book are arranged in a proper sequence that permits each topic to build upon earlier studies. All care has been taken to make students comfortable in understanding the basic concepts of the subject.

The book not only covers the entire scope of the subject but explains the philosophy of the subject. This makes the understanding of this subject more clear and makes it more interesting. The book will be very useful not only to the students but also to the subject teachers. The students have to omit nothing and possibly have to cover nothing more.

I wish to express my profound thanks to all those who helped in making this book a reality. Much needed moral support and encouragement was provided on numerous occasions by my whole family. I wish to thank the **Publisher** and the entire team of **Technical Publications** who have taken immense pain to get this book in time with quality printing.

Any suggestion for the improvement of the book will be acknowledged and well appreciated.

*Author*
*Anup Goel*

*Dedicated to Family, Friends and my Dear Students.*

# **S**yllabus (Elements of Mechanical Engineering)

## Module - 1 (Chapters - 1, 2)

**Energy Resources :** Non-renewable and renewable energy resources, **Petroleum based** solid, liquid and gaseous fuels, Calorific values of fuels, Combustion and combustion products of fuels, **Solar Power :** Solar radiation, Solar constant (definition only), Solar thermal energy harvesting, ex : Liquid flat plate collectors, Solar ponds (principle of operation only), Solar photovoltaic principle. **Wind Power :** Principle of operation of a typical windmill. **Hydro Power :** Principles of electric power generation from hydropower plants, **Nuclear Power :** Principles of nuclear power plants, **Bio Fuels :** Introduction to bio fuels, Examples of various biofuels used in engineering applications, Comparison of biofuels with petroleum fuels in terms of calorific value and emission. **Steam Formation and Properties :** Classification of boilers, Lancashire boiler, Babcock and Wilcox boiler, Boiler mountings and accessories (No sketches for mountings and accessories), Wet steam, Saturated and superheated steam, Specific volume, Enthalpy and internal energy. (No numerical problems in this module).

## Module - 2 (Chapters - 3, 4)

**Turbines and IC Engines and Pumps Steam Turbines :** Classification, Principle of operation of impulse and reaction turbines, Delaval's turbine, Parson's turbine. (No compounding of turbines).

**Gas Turbines :** Classification, Working principles and operations of open cycle and closed cycle gas turbines.

**Water Turbines :** Classification, Principles and operations of Pelton wheel, Francis turbine and Kaplan turbine.

**Internal Combustion Engines :** Classification, I.C. engines parts, 2 stroke and 4 stroke petrol engines, 4 stroke diesel engines. P-V diagrams of Otto and Diesel cycles. Problems on indicated power, Brake power, Indicated thermal efficiency, Brake thermal efficiency, Mechanical efficiency and specific fuel consumption, [Numericals on IC engines].

## Module - 3 (Chapters - 5, 6)

**Machine Tools and Automation Machine Tools Operations :**

Turning, Facing, Knurling, Thread cutting, Taper turning by swivelling the compound rest, Drilling, Boring, Reaming, Tapping, Counter sinking, Counter boring. Plane milling, End milling, Slot milling. (No sketches of machine tools, Sketches to be used only for explaining operations. Students to be shown the available machine tools in the machine shop of the college before explaining the operations).

**Robotics and Automation :**

**Robotics :** Introduction, Classification based on robots configuration; Polar, Cylindrical, Cartesian coordinate and spherical. Application, Advantages and disadvantages.

**Automation :** Definition, Types - Fixed, Programmable and flexible automation. NC / CNC machines : Basic elements with simple block diagrams, Advantages and disadvantages.

## Module - 4  (Chapters - 7, 8)

**Engineering Materials and Joining Processes :**

**Engineering Materials :**

Types and applications of ferrous and nonferrous metals and alloys,

**Composites :** Introduction: Definition, Classification and applications (aircraft and automobiles)

**Soldering, Brazing and Welding :**

Definitions, Classification and method of soldering, Brazing and welding. Differences between soldering, Brazing and welding. Description of electric arc welding and oxy-acetylene welding.

## Module - 5  (Chapter - 9)

**Refrigeration, Air-conditioning :**

**Refrigerants :** Properties of refrigerants, List of commonly used refrigerants.

**Refrigeration -** Definitions - Refrigerating effect, Ton of refrigeration, Ice making capacity, COP, Relative COP, Unit of refrigeration. Principle and working of vapour compression refrigeration and vapour absorption refrigeration : Principles and applications of air conditioners, Room air conditioner.

# **T**able of Contents

## Chapter - 3    Turbines                                      (3 - 1) to (3 - 22)

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## Chapter - 4     Internal Combustion (I.C.) Engines     (4 - 1) to (4 - 42)

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## Chapter - 5     Machine Tools and Automated Machine Tool Operations
###     (5 - 1) to (5 - 26)

## Chapter - 6     Robotics and Automation        (6 - 1) to (6 - 18)

## Chapter - 7     Engineering Materials        (7 - 1) to (7 - 22)

## Chapter - 8    Joining Processes    (8 - 1) to (8 - 22)

## Chapter - 9     Refrigeration and Air Conditioning     (9 - 1) to (9 - 18)

# Module - I

## CHAPTER - 1

# ENERGY RESOURCES

**Syllabus :** Non-renewable and renewable energy resources, **Petroleum based** solid, liquid and gaseous fuels, Calorific values of fuels, Combustion and combustion products of fuels, **Solar Power :** Solar radiation, Solar constant (definition only), Solar thermal energy harvesting, ex : Liquid flat plate collectors, Solar ponds (principle of operation only), Solar photovoltaic principle. **Wind Power :** Principle of operation of a typical windmill. **Hydro Power :** Principles of electric power generation from hydropower plants, **Nuclear Power :** Principles of nuclear power plants, **Bio Fuels :** Introduction to bio fuels, Examples of various biofuels used in engineering applications, Comparison of biofuels with petroleum fuels in terms of calorific value and emission.

## 1.1 Introduction to Energy Resources

☞ **[ June 2010, Dec. 2011, June 2012, June 2013 ]**

- Energy is the primary measure that causes changes and movement in all kinds of work by human beings and nature.

- All living things use energy constantly and hence energy is always being changed and flows from one form to another.

- The sources of energy available can be cla8ssified as follows :

  i)  Renewable energy resources
  ii) Non-renewable energy resources

### i) Renewable Energy Resources

- Renewable energy is the energy which comes from resources that are naturally replenished.

- These energy resources includes solar energy, wind energy, geothermal energy, hydropower, ocean thermal energy and biomass.

- These resources are sustainable resources and never ending type.

- Renewable energy sources occurs over wide geographical areas abundantly.

### ii) Non-renewable Energy Resources

- Non-renewable energy is the energy which comes from the resources that are not sustainable resources.

- Non-renewable resources does not renew itself at sufficient rate.

- They includes fossil fuels such as coal, petroleum and natural gas, earth minerals and ores, nuclear fuels.

- These resources of energy required thousands of years to form naturally and can not be replaced as fast as they consumed for use.

- Now-a-days there is increasing levels of investment in the field of sustainable energy.

- As the non-renewable sources are decline, the renewable energy has become mainstream and the future of energy production.

## 1.2 Petroleum Based Fuels

- **Fuels** can be defined as a source of heat energy that releases heat on combustion.

- Fuel contains chemical energy which is released during combustion i.e. burning of fuel in presence of oxygen.

- Fuels may be primary (naturally occuring) or secondary (prepared or artificial).
- Petroleum based fuels can be classified into the following categories :

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

## 1. Solid Fuels

- Solid fuels includes primary fuels like wood, peat, lignite, bituminous, anthracite and secondary fuels like coke, charcoal, briquettes, etc.
- Following are the some solid fuels with their sailent features :

> i)  Wood         ii)  Coal          iii) Peet
> iv) Lignite       v)   Bituminous    vi) Anthractie
> vii) Coke         viii) Briquettes

i)   **Wood :** This is not a commercial solid fuel. It is used for household purposes such as cooking and heating the space, water, etc.

ii)  **Coal :** Coal is produced from vegetation in earth crust due to pressure and heat over a large period. Following are the stages in the formation of coal from vegetation :

> Plant decay → Peat → Lignite → Bituminous coal → Anthracite

iii) **Peat :** Peat is the first stage in the formation of coal. It contains moisture and decayed vegetable matter. It burns without smoke formation.

iv)  **Lignite :** Lignite has woody or clay like appearance. It burns with smoky flame due to high moisture and ash content. It is suitbale for local use only.

v)   **Bituminous coal :** Bituminous has high content of volatile matter and burns with large yellow flame. It's heat content is upto 31,000 kJ/kg.

vi)  **Anthracite :** It is the high quality, hard and shiny black coloured coal. It burns with short blue flames. It's having higher calorific value about 35,000 kJ/kg.

vii) **Coke :** Coke is prepared from destructive distillation of coals. It is a clean and smokeless fuel.

viii) **Briquettes :** By compressing the mixture of coal and coke under high pressure briquettes are formed. It facilitate easy burning in any equipment.

## 2. Liquid fuels

- Liquid fuels are extrated from wells under earth's crust.
- The primary source of liquid fuels is crude oil or petroleum and secondary liquid fuels includes artificially prepared fuels like alchohols, tar, oils, spirits, etc.

- Heavy oils or crude oils are refined in the refineries to form petrol, kerosene, fuel oils and alchohols.

- Liquid fuels are hydrocarbons and compounds of hydrocarbons such as parafins, olefins, napthenes and benzenes, etc.

- Liquid fuels are used in IC engine as a fuel for burning.

### 3. Gaseous fuels

- The primary source of gaseous fuels is natural gas and the secondary fuels includes prepared gases such as methane, coal gas, coke-oven gas, blast furnace gas, producer gas, sewer gas, etc.

- Following are the some gaseous fuels :

| | |
|---|---|
| i) Natural gas | ii) Coal gas |
| iii) Coke oven gas | iv) Blast furnace gas |
| v) Producer gas | vi) Sewer gas |

i) **Natural gas :** Natural gas occurs in the oil or gas wells. It constitute of methane and ethane and small quantities of higher hydrocarbons. It has higher calorific value about 35000 kJ/kg to 37000 kJ/kg.

ii) **Coal gas :** Coal gas mainly consist of hydrogen, carbon monoxide and hydrocarbons and prepared by carbonisation of coals. Coal gas is suitable for boiler firing.

iii) **Coke-oven gas :** It is produced during combustion of bituminous coal. This gas must be filtered before using because it contains flue particles.

iv) **Blast furnace gas :** During the extraction of iron from iron ore, the blast furnace gas is produced. After filtering it is used directly or blended with rich gas in gas engine application.

v) **Producer gas :** It is obtained during the incomplete combustion or partial oxidation of coal or coke. It is used in firing open hearth furnace.

vi) **Sewer gas :** It is obtained during fermentation and decay of sewage waste. Sewer gas works as fuel for gas engines.

## 1.3 Calorific Values of Fuel

- Calorific value of fuel (solid, liquid) is the amount of heat liberated during complete combustion of unit mass of fuel.

- Also, for gaseous fuels the calorific value is the amount of heat developed by complete combustion of unit cubic meter of gas at standard temperature and pressure.

- Calorific value or heating value is expressed in terms of kJ/kg for solid and liquid fuels and in terms of kJ/m$^3$ for gaseous fuels.
- Higher Calorific Value (H.C.V.) of fuel is obtained when water formed by combustion is completely condensed. Condensation of water will add its latent heat to the calorific value.
- Lower Calorific Value (L.C.V.) is obtained when the steam formed during combustion exits completely without condensing.
- Lower calorific value of fuel is given by,

    L.C.V. = H.C.V. – Latent heat of vaporisation

    L.C.V. = H.C.V. – [$M_W \times 2460$],      kJ/kg

- Higher calorific value of fuel is given by,

$$\text{H.C.V.} = \frac{1}{100}\left[35000C + 143000\left(H - \frac{O}{8}\right) + 9160\ S\right], \text{ kJ/kg}$$

where,          $M_W$ = Mass of water vapour formed per kg of fuel burned

   H, C, O and S = Percentage of hydrogen, carbon, oxygen and sulphur

- Generally, the heating value used is lower calorific value.

## 1.4 Combustion of Fuels

- All the fuels contains chemical energy which liberate heat energy during combustion in presence of oxygen.
- The combustible matter in the fuel such as carbon, hydrogen, sulphur which easily combine with the oxygen during combustion.
- Hence, heat is liberated from this chemical reaction.
- To ensure complete combustion process of fuels, sufficient amount of air should be provided.
- Therefore, it is necessary to calculate the mass of air required for complete combustion.
- If the sufficient amount of air is not supplied, there will be incomplete combustion of fuel.
- This results in burning of carbon to carbon monoxide (CO) instead of carbon dioxide ($CO_2$) and amount of heat produced is reduced significantly.
- Following are the combustion equations for calculating amount of oxygen required for combustion and amount of gases produced after combustion :

> i) Combustion of carbon
> ii) Combustion of hydrogen
> iii) Combustion of sulphur
> iv) Combustion of hydrocarbons

## i) Combustion of carbon

- Complete combustion of carbon to carbon dioxide is given by considering molecular weights of the elements

$$C + O_2 \longrightarrow CO_2$$
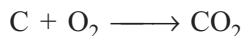
- 12 kg of carbon combines with 32 kg of oxygen to form 44 kg of $CO_2$.

$$\therefore 1 \text{ kg of C} + \frac{8}{3} \text{ kg } O_2 \longrightarrow \frac{11}{3} \text{ kg of } CO_2 \qquad \dots \left( \frac{32}{12} = \frac{8}{3} \text{ and } \frac{44}{12} = \frac{11}{3} \right)$$

- Incomplete combustion of carbon to carbon monoxide is given by the following reaction :

$$2C + O_2 \longrightarrow 2\ CO$$

- 24 kg of carbon combines with 32 kg of oxygen to form 56 kg of carbon monoxide.

$$\therefore \ 1 \text{ kg of C} + \frac{4}{3} \text{kg } O_2 \longrightarrow \frac{7}{3} \text{ kg of CO} \qquad \dots \left( \frac{32}{24} = \frac{4}{3} \text{ and } \frac{56}{24} = \frac{7}{3} \right)$$

- 56 kg of CO combines with 32 kg of $O_2$ and forms 88 kg of $CO_2$.

$$\therefore \ 1 \text{ kg of CO} + \frac{4}{7} \text{kg } O_2 \longrightarrow \frac{11}{7} \text{ kg of } CO_2 \qquad \dots \left( \frac{32}{56} = \frac{4}{7} \text{ and } \frac{88}{56} = \frac{11}{7} \right)$$

## ii) Combustion of hydrogen

- Hydrogen reacts with oxygen to form steam or water

$$2H_2 + O_2 \longrightarrow 2\ H_2O$$

- 4 kg of $H_2$ combines with 32 kg of $O_2$ to form 36 kg of water.
  On simplifying we get,

$$1 \text{ kg of } H_2 + 8 \text{ kg of } O_2 \longrightarrow 9 \text{ kg of } H_2O$$

## iii) Combustion of sulphur

- Sulphur reacts with the oxygen to form sulphur dioxide

$$S + O_2 \longrightarrow SO_2$$

- 32 kg of sulphur combines with 32 kg of oxygen to form 64 kg of sulphur dioxide

$\therefore$ $\qquad$ 1 kg of S + 1 kg of $O_2$ $\longrightarrow$ 2 kg of $SO_2$
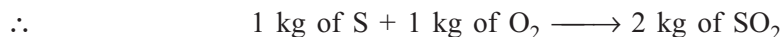
### iv) Combustion of hydrocarbon

- Assume hydrocarbon fuel is $C_nH_{2n+2}$ when reacts with oxygen forms carbon dioxide and steam or water.

$$C_nH_{2n+2} + \left(\frac{3n+1}{2}\right) O_2 \longrightarrow nCO_2 + (n+1) \ H_2O$$
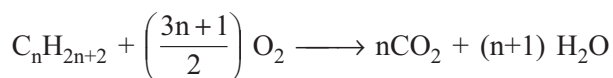
## 1.5 Solar Energy and its Measurements

- The energy produced and radiated by the sun or sun's energy reaches to the earth.
- This energy is received in the form of radiations and it can be converted directly or indirectly into other forms of energy like heat, electricity, etc.
- As the sun is expected to radiate at constant rate for a billion of years, it may be considered as an inexhaustible source of energy.
- Solar energy which falls on the earth is at considerably low density and hence it cannot be used directly for power generation.
- **Solar radiation** is the radient energy that is emitted by the sun.
- Solar radiations are produced due to nuclear fusion reaction and it creates large amount of electromagnetic energy at the temperature of 5800 K.
- Solar radiations are in the form of visible short waves of electromagnetic spectrum, infrared radiations and ultraviolet spectrum.
- It is measured in the term called solar constant.
- **Solar constant** is defined as the amount of energy received in unit time on the unit area perpendicular to the solar radiations.
- It is measured in watt per square meter ($W/m^2$).
- Solar constant is a measure of flux density.
- It is measured by satellite near the outer surface of earth's atmosphere.
- Its approximate value is upto 1.361 $kW/m^2$.

## 1.6 Solar Thermal Energy Harvesting

- The energy conversion in all the processes is inefficient due to the loss of energy in the form of heat.
- For examples, in case of motors, automobile engines, electric bulbs the energy is lost in the form of heat.
- There are some devices known as **harvesting devices** which recover some energy from the wasted energy and convert it into electricity.

- The large solar panels is one of the harvesting collectors which provides major alternate energy source to power grid.

- Fig. 1.1 shows the schematic diagram of solar thermal energy harvesting.
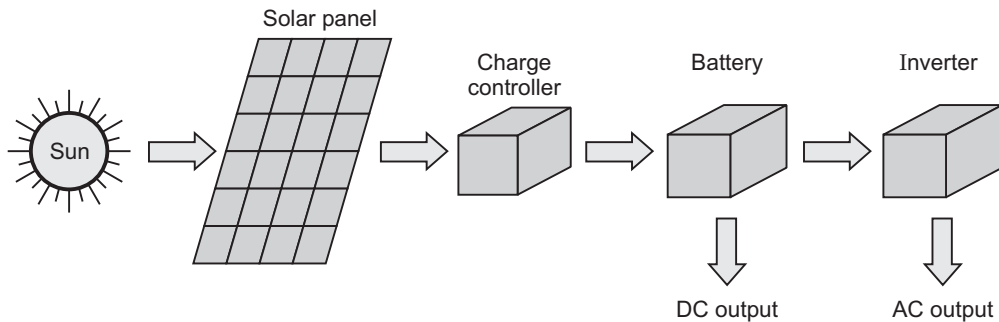


**Fig. 1.1 : Solar thermal energy harvesting**

- Following are the some types of solar thermal energy harvesting devices.

  1. Liquid flat plate collector

  2. Solar air heater

  3. Cylindrical solar collector

  4. Solar pond, etc.

## 1.6.1 Liquid Flat Plate Collector

- It is a most important type of solar energy harvesting devices.

- Flat plate collector is based on the principle that, the dark surface which is exposed to solar radiations absorb the solar radiations.

- The part of this absorbed radiation is transferred by means of a media i.e. air, water, etc.
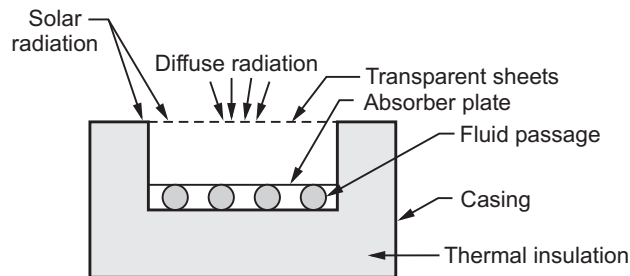


**Fig. 1.2 : Liquid flat plate collector**

The function of various elements of liquid flat plate collector is as follows :

1. **Casing :** It provides housing for the liquid passage and other parts of the collector. Thermal insulation is provided to the casing in order to avoid the loss of solar radiation.

2.  **Absorber plate :** It is the most important part of the collector. The main function of absorber plate is to absorb maximum possible amount of solar radiations and allow very less amount of heat loss to the atmosphere.

3.  **Transparent sheets :** These sheets are made up of glass. The transparent sheets covers the absorber plate in order to reduce the convective heat loss. The closed air passage is formed between the transparent sheets and absorber plate which helps to reduce the convective heat loss. There can be one or more transparent sheets on a liquid flat plate collector.

4.  **Fluid passage :** The heat absorbed by absorber plate is transferred to the liquid present in tubes in fluid passage. In case of liquid flat plate collector, the liquid used is mostly water.

*   A liquid flat plate collector is usually held tilted in a fixed position.

**Advantages**

*   Simple in design.
*   It has no moving parts such as motors, etc.
*   It requires less maintenance.
*   It makes use of diffuse solar radiation.
*   Less expensive than concentrating collectors.

**Disadvantages**

*   Loss of heat to the environment is more than that of other type of collectors.
*   Inappropriate for high temperature applications such as steam production.

**Applications**

*   Heating of water for domestic purpose and space heating.
*   Process water heating.
*   Sanitation, etc.

## 1.6.2 Solar Ponds

*   Solar ponds are one of the important solar energy harvesting technique.
*   A solar pond is a pool of salt water which collects and stores the solar thermal energy.
*   A solar pond is based on the principles of energy transfer by convection to heat the water.
*   Fig. 1.3 shows the schematic diagram of a solar pond.
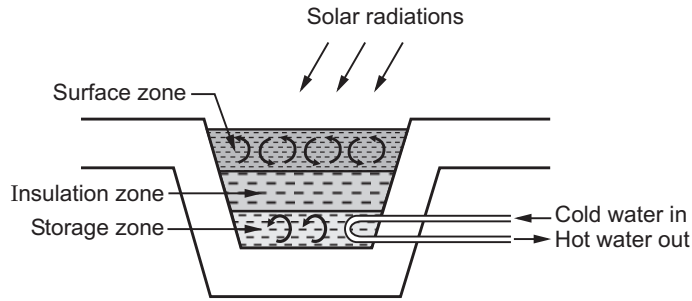
**Fig. 1.3 : Solar pond**

- The salt water in the pool naturally forms a gradient because of difference in density. The different levels in the solar ponds are as follows :

  i) Surface zone
  ii) Insulation zone
  iii) Storage zone

### i) Surface zone

- The surface zone lies at the top of a the solar pond due to low density.
- It is convective due to daily heating and cooling and mixing due to wind movement.

### ii) Insulated zone

- Below the surface zone, there is a non convective zone known as insulation zone.
- The density gradient also facilitates the temperature gradient and forms as an insulation.
- There is no convection in this layer because the high salt concentration at the lower layer does not allow the water level to rise.

### iii) Storage zone

- It is the bottom most and dense layer of the solar pond.
- It is convective and can store a working temperature upto 80º to 90º C.
- This zone of the pond is dark in colour to absorb sun radiations.
- The various salts used to make saline water are NaCl, $MgCl_2$, sodium carbonate, sodium sulphate etc.
- The hot salt water at the bottom can be extracted and used for direct heating purpose and low temperature applications.

**Advantages of solar ponds**
- Simple in construction and can be located anywhere.
- Very large area collectors can be set up just on the expense of clay or plastic liner.
- There is no need of a separate collector for thermal energy storage.
- Eco-friendly system.
- Cost free operation.

**Disadvantages of solar ponds**
- Energy efficiency is low.
- There is need of adding new salt water continusouly as the bottom layer is continuously pumped for use.
- The accumulation of salt crystals must be avoided to prevent built up.
- The surface area required is very large.
- Location of solar pond requires solar energy access to operate.

**Applications of solar ponds**
- Process heating for textile and dairy industries.
- Refrigeration.
- Solar power generation.
- Desalination of drinking water.
- Heating and cooling of buildings.
- Heating animal housing and drying crops on farms.
- Heat required for biomass conversion into alchohol or methane.

## 1.7 Solar Photo-Voltaics

- Solar photo-voltaics refers to the conversion of solar energy into electrical energy by means of photovoltaic effect.
- The main principle of solar photo-voltaic is to generate an electromotive force by absorption of ionizing radiation.
- A photo-voltaic (PV) system consist of the following elements :
  i) Solar cell array      ii) Load leveller

  iii) Storage system      iv) Tracking system
- A photo voltaic cells or solar cells are made from semiconductors that generate electricity when they absorb light.
- When the photons from the sun are absorbed in the semiconductor, they creates free electrons.
- These free electrons have higher energy than the bonded electrons.

- There must be electric field to induce the higher energy free electrons to flow out of the semiconductor.
- Hence the solar energy is converted to the electrical energy.

**Advantages of solar photovoltaic cell**

- No need to work at higher temperature.
- No moving parts.
- Solar energy conversion is without pollution.
- Higher power handling capacity.
- Rapid response to changes in input radiation.
- No requirement of fuel as solar energy is free.
- They have high power to weight ratio.
- They have highly effective long life.

**Disadvantages of solar photovoltaic cell**

- Higher cost.
- Energy storage is required as the solar energy is unavailable at night.

**Applications of solar photovoltaic cell**

- Street lighting and railway signalling.
- Electrical power generation in space craft.
- In small or large power plants.
- Automatic weather monitoring.
- It is used to operate irrigation pump and drinking water supply, etc.

# 1.8 Wind Power

- Wind energy is an indirect form of solar energy, because wind is mainly induced by the uneven heating of the earth's surface by the sun.
- Winds can be classified as **planetary wind** and **local wind.**
- Planetary winds are caused by greater solar heating of the earth's surface near the equator; whereas local winds are caused by differential heating of land and water, and also by hills and mountain sides.
- During the operation, the wind approaching the blades moves the wind mill shaft thereby rotating the rotor of generator.
- In this way, kinetic energy of the wind is converted into mechanical energy by the wind mill and then converted into electrical energy by using a generator.
- Fig. 1.4 shows the general layout of wind mill.
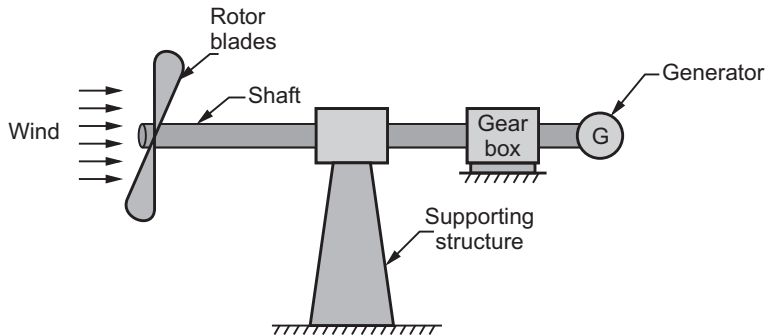
**Fig. 1.4 : Wind mill**

**Advantages of wind energy system**

- Wind is available at no cost.
- It does not cause any kind of pollution while generating power.
- It is available in many off-shore, on-shore and remote areas which is helpful in supplying the electric power in those areas.
- It has low maintenance cost and low power generation cost.

**Disadvantages of wind energy system**

- It has low energy density.
- It is favourable in locations which are away from cities.
- The wind supply is variable, unsteady, intermittent and sometimes dangerous also.
- The initial cost of plant set-up is high.

## 1.8.1 Solar-Wind Hybrid Power System

- We have already discussed that, solar energy is not available at night whereas wind energy is not so strong when sun is shining.
- To overcome the drawbacks of both these plants, hybrid power system came into picture.
- Hybrid power system is a combination of wind power and solar power system, hence called as **solar-wind hybrid system**.
- These systems are still under development.
- This system can be located in flat open areas (away from forests and tall buildings) where both solar radiation and wind speeds are easily available in large quantity.
- Hence, these type of power plants ensure continuous supply of power at remote locations where grid is not available.

- Fig. 1.5 shows the general layout of solar-wind hybrid power system.
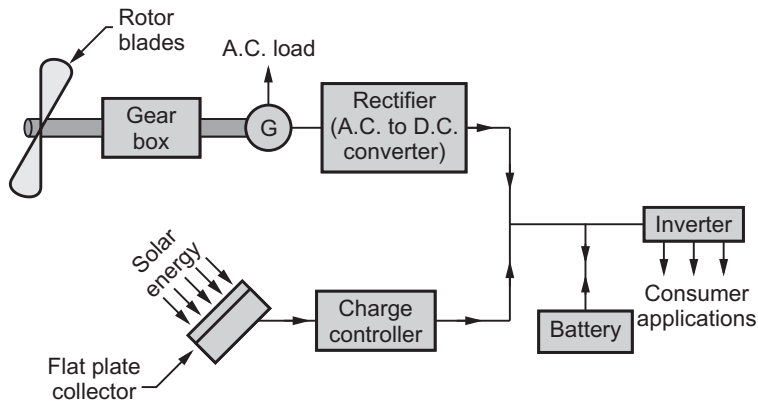


**Fig. 1.5 : Solar-wind hybrid system**

- During the period of high wind speed (evening time), the wind speed generator generates A.C. power which may be used directly by connecting it to A.C. applications (loads).

- The extra amount of A.C. power is converted into D.C. with the help of rectifier and stored in the battery.

- During the period of high solar energy (day time), the solar photovoltaic (PV) system converts the solar radiations directly into D.C. power which is stored in the battery.

- With the help of inverter D.C. power is converted into A.C. and supplied to various applications like street lighting, water pumping, etc.

- Battery acts as a storage device which stores the excess amount of power when energy demand by consumer is less than the generated power or supplies excess power when energy demand by the consumer is more than the generated power.

**Advantages of solar-wind hybrid power system**
- This type of power plant ensures continuous power supply.
- It can be used in the remote areas where transmission lines are not readily available.
- Both the sources i.e. wind and solar are available at no cost.
- This power system does not create any kind of pollution while power generation.
- Cost of maintenance and power generation is low.

**Disadvantages of solar-wind hybrid power system**
- This type of power plant can be located away from load centre which increases transmission loss and cost.

- Both the sources are nature dependent.
- Initial cost and time of plant set-up is very high.

## 1.9 Hydro-Power Plant

- In hydroelectric power plants the potential energy of water is utilised to drive the turbine which in turn runs the generator to produce electricity.
- The basic requirement of hydroelectric power plant is a reservoir where large amount of water is stored during rainy season and used during other seasons.
- Therefore these types of power plants are located where the water resources are available in large quantity with high head.
- During the operation, the water is supplied to the turbine (prime mover) through the penstock which is located at much lower level than the height of water in the reservoir.
- Then, the water is impinged on the turbine blades which drives the turbine shaft to generate power.
- Fig. 1.6 shows the general layout of hydroelectric power plant.
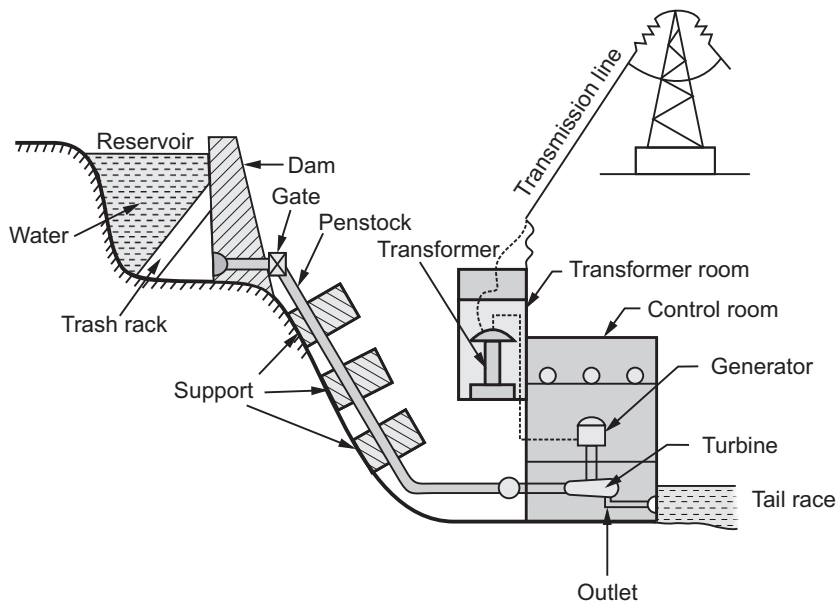


**Fig. 1.6 : Hydroelectric power plant**

- The function of various elements of hydroelectric power plant is as follows :
1. **Reservoir :** Reservoir is used to store large amount of water during rainy season and supply water during other seasons. Water stored is not only used for power generation, but also for fload control, irrigation, water supply, navigation, etc. A reservoir may be natural or artificial.

2. **Dam :** Dam is a structure of considerable height built across the reservoir. It develops a reservoir to store water and it builds up a head for power generation.

3. **Trash rack :** It is provided for preventing the entry of debris (dust, dirt, etc.) from the dam, because any debris into the intake water pipe may damage the turbine blades or choke up the flow. It is generally made of steel.

4. **Gate :** It is provided to control the flow of water from reservoir to the turbine. According to the requirement, gate opening can be changed.

5. **Penstock :** It is a pipeline which carries water from reservoir to the turbine. Generally, to the withstand high pressures, it is made of concrete and of 1 to 2 m in diameter.

6. **Control room :** Control room or power house consists of turbine, generator and other electric equipments to convert mechanical energy of turbine into electrical energy.

7. **Turbine :** Turbine is used to convert kinetic energy of water into mechanical energy. Generally used hydraulic turbine are Pelton turbine, Kaplan turbine, Francis turbine, etc.

8. **Tail race :** It is a path to lead the water discharged from the turbine to the river.

**Advantages of hydroelectric power plant**

- Water source is easily and readily available.
- No fuel is to be burnt to generate the power.
- The running cost of these power plants is very low as compared to thermal power plants.
- These power plants are more reliable.
- There is no problem of disposal of ash, emission of polluting gases and particulates.
- Life expectancy of these power plants is higher.
- Due to simple design and operation, these power plants do not require highly skilled operators. Manpower requirement is also low.

**Disadvantages of hydroelectric power plant**

- Power generation is dependent on the quantity of water available, which may vary from season to season.
- These power plants are located far away from the load centre which requires long transmission lines. The cost of these transmission lines and losses are more.
- The time required for the set-up of plant is more.
- Initial cost of set-up is very high.

## 1.10  Nuclear Power Plant

- Nuclear power plant is similar to thermal or steam power plant; the only difference is that, the boiler of steam power plant is replaced by nuclear reactor.
- Nuclear power plant utilises nuclear energy produced by nuclear reactions for generation of steam.
- The heat is produced by nuclear fission of the atoms of fissionable material and it is utilised in special heat exchangers for the production of steam.
- The commonly used nuclear fuels are unstable atoms like Uranium ($U^{235}$), Thorium ($Th^{232}$) and artificial element plutonium ($Pu^{239}$).
- These unstable atoms liberate large amount of heat energy. The energy released by the complete fission of 1 kg of $U^{235}$ is equal to the heat energy obtained by burning 4500 tonnes of coal or 2200 tonnes of oil.
- But there are some limitations in the use of nuclear energy like high cost of plant set-up, limited availability of raw materials, problem with disposal of radioactive waste and highly skilled operators.
- Due to these reasons, nuclear power plants are still developing in India. Only 1% to 3% energy requirement is fulfilled by nuclear power plant in countries like India, whereas in France about 30% of its energy requirement is generated by nuclear method.
- The general layout of nuclear power plant is shown in Fig. 1.7.
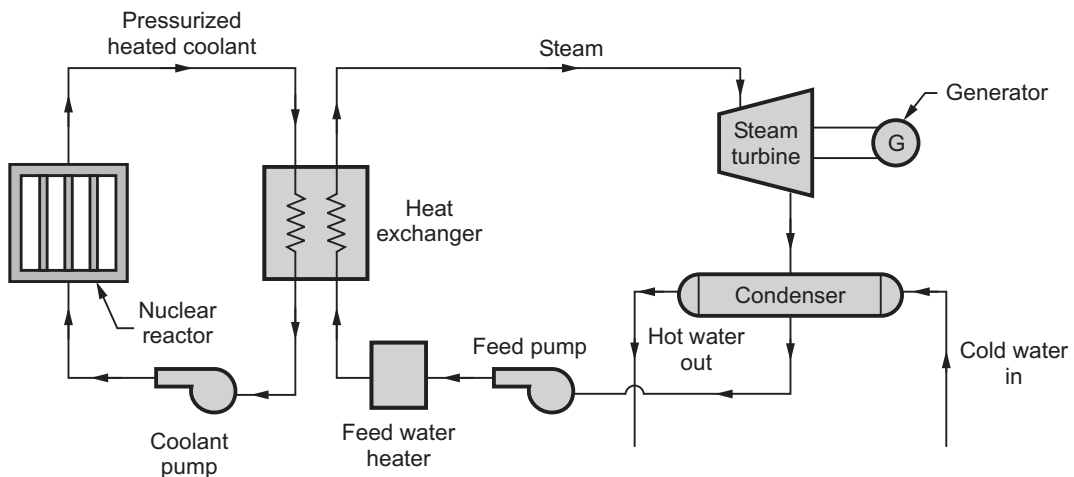


**Fig. 1.7 : Nuclear power plant**

- The function of various elements of nuclear power plant is as follows :
1. **Nuclear reactor :** In the nuclear reactor, nuclear energy is produced by the nuclear fission of unstable atoms like uranium. Uranium is in the form of thin rods or plates. This energy is transferred to the circulating coolant.

2. **Heat exchanger :** The heat exchanger will act as a boiler for the power plant. The heat absorbed by the coolant in the reactor is transferred to the water and steam is generated. Generally, U-tube type heat exchanger is used. The commonly used coolants are carbon dioxide, helium, liquid metals like sodium, potessium, etc.

3. **Steam turbine :** It converts high pressure and high temperature steam supplied by the heat exchanger into shaft work and low temperature steam is exhausted to a condenser.

4. **Generator :** The mechanical energy of steam turbine is converted into electrical energy with the help of generator.

5. **Condenser :** Steam exhausted from steam turbine is collected in the condenser and condensed by using recirculated cooling water.

6. **Feed pump :** The collected amount of condensate is again fed back to the heat exchanger with the help of feed pump.

7. **Feed water heater :** The water pumped from feed pump is initially heated in the feed water heater and then supplied to the heat exchanger.

8. **Coolant pump :** The coolant after transferring the heat in the heat exchanger is again fed back to the nuclear reactor with the help of coolant pump.

**Advantages of Nuclear Power Plant**

- The cost of generated power is less than the thermal power plant.
- There is no problem of environmental pollution, fuel transportation, mine safety, etc.
- Nuclear power plant does not require fossil fuels like coal, coke, natural gas which can be used in other areas.
- Less space is required as compared to steam power plant.
- Large amount of energy is generated by burning small amount of fuel.

**Disadvantages of Nuclear Power Plant**

- Initial cost of plant set-up is high.
- Nuclear reactor fuels are not easily available.
- There is problem of disposal of radioactive waste.
- For the operation of power plant highly skilled operator is required.
- Cost of nuclear reactor fuels is also high.
- During the operation, nuclear radiations are produced hence high degree of safety is required for the operators.

## 1.11 Introduction to Biofuels

- As the prices of crude oil are increasing day by day, we need an alternate source of fuel.

- Hence most of the people are switching to the biofuels to save money and decrease the dependency on the fossil fuels.
- *Biofuels are the fuels that produced from plants and crops.*
- They contains energy from geologically recent carbon fixation i.e. conversion of $CO_2$ to the organic compounds by living organisms.
- These fuels are made by biomass (plants or plant derived materials) conversion by means of thermal, chemical or biochemical conversion.
- This biomass conversion results into solid, liquid or gaseous biofuels.
- Biofuels are produced from wheat, corn, soyabeans, sugarcane, etc.
- They are used after blending with the gasoline.
- Most commonly extracted and used biofuels are **Ethenol** and **Biodiesel**.

**Advantages of Biofuels**

- Overall cost benefit from biofuels is higher than gasoline.
- Biofuels are adapted current engine designs and perform very well in most of the conditions.
- They are clean fuels and produce few emissions on burning.
- Biofuels are derived from sustainable sources such as manure, waste from crops and plants hence its source is easily available.
- They are renewable source of energy.
- Biofuels helps in reducing green house gases such as $CO_2$ upto 65 % thereby reducing global warming.
- Biofuels decreases the dependence on the crude oil and keeps the economy secure.
- Biofuels are cleaner and cause lesser pollution.

**Disadvantages / Limitations of Biofuels**

- The production of the biofuels is expensive in the current market.
- Growing of same crop every year may decrease the soil nutrients.
- Use of fertilizers for growing crops can have harmful effects on surrounding environment.
- As biofuels are extracted from plants and crops, most of these crops are food crops. Hence it may cause shortage and rise in prices of food.
- Production of biofuels largely depends on the lots of water and oil which leads to industrial pollution due to used water and oil.

## 1.11.1 Examples of Biofuels used in Engineering Applications

- Following are the types of biofuels used efficiently in engineering applications. Refer Fig. 1.8.

```
                          ┌──────────┐
                          │ Biofuels │
                          └──────────┘
              ┌───────────────┼───────────────┐
              ▼               ▼               ▼
         ┌────────┐      ┌────────┐      ┌──────────┐
         │ Solid  │      │ Liquid │      │ Gaseous  │
         └────────┘      └────────┘      └──────────┘
              ▼               ▼               ▼
    ┌──────────────┐  ┌──────────────┐  ┌──────────────┐
    │ i) Wood      │  │ i) Methanol  │  │ i) Biogas    │
    │ ii) Straw    │  │ ii) Ethanol  │  │ ii) Methane  │
    │ iii) Refuse  │  │ iii) Biodiesel│ │ iii) Fuel gas│
    │              │  │ iv) Vegetable│  │              │
    │              │  │    oils      │  │              │
    └──────────────┘  └──────────────┘  └──────────────┘
```
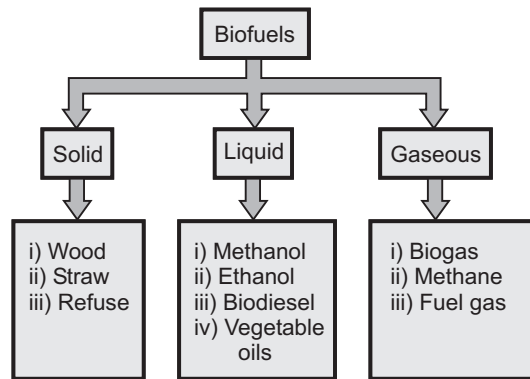
**Fig. 1.8 : Types of biofuels**

### i) Wood

- Wood chips and saw dust are used for domestic heating.
- Also used to provide process heat in timber and furniture industries.

### ii) Straw

- Straws are used to provide heat for crop drying and space and water heating.
- Straw burning stoves and furnaces are most commonly used now-a-days.

### iii) Refuse

- Municipal refuse can be dried, sorted and shreadded and then burnt to provide heat and power.
- Refuse derived fuels can be burnt directly or combined with other fuels such as oil or coal.

### iv) Methanol and Ethanol

- Bioethanol and methanol are alchohols made by fermentation process of carbohydrates produced from crops like corn, sugarcane, wheat, etc.
- Ethanol can be used in petrol engines as a replacement for gasoline.
- It can be blended with gasoline upto any percentage.
- It requires minor engine modifications for blends containing more than 20 % alchohol.

### v) Biodiesel

- It is the most commonly used biofuel and it is similar to the fossil diesel in composition.
- It is produced from animal fats, vegetable oils, soy, mustard, sunflower, palm oil, etc.

- Biodiesel can be used in any diesel engine when mixed with mineral diesel.

### vi) Vegetable oils

- Vegetable oil fuels can be used in unmodified diesel engines.
- They can be blended or used directly in tractors and other agriculture equipments.

### vii) Biogas

- Biogas is a mixture of methane and $CO_2$.
- It can be used as fuel in stationary engines and turbines to generate heat and mechanical or electrical energy.
- This can be used in space and water heating and cooking purpose.

### viii) Methane

- Methane is a clean gas with higher calorific value.
- It can be compressed to use in vehicles like tractors and fork-lift trucks.

### iv) Fuel gas

- Fuel gas is produced from thermal degradation of biomass.
- It is used at sites to provide heat and energy or converted into more useful biofuels such as methane and methanol.

## 1.11.2 Comparison between Biofuels and Petroleum Fuels

| Sr. No. | Biofuels | Petroleum fuels |
|---|---|---|
| 1. | Biofuels do not release as much carbon as petroleum fuels and are less toxic. | Petroleum fuels give off toxic emissions and green house gases emissions. |
| 2. | Bio-fuels are renewable source of energy. | Petroleum fuels are non renewable source of energy. |
| 3. | Biofuels are biodegradable as they are made out of organic substances. | Petroleum fuels are not biodegradable and affect the environment badly. |
| 4. | Biofuels have low calorific or heating value than petroleum fuel. | Petroleum fuels have higher calorific value. |
| 5. | Production of biofuels is not as much dangerous as petroleum fuels. | Production of petroleum fuels in the earth's crust is dengerous. |

## Review Questions

1. *Explain in brief sources of energy.*

2. *Define renewable and non-renewable sources of energy.*

3. *Classify various petroleum based fuels.*

4. *Write short note on calorific value of fuels.*

5. *Explain the combustion of fuels and combustion products of various combustible elements.*

6. *Define the following terms :*

   *i) Solar radiation ii) Solar constant*

7. *What is solar energy harvesting ? Show how the solar energy is converted into the electricity.*

8. *List various solar energy harvesting devices. Explain any one of them.*

9. *Write short note on :*

   *i) Liquid flat plate collector*

   *ii) Solar ponds*

10. *Explain the concept of solar photovoltaics.*

11. *What are the advantages of wind energy ? Explain simple modern wind mill with neat sketch.*

12. *Explain working of solar-wind hybrid power plant.*

13. *Write short note on :*

    *i) Hydroelectric power plant*

    *ii) Nuclear power plant*

14. *What are the biofuels ? Give their advantages and disadvantages.*

15. *Explain the use of biofuels in engineering applications.*

16. *Differentiate between biofuels and petroleum based fuels.*

## 1.12 Multiple Choice Questions with Answers

**Q.1** _____ is the non renewable energy resource

| | |
|---|---|
| a) Solar | b) Methane |
| c) Hydroelectric | d) Coal **[Ans. : d]** |

**Q.2** Solar energy source is a _____ source of energy. ☞ **[ June 2010 ]**

    a) non-conventional          b) conventional

    c) mechanical                d) electrical          **[Ans. : a]**

**Q.3** Energy resources derived from natural organic materials are called as _____.

    a) geothermal energy sources     b) fossil fuels

    c) biomass                 d) all of these         **[Ans. : c]**

**Q.4** Solar energy stored in materials such as wood, grains, sugar and municipal waste is called as _____ .

    a) fossil fuels               b) biomass

    c) natural gas              d) geothermal energ     **[Ans. : b]**

**Q.5** The world faces an energy crisis because _____ .

    a) increasing demand for energy

    b) world oil production is at peak and begin to decline

    c) shortages and resulting rising of prices can shock the economic order

    d) all of the above                         **[Ans. : d]**

**Q.6** Fossil fuels are _____ .             ☞ **[ June 2012 ]**

    a) solid fuels               b) liquid fuels

    c) gaseous fuels            d) all of these         **[Ans. : d]**

**Q.7** Which of the energy sources does not produce carbon dioxide ?

    a) Oil                   b) Uranium

    c) Coal                  d) Natural gas       **[Ans. : b]**

**Q.8** Which of the following problems associated with the burning of coal ?

    a) $CO_2$ emissions         b) Ash with toxic impurities

    c) Acid rain               d) All of these        **[Ans. : d]**

**Q.9** In Fig. 1.9, layer A shows _____.
(See Fig. 1.9 on next page)

    a) anthracite             b) bituminous

    c) lignite                d) tar               **[Ans. : c]**
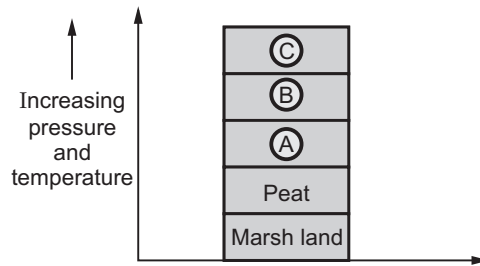
**Fig. 1.9**

**Q.10** In Fig. 1.9, layer B indicates _____ .

    a) anthracite                           b) bituminous

    c) lignite                                d) tar                    **[Ans. : b]**

**Q.11** In Fig. 1.9, layer C indicates _____ .

    a) anthracite                           b) bituminous

    c) lignite                                d) tar                    **[Ans. : a]**

**Q.12** As the pressure and temperature increases in Fig. 1.9, _____ of coal also increases.

    a) heating value                   b) carbon content

    c) metamorphism                d) all of the above      **[Ans. : d]**

**Q.13** The primary processes of solar energy are _____ process.   ☞ **[ Dec. 2012 ]**

    a) heliochemical                  b) helioelectrical

    c) heliothermal                     d) all of these         **[Ans. : d]**

**Q.14** Solar constant is approximately _____ .

    a) $1.4 \text{ kW/m}^2$                  b) $1.4 \text{ W/m}^2$

    c) $140 \text{ W/m}^2$                   d) $1.4 \text{ MW/m}^2$      **[Ans. : a]**

**Q.15** _____ is not a source of biomass.

    a) Gobar gas                      b) Coal

    c) Wood                           d) Nuclear fuel         **[Ans. : d]**

**Q.16** _____ energy is not derived from the sun.

    a) Biomass                         b) Fossil fuels

    c) Nuclear energy                d) Geothermal energy      **[Ans. : c]**

**Q.17** Harmful radiations emitted by sun are called as _____ radiations.

a) visible                                  b) ultraviolet

c) infrared                                 d) radio waves                    **[Ans. : b]**

**Q.18** _____ is a substance that produces large amount of heat after burning.

a) Biogas                                   b) Biomass

c) Fossil fuels                             d) Oxidising agent                **[Ans. : c]**

**Q.19** _____ causes the less pollution after burning.

a) Natural gas                              b) Petrol

c) Diesel                                   d) Coal                           **[Ans. : a]**

**Q.20** A solar cell is made up of _____ .

a) titanium                                 b) chromium

c) teflon                                   d) silicon                        **[Ans. : d]**

**Q.21** A solar cell converts _____ .

a) solar energy into mechanical energy      b) heat energy into light energy

c) solar energy into electrical energy      d) none of these                  **[Ans. : c]**

**Q.22** Source of energy of the sun is _____ .

a) nuclear fusion                           b) chemical reaction

c) nuclear fission                          d) PV effect                      **[Ans. : a]**

**Q.23** Source of energy at the nuclear power plant is _____ .

a) nuclear fusion                           b) chemical reaction

c) nuclear fission                          d) PV effect                      **[Ans. : c]**

**Q.24** The fuel used in the nuclear reactor is _____ .

a) cadmium                                  b) uranium

c) bromium                                  d) helium                         **[Ans. : b]**

**Q.25** The devices that recover the solar thermal energy and convert it into the the electricity are _____ .

a) energy harvesting devices                b) generators

c) inverters                                d) all of these                   **[Ans. : a]**

**Q.26** _____ is the solar energy harvesting device.

    a) Liquid flat plate collector        b) Solar ponds

    c) Solar air heaters               d) All of these        **[Ans. : d]**

**Q.27** In Fig. 1.10 layer (A) shows _____.
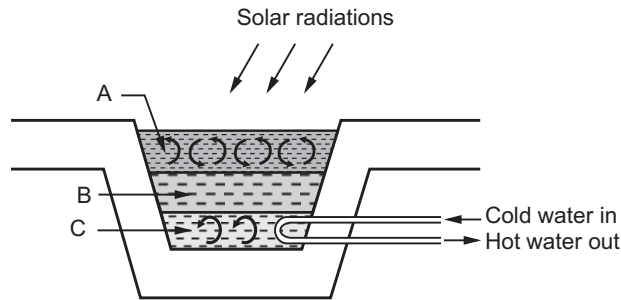


**Fig. 1.10**

    a) insulation zone              b) storage zone

    c) surface zone                d) none of these       **[Ans. : c]**

**Q.28** In Fig. 1.10 layer (B) shows _____.

    a) insulation zone              b) storage zone

    c) surface zone                d) none of these       **[Ans. : a]**

**Q.29** In Fig. 1.10 layer (C) shows _____.

    a) insulation zone              b) storage zone

    c) surface zone                d) none of these       **[Ans. : b]**

**Q.30** Insulation zone in solar pond is _____ zone.

    a) convective                   b) non-convective

    c) conduction                  d) water rising        **[Ans. : b]**

**Q.31** In solar ponds _____ act as source of heat.

    a) insulation zone              b) storage zone

    c) surface zone                d) none of these       **[Ans. : b]**

**Q.32** Hydroelectric power plant converts _____.

    a) kinetic energy of water to electrical energy

    b) potential energy of water to electrical energy

    c) heat energy of water to electrical energy

    d) none of these        **[Ans. : b]**

**Q.33** Wind energy is _____ form of solar energy.

    a) primary                               b) direct

    c) indirect                              d) none of these       **[Ans. : c]**

**Q.34** Biofuels contains energy due to _____ .

    a) carbon fixation                    b) photosynthesis

    c) thermal degradation           d) none of these       **[Ans. : a]**

## 1.13 University Questions with Answers

### June 2010

**Q.1** List various sources of energy with minimum two examples of each.
**(Refer section 1.1)**                                                     **[6]**

### Dec. 2011

**Q.2** Differentiate between renewable and non-renewable sources of energy.
**(Refer section 1.1)**                                                     **[6]**

### June 2012

**Q.3** List any four sources of energy with suitable examples. **(Refer section 1.1)**     **[4]**

### June 2013

**Q.4** Differentiate between renewable and non-renewable sources of energy.
**(Refer section 1.1)**                                                     **[6]**

*Energy Resources ends ...*

# Module - I

## Chapter - 2

# STEAM FORMATION AND PROPERTIES

**Syllabus :** Classification of boilers, Lancashire boiler, Babcock and Wilcox boiler, Boiler mountings and accessories (No sketches for mountings and accessories), Wet steam, Saturated and superheated steam, Specific volume, Enthalpy and internal energy. (No numerical problems in this module).

| Section No. | Topic Name |
|---|---|
| 2.1 | Boilers |
| 2.2 | Package Boilers |
| 2.3 | Boiler Mountings and Accessories |
| 2.4 | Formation of Steam |
| 2.5 | Conditions of Steam |
| 2.6 | Properties of Steam |
| 2.7 | Mulitiple Choice Questions with Answers |
| 2.8 | University Questions with Answers |

## 2.1 Boilers

- **Boiler** or **steam generator** is a closed pressure vessel used for generation of steam under high pressure.
- This steam is mainly used for power generation, process heating and space heating purposes.
- A boiler is commonly made of steel in which the chemical energy of fuel is converted into heat by the combustion process. This heat energy is transferred to water so as to produce steam.
- The design of boilers is very complicated and depends on the type of fuel used and its power (capacity).

## 2.1.1 Classification of Boilers

The boilers may be classified as follows :

### 1. According to the relative position of water and flue gases

**a) Water tube boilers :** In these boilers, the water passes through the tubes and flue gases pass through the external surface of the tubes.

*For example :* Babcock-Wilcox, La-mont, Benson and Package boilers.

**b) Fire tube boilers :** In these boilers, the flue gases are passed through the tubes and the tubes are surrounded by the water.

*For example :* Cochran, Lancashire and Locomotive boilers.

### 2. According to the method of furnace

**a) Externally fired boilers :** In these boilers, the furnace is placed outside the boiler shell.

*For example :* All water tube boilers.

**b) Internally fired boilers :** In these boilers, the furnace is placed inside the boiler shell.

*For example :* All fire tube boilers.

### 3. According to the method of water circulation

**a) Natural circulation boilers :** In these boilers, the water is circulated by natural convection which is set up due to heating of water. Due to temperature gradient water flows from high density region to low density region.

*For example :* Babcock and Wilcox boiler.

**b) Forced circulation boilers :** In these boilers, the water is circulated by using a pump driven by motor.

*For example :* La-mont and Benson boilers.

**4. According to the use**

**a) Stationary boilers :** These type of boilers are commonly used in industries, power plants, etc. for power generation.

*For example :* Lancashire and Babcock-Wilcox boilers.

**b) Mobile boilers :** These boilers are used in ships, locomotives, etc. because they continuously move from one place to another place.

*For example :* Locomotive boilers.

**5. According to the axis of shell**

**a) Vertical boilers :** In these boilers the axis of shell is vertical.

*For example :* Cochran boilers.

**b) Horizontal boilers :** In these boilers, the axis of shell is horizontal.

*For example :* Lancashire and Locomotive boilers.

**6. According to the pressure of steam generated**

**a) Low pressure boilers :** When the pressure of generated steam is below 25 bar, then it is called as low pressure boiler.

*For example :* Cochran, Lancashire and Locomotive boilers.

**b) High pressure boilers :** When the pressure of generated steam is above 25 bar and upto 160 bar then it is called as high pressure boiler.

*For example :* La-mont and Loeffler boilers.

**7. According to the heat source**

a) Heat is generated due to combustion of solid, liquid and gaseous fuels.

b) Waste heat from other processes or nuclear energy.

## 2.1.2 Requirements of a Good Boiler

A good boiler must possess the following qualities :

- The boiler should be capable to generate steam at the desired pressure and quantity in minimum possible time with minimum fuel consumption.
- The boiler should be light in weight and it should occupy less floor area.
- The boiler must be able to meet the fluctuating demands without fluctuations in pressure.
- All the boiler parts should be easily accessible or approachable for cleaning and inspecation.
- The boiler should be leak proof.
- It should have simple installation with minimum time and manpower.
- It should start quickly.
- There should be no deposition of mud and foreign materials on heated surface because it affect the efficiency of boiler.

- The design of boiler should allow high heat transfer rates with minimum pressure drop by providing high velocity of water and flue gases.
- The initial cost, installation cost and maintenance cost of boiler should be minimum.
- The boiler should confirm to the safety regulations as per the *Indian Boiler Act (IBA) 1923.*

### 2.1.3 Selection Criteria of a Boiler

While selecting a boiler for a particular application the following factors should be considered :

- Pressure and steam generation rates.
- Available floor space.
- Quality of generated steam.
- The availability of fuel and water.
- The requirement of power.
- Erection facilities.
- The cost of operation, installation and maintenance.

## 2.2 Package Boilers

- Package boilers are widely used in the pharmaceutical industries, food industries and ceramic industries.
- These boilers require less fuel and electricity for their operation.
- If the oxygen concentration in the flue gases is reduced then these boilers operate more efficiently.
- But, insufficient oxygen causes incomplete combustion which results in increased smoke emission.
- The typical package boiler is either *water tube* or *fire tube* with a capacity of 5 to 25 tonns/hr steam generation capacity.
- The most commonly used fuels for these boilers are heavy oil, light oil or gas.

**Fire tube package boiler**

- A fire tube boiler is a boiler in which hot gases from a fire pass through one or more tubes running through a sealed container of water.
- The heat of these gases is transferred through the walls of the tubes by thermal conduction hence heating the water and ultimately creating the steam. Refer Fig. 2.1.
- These type of boilers are commonly used in locomotives, marine applications, rockets, etc.
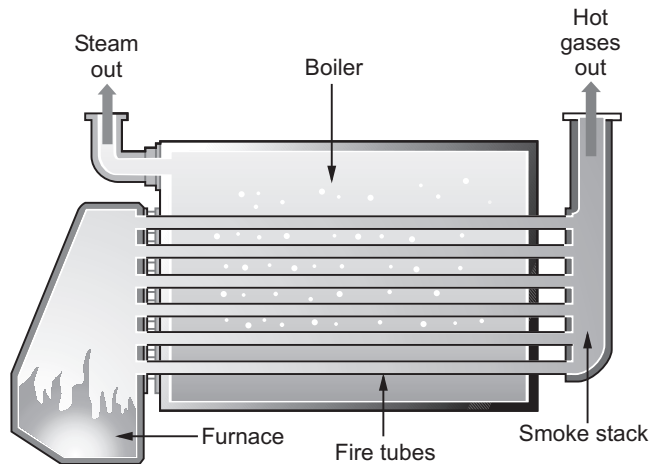
**Fig. 2.1 : Fire tube package boiler**

- Cornish boiler, Lancashire boiler, Locomotive boiler, Vertical boiler are the types of fire tube boiler.

- In these boilers, the fuel is burnt in a firebox to produce hot combustion gases.

- The firebox is surrounded by a cooling jacket of water connected to the long, cylindrical boiler shell.

- The hot gases are directed along a series of fire tubes that penetrate the boiler and heat the water, in this way generating wet steam.

- Sometimes, this steam is passed through the superheater to dry the steam or superheat the steam.

**Water tube package boiler**

- A water tube boiler is a type of boiler in which water circulates in tubes heated externally by the fire.

- In these boilers, fuel is burned inside the furnace, creating hot gas which heats water in the steam generating tubes.

- In small boilers additional generating tubes are separate in the furnace while in large boilers water filled tubes make up the walls of the furnace to generate the steam. Refer Fig. 2.2.

- The heated water then rises into the steam drum where saturated steam is drawn off the top of the drum.

- In some cases, the steam will pass through the superheater to become superheated.

- Cool water at the bottom of the steam drum returns to the feedwater drum through down-comer tubes, where it pre-heats the feedwater supply.
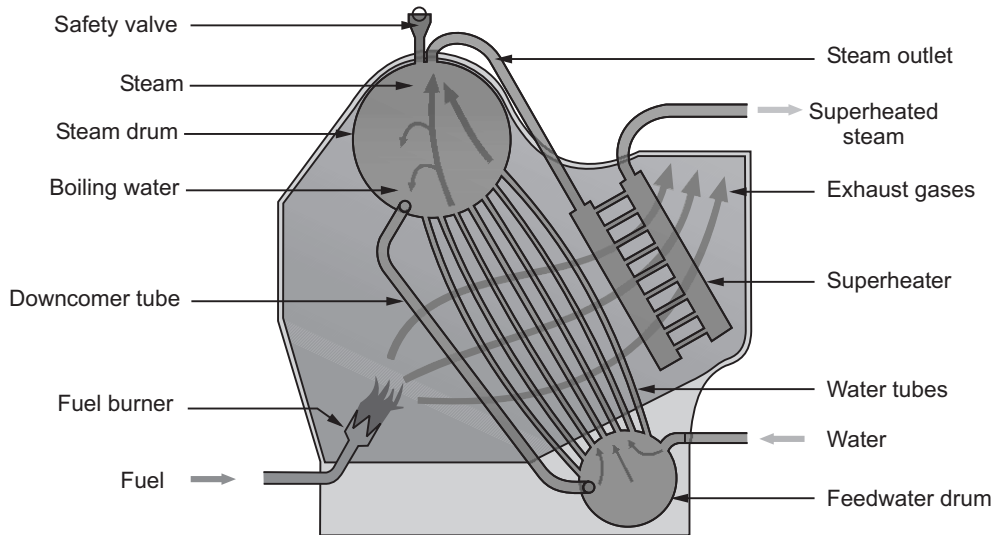
**Fig. 2.2 : Water tube package boiler**

- These boilers are used for power generation, sugar industry, textile industry, food processing plant, marine applications, locomotives, etc.

- Babcock-Wilcox boiler, La-mont boiler, Benson boiler are the types of water tube boiler.

## 2.2.1 Lancashire Boiler                    ☞ **[ June 2010, Dec. 2012 ]**

- Lancashire boiler is a fire tube boiler as the hot flue gases flows inside the tube and the water flows around these tubes.

- It is stationary, internally fired and natural circulation type of boiler.

- Its shell consist of the brick work as shown in Fig. 2.3.

- This boiler consist of a cylindrical shell and two large tubes are passed through this shell.

- The brick work forms the channels for flow of flue gases known as bottom flue and side flue passage.

- The grate is provided at the front end of the flue tube and the coal is fed to grate through the fire doors.

- A brick bridge arch is provided at the end of grate to avoid the coal and ash particle to pass through the fire tubes.

- This helps in preventing deposition of particles on the wall of fire tubes and enhance the heat transfer rate.

- The hot flue gases passed through the flow channels from the side and bottom of the boiler and transfers the heat to the water which converts it into the steam.
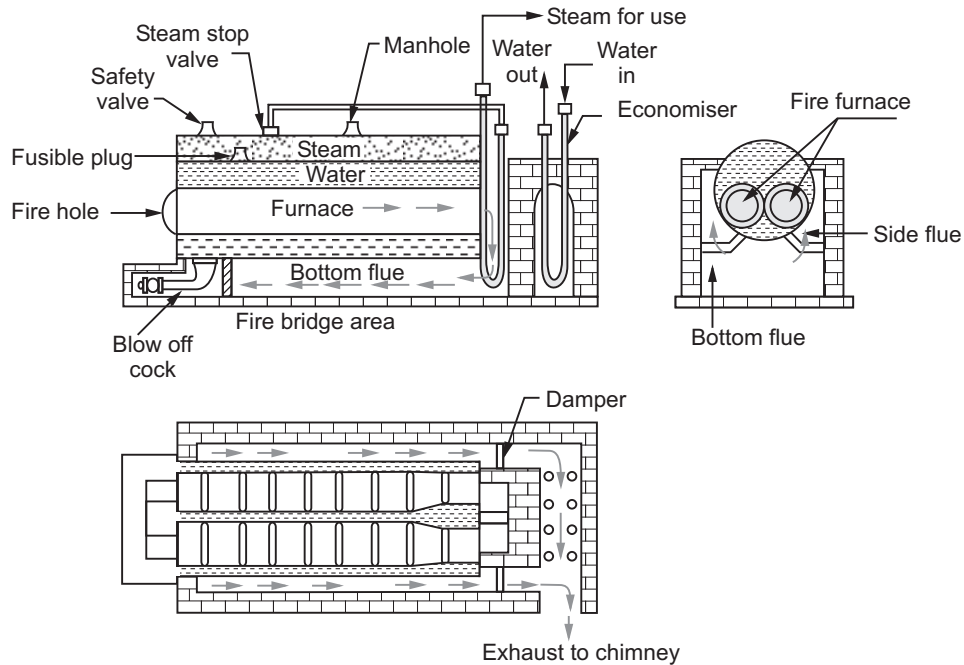
**Fig. 2.3 : Lancashire Boiler**

- Dampers are provided at the end of the fire tubes to control the flow of gases and to regulate the combustion.
- The superheater and the economiser are easily fitted in the lancashire boiler system.
- The superheater is placed at the end of main flue tube so that the flue gases can passed over the superheater before entering the bottom flow passage.
- The evaporative capacity of this boiler is upto 10000 kg/h and operating pressure is upto 15 bar.

**Advantages of Lancashire Boiler**
- Good evaporation quality.
- Inferior quality of coal can be used as a fuel.
- Heating surface area per unit volume is large.
- Easy maintenance.
- Efficiency is high (upto 80 - 85 %)
- Load fluctuations can be easily met.

**Disadvantages of Lancashire Boiler**
- It requires large space.
- Large amount of material and labour requires for boiler construction.

- Due to repeted heating and cooling, there is resultant expansion and contraction. This results in upsetting the brickwork and hence infiltration of air.

- Slow steam generation.

**Applications of Lancashire Boiler**

- Processing agent in textile, paper, sugar and chemical industries.

- To drive steam turbines, locomotives and marine applications.

## 2.2.2 Babcock and Wilcox Boiler ☞ **[ Dec. 2010, June 2012 ]**

- Babcock and Wilcox boiler is a water tube boiler as the water is inside the tubes and hot flue gases flows over the tubes.

- Fig. 2.4 shows the schematic diagram of Babcock and Wilcox boiler with its different functional parts.
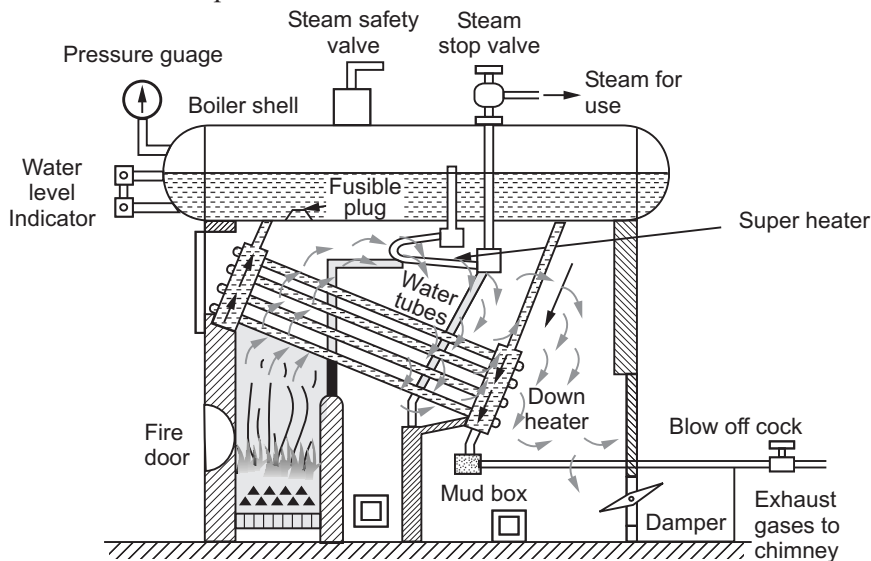
**Fig. 2.4 : Babcock and Wilcox Boiler**

- The boiler shell consist of high quality of steel and is placed longitudinally. It is known as water and steam drum. The water level in the drum should be kept slightly above the center.

- The drum is connected by short tubes with uptake header and by long tubes with downtake header.

- A series of water tubes are connected to the uptake and downtake header at an angle of 15° to horizontal. This inclined position helps to make water flow.

- The grate is arranged below the uptake header. The fuel is supplied to grate through fire door. The fuel is burnt and forms hot flue gases.

- These flue gases are force to move in a specific path over the water tube due to baffle arrangement.

- The heat is transferred from hot flue gases to the water tubes and bottom cylindrical surface of the drum.

- The water flow is set due to the density difference in the water.

- The portion of water tubes at uptake header is subjected to the high temperature hot gases so the temperature of the water in this section rises due to decreased density and it flows to the drum via uptake header.

- Simultenously the water enters into tubes through downtake header and flow of water sets.

- The water and steam are seperated in the drum and as the steam is lighter it is collected in the upper portion of drum.

- To improve the quality of steam the superheater is placed between water drum and tubes.

- The steam formed in the drum is passed through the superheater and it becomes superheated.

- This superheated steam is then supplied to the turbine for electricity generation.

- The evaporative capacity for this boiler is upto 40000 kg/hr and operating pressure is 11 to 17 bar.

## 2.3  Boiler Mountings and Accessories

☞ **[ June 2011, June 2013, Dec. 2013 ]**

**Boiler mountings**

- For the operation and safety of the boiler different fittings and devices are necessary. These devices are called as **boiler mountings**.

- For example : Safery valve, feed check valve, water level indicator, steam stop valve, etc.

- Table 2.1 gives function and location of various boiler mountings :

**Table 2.1 : Location and function of various boiler mountings**

| Sr. No. | Boiler mounting | Location | Function |
|---------|-----------------|----------|----------|
| 1. | Bourdon's pressure gauge | It is attached on the upper part of the front end plate. | It is used to indicate the steam pressure in the boiler. |
| 2. | Safety valves | It is attached on the top of front end plate. | It is used to release the excess steam when the steam pressure inside the boiler exceeds. |

| | | | |
|---|---|---|---|
| 3. | Water level indicator | It is attached to the lower part of front end plate. | It is used to indicate the water level inside the boiler. |
| 4. | Fusible plug | It is fitted over the crown of the furnace or over the combustion chamber. | It is used to put off the fire in the furnace of boiler when the water level falls below unsafe level. |
| 5. | Feed check valve | It is fitted to the shell below the water level of the boiler. | It is used to allow the supply of water at high pressure to the boiler and prevent the back flow of water. |
| 6. | Blow-off cock | It is fitted to the lowest part of the boiler shell. | It is used to empty the boiler for cleaning, repair and inspection. It is also used to discharge the mud and sediments carried with the feed water. |
| 7. | Steam stop valve | It is fitted to the highest part of the boiler shell. | It is used to regulate the flow of steam from the boiler to the engine and shut off the steam flow when not required. |

**Boiler accessories**

- The auxillary parts which are used to increase the overall efficiency of the plant are called as **boiler accessories.**
- For example : Economiser, air-preheater, water feeding equipment, superheater, etc.
- Table 2.2 gives the function and location of various boiler accessories :

**Table 2.2 : Location and function of various boiler accessories**

| Sr. No. | Boiler accessory | Location | Function |
|---|---|---|---|
| 1. | Economiser | It is fitted at the passage of flue gases from the boiler to chimney. | It extracts the waste heat of the chimney gases to preheat the water before feeding into the boiler. This reduces fuel consumption. |
| 2. | Air-preheater | It is placed after the economiser and before the gases enter the chimney. | It extracts the waste heat of the flue gases and pre-heat the air supplied to the combustion chamber. It reduces fuel consumption. |

| 3. | Superheater | It is fitted in the path of flue gases flowing to the chimney. | It is used to increase the temperature of the steam above its saturation temperature by passing the steam through a small set of tubes and hot gases over them. |
|----|-------------|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## 2.4  Formation of Steam

- Steam produced form the water act as working fluid for the thermal power plant.

- Formation of steam from ice at constant pressure is shown in Fig. 2.5 on a temperature enthalpy (T - h) diagram.
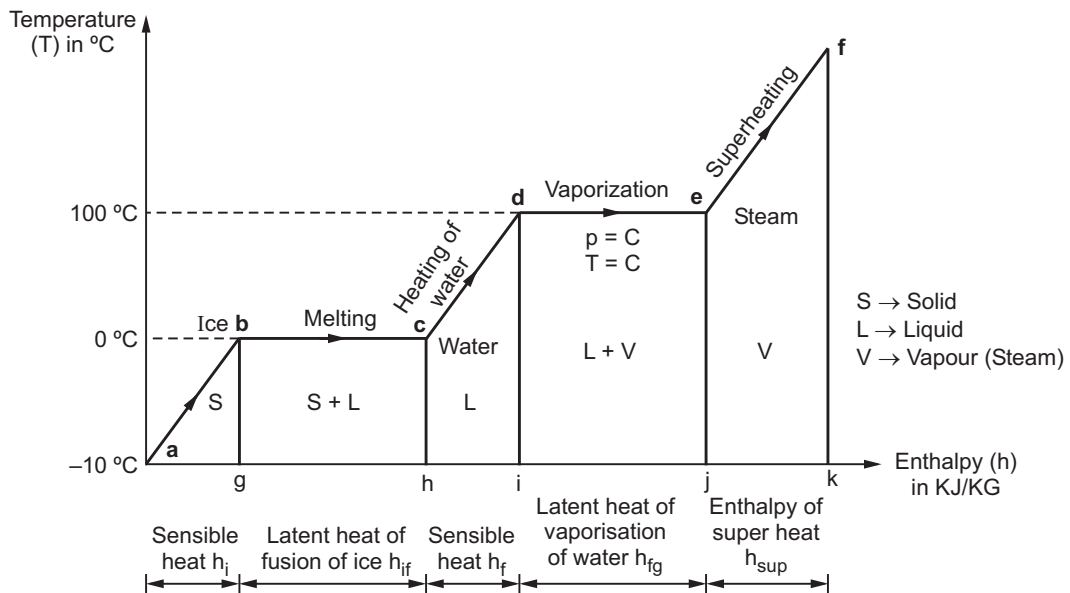


**Fig. 2.5 : Graphical representation of steam formation process**

- **Process AB :** As heat is supplied, temperature of ice increases from $-15°$ C till it reaches $0°$ C. This is the sensible heating of ice.

- **Process BC :** On further addition of heat, melting of ice takes place at constant temperature till the complete ice melts. The amount of heat added is latent heat of fusion or enthalpy of fusion.

- **Process CD :** Further heat addition after point C causes the increase in temperature of water upto 100 ºC. Water at point D is saturated liquid and this process of heating is sensible heating of water.

- **Process DE :** This process shows the complete conversion of water to steam and amount of heat added is known as latent heat of vaporisation or enthalpy of vaporisation ($h_{fg}$). This heat is added at constant temperature.

- **Process EF :** This process represents the superheating of steam. The heat is being added to improve the quality of steam. The temperature of steam is raised above the 100 ºC.

## 2.5 Conditions of Steam                    ☞ [ June 2011, June 2013 ]

**1. Wet steam**

- Wet steam can be defined as the mixture of vapour (steam) and water particles at saturated temperature.

- The amount of water particles suspended in the steam can be found out by knowing the dryness fraction of steam.

- The dryness fraction of steam (x) is given by,

$$x = \frac{\text{Mass of dry saturated steam}}{\text{Mass of mixture}} = \frac{m_g}{m_f + m_g}$$

where,           $x$ = Dryness fraction of steam.

                $m_g$ = Mass of dry steam in mixture.

                $m_f$ = Mass of water in mixture.

- Dryness fraction gives the quality of mixture.

- For example, if the dryness fraction of steam is 0.8 then it contains 80 % dry steam and 20 % water particles.

**2. Dry saturated steam**

- When the water is completely converted into the steam and the steam does not contain any water particle it is known as dry saturated steam.

- For dry saturated steam, the dryness fraction (x) is equal to 1.

**3. Superheated steam**

- If the dry saturated steam is furthur heated above the 100 ºC then the steam becomes superheated steam.

- In this process, the phase remains same as gaseous state but the heat is added in the steam.

## 2.6 Properties of Steam

- For any fluid which is used as a working fluid, the basic thermodynamic properties such as pressure, temperature, specific volume, internal energy, enthalpy and entropy at various state are necessary to analyse the thermodynamic cycle.
- Following are the properties of steam at various conditions :

### 1) Specific volume of wet steam

- Specific volume is defined as the volume of substance per unit mass or it is the reciprocal of the density.
- It is denoted by 'v' and is given by,

$$v = \frac{1}{\rho}$$

where,     $v$ = Specific volume and $\rho$ = Density

- The specific volume of wet steam is,

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

- As the specific volume of liquid is negligible than the specific volume of saturated steam in wet steam we can write,

$$v = x \cdot v_g$$

### 2) Specific volume of superheated steam

- At superheated state, steam behaves like a gas hence the specific volume of superheated steam is given by Charl's law

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

where,     $v_g$ = Specific volume of saturated steam

$v_{sup}$ = Specific volume of superheated steam

$T_s$ = Temperature of saturated steam

$T_{sup}$ = Temperature of superheated steam

### 3) Enthalpy of evaporation

- Enthalpy of evaporation is defined as the amount of heat energy required for complete conversion of saturated liquid into dry saturated steam.
- It is denoted by $h_{fg}$ and its value can be found out in steam table at given pressure.

**4) Enthalpy of dry saturated steam**

- It is defined as the amount of heat energy required to convert 1 kg of water at $0°$ C to the dry saturated steam.

- It is denoted by $h_g$ and is given by,

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

where,    $h_g$ = Enthalpy of dry saturated steam in kJ/kg

$h_f$ = Enthalpy of water (4.187 kJ/kg K)

$h_{fg}$ = Enthalpy of evaporation in kJ/kg

**5) Enthalpy of superheated steam**

- On further heating of dry saturated steam, the temperature of steam will increase and hence the enthalpy, also increases

- The enthalpy of superheated steam is given by,

$$h_{sup} = h_g + C_p \ (T_{sup} - T_s) \qquad \qquad \dots (2.1)$$

where,    $h_{sup}$ = Enthalpy of superheated steam

$h_g$ = Enthalpy of dry saturated steam

$T_{sup}$ = Temperature of superheated steam

$T_s$ = Temperature of saturated steam

$C_p$ = Specific heat of superheated steam

= 2 kJ/kgK to 2.73 kJ/kgK

**6) Internal energy of steam**

- Internal energy is defined as the amount of energy stored in the steam.

- The total heat supplied during the heating is partly used for the evaporation work and the remaining energy is stored in the steam. It is given as,

$$h = u + W_e = u + p \cdot v$$

- Therefore, internal energy is given by,

$$u = h - p \cdot v \qquad \qquad \dots (2.2)$$

where,    $u$ = Internal energy

$h$ = Enthalpy of the system

$W_e$ = $p \cdot v$ = Evaporation work

## Review Questions

1. *What is boiler ? Explain detail classification of boilers.*

2. *What are the requirements of good boiler ?*

3. *Explain the selection criterion for a boiler.*

4. *Write short note on following package boilers :*

    *i) Fire tube package boiler      ii) Water tube package boiler.*

5. *With neat sketch explain the working of Lancashire boiler.*

6. *Explain in brief Babcock and Wilcox boiler.*

7. *Explain the stages in the formation of steam.*

8. *Write short note on various conditions of steam.*

9. *Explain the following properties of steam :*

    *i) Specific volume      ii) Enthalpy of steam at various conditions*

    *iii) Internal energy.*

## 2.7 Mulitiple Choice Questions with Answers

**Q.1**    ___ is an externally fired boiler.

   a) Babcock and Wilcox          b) Lancashire

   c) Cochran                     d) All of the above          **[Ans. : a]**

**Q.2**    ___ is a vertical boiler.

   a) Babacock and Wilcox         b) Lancashire

   c) Cochran                     d) All of hte above          **[Ans. : c]**

**Q.3**    _____ is a natural circulation boiler.

   a) Babcock and Wilcox          b) Lancashire

   c) Cochran                     d) All of hte above          **[Ans. : a]**

**Q.4**    Safety valves are mounted on the _____.

   a) upper part of front end plate      b) top of front end plate

   c) lower or part of front end plate   d) none of the above   **[Ans. : b]**

**Q.5**    Water level indicator is mounted on the _____.

   a) upper part of front end plate      b) top of front end plate

   c) lower part of front end plate      d) none of the above   **[Ans. : c]**

**Q.6** Fusible plug is located _____.

a) upper part of front end plate      b) top of front end plate

c) lower part of front end plate      d) none of the above      **[Ans. : d]**

**Q.7** Function of steam stop valve is _____.

a) to regulate the flow of steam from boiler to engine

b) shut off the steam flow when not required

c) to release the excess steam when required

d) both a) and b)      **[Ans. : d]**

**Q.8** _____ is used to extract the waste heat of flue gases and pre-heat the air supplied to combustion chember.

a) Economiser      b) Fusible plug      c) Superheater      d) Air-preheater

     **[Ans. : d]**

**Q.9** _____ is used to reduce fuel consumption.

a) Economiser      b) Air-preheater      c) both a) and b)      d) none of these

     **[Ans. : c]**

**Q.10** Which of the following is not a boiler mounting ?

a) Safety valves      b) Fusible plug      c) Economiser      d) Both a) and b)

     **[Ans. : c]**

**Q.11** Actual energy stored in steam is called as _____.      ☞ **[ Dec. 2008 ]**

a) internal latent heat      b) sensible heat

c) internal energy of steam      d) latent heat of evaporation      **[Ans. : c]**

**Q.12** Babcock and Wilcox boiler is _____ pressure boiler.      ☞ **[ Dec. 2008 ]**

a) low      b) high      c) medium      d) none      **[Ans. : b]**

**Q.13** If x is the weight of dry steam and y is weight of water in suspension, then dryness fraction is equal to _____.      ☞ **[ June 2009 ]**

a) $\dfrac{x}{x + y}$      b) $\dfrac{y}{x + y}$      c) $\dfrac{x}{x - y}$      d) $\dfrac{y}{x - y}$ **[Ans. : a]**

**Q.14** The condition of steam in boiler drum is always _____.      ☞ **[ June 2009 ]**

a) dry      b) wet      c) saturated      d) superheated

     **[Ans. : b]**

**Q.15** Lancashire boiler is of _____.  ☞ **[ June 2009 ]**

    a) stationary fire tube type      b) horizontal type

    c) natural circulation type      d) all of the above     **[Ans. : d]**

**Q.16** The function of economizer used in boiler is to _____.  ☞ **[ June 2009 ]**

    a) economise on fuel

    b) to heat feed water using exact heat from the exhaust fire gases

    c) to increase flue gas temperature      d) to increase the life of boiler. **[Ans. : b]**

**Q.17** Blow off valve is used _____.  ☞ **[ Dec. 2009 ]**

    a) to reduce steam pressure      b) to stop steam supply

    c) to remove sediments collected at the bottom of the boiler

    d) to remove extra steam from the boiler.      **[Ans. : c]**

**Q.18** Superheater is used _____.  ☞ **[ Dec. 2009 ]**

    a) inside the boiler drum      b) to convert wet steam into dry steam

    c) in the path of flue gases to increase volume of steam

    d) to increase temperature of steam above saturation temperature      **[Ans. : d]**

**Q.19** Economisers are used to _____.  ☞ **[ Dec. 2009 ]**

    a) conserve water

    b) to abosorb heat from exit gases by feed water

    c) to improve combustion of fuel      d) to convert water into steam **[Ans. : b]**

**Q.20** The sum of internal energy and work done is _____.  ☞ **[ June 2010 ]**

    a) wet steam      b) enthalpy      c) dry steam      d) superheat

    **[Ans. : b]**

**Q.21** Babcock and Wilcox boiler is an example of _____ boiler.

    ☞ **[ June 2010, Dec. 2013 ]**

    a) fire tube      b) water tube      c) air tube      d) gas tube

    **[Ans. : b]**

**Q.22** The difference between superheated temperature and the saturation temperature is called as _____.  ☞ **[ Dec. 2010 ]**

    a) sensible heat      b) latent heat

    c) amount of superheat      d) degree of superheat      **[Ans. : d]**

**Q.23** _____ is an accessory of a boiler. ☞ **[ Dec. 2010 ]**

    a) Pressure gauge          b) Safety valve

    c) Economizer            d) Feed check valve     **[An.s : c]**

**Q.24** Example of water tube boiler is _____. ☞ **[ Dec. 2010 ]**

    a) Babcock and Wilcox boiler        b) Lancashire boiler

    c) Cornish boiler                 d) Cochran boiler     **[Ans. : a]**

**Q.25** The steam heated beyond its dry saturated stage is ____. ☞ **[ June 2011 ]**

    a) dry steam               b) wet steam

    c) saturated steam           d) superheated steam     **[Ans. : d]**

**Q.26** Sensible heat is also called as ____. ☞ **[ June 2011 ]**

    a) enthalpy of saturated water       b) enthalpy of evaporation

    c) enthalpy of dry saturated water    d) enthalpy of superheated steam

                                                               **[Ans. : a]**

**Q.27** Economiser is a device used to _____. ☞ **[ June 2011 ]**

    a) heat the air feed to the furnace

    b) increase the temperature of steam above the saturation temeprature

    c) heat the feed water

    d) separate the water particles present in the steam     **[Ans. : c]**

**Q.28** Lancashire boiler is of _____. ☞ **[ June 2011 ]**

    a) fire tube type              b) stationary type

    c) horizontal type           d) all of these     **[Ans. : d]**

**Q.29** Quality of wet steam is decided by its _____. ☞ **[ Dec. 2011 ]**

    a) temperature             b) pressure

    c) dryness fraction          d) none of these     **[Ans. : c]**

**Q.30** Specific volume of superheat steam ($v_{sup}$) with usual notations is _____.

                                                       ☞ **[ Dec. 2011 ]**

    a) $= v_g \times \dfrac{T_{sat}}{T_{sup}}$     b) $= v_g \times \dfrac{T_{sup}}{T_{sat}}$     c) $= v_f \times \dfrac{T_{sat}}{T_{sup}}$     d) $= v_f \times \dfrac{T_{sup}}{T_{sat}}$

                                                                  **[Ans. : b]**

**Q.31** The water tubes in Babcock and wilcox boiler are inclined to ____.

☞ **[ June 2012 ]**

a) improve radiation heat transfer     b) improve convective heat transfer

c) accommodate the furnace     d) promote natural convection of water

**[Ans. : d]**

**Q.32** With increase in pressure, the enthalpy of dry saturated steam _____.

☞ **[ June 2012 ]**

a) increases     b) decreases     c) remains same

d) first increases and then decreases     **[Ans. : a]**

**Q.33** The specific volume of water, when heated at 0 ºC _____. ☞ **[ June 2012 ]**

a) first increases then decreases     b) first decreases then increases

c) increases steadily     d) decreases steadily     **[Ans. : c]**

**Q.34** Lancashire boiler is a _____ boiler. ☞ **[ Dec. 2012 ]**

a) water tube     b) fire tube     c) gas tube     d) air tube

**[Ans. : b]**

**Q.35** The temperature at which water starts to boil in static pressure is _____.

☞ **[ Dec. 2012 ]**

a) sensible heat     b) saturation temeprature

c) wet steam temperature     d) dry steam temperature     **[Ans. : b]**

**Q.36** Enthalpy is also called as _____. ☞ **[ June 2013 ]**

a) sufficient heat     b) insufficient heat

c) total heat     d) incomplete heat     **[Ans. : c]**

**Q.37** Steam pressure is ____ in water tube boilers. ☞ **[ June 2013 ]**

a) low     b) high     c) medium     d) absolute

**[Ans. : b]**

**Q.38** Feed check valve is a boiler mounting for ____. ☞ **[ June 2013 ]**

a) safety     b) operation     c) testing     d) security

**[Ans. : b]**

**Q.39** Partially dry steam and partially wet particles in steam called as _____.

☞ **[ Dec. 2013 ]**

a) dry steam                                    b) superheated steam

c) saturated steam                          d) wet steam                    **[Ans. : d]**

## 2.8 University Questions with Answers

**June 2010**

**Q.1** With neat sketches, explain the constructional features and operation of Lancashire boiler. **(Refer section 2.2.1)**                                                                          **[10]**

**Dec. 2010**

**Q.2** Explain with neat sketch working principle of Babcock and Wilcox boiler.
**(Refer section 2.2.2)**                                                                                            **[6]**

**June 2011**

**Q.3** Differentiate between :
i) Boiler mountings and accessories **(Refer section 2.3)**
ii) Dry saturated steam and superheated steam **(Refer section 2.5)**          **[4]**

**June 2012**

**Q.4** Describe with a neat sketch, working of a Babcock and Wilcox boiler. Indicate clearly the direction of flow of flue gases. **(Refer section 2.2.2)**                  **[8]**

**Dec. 2012**

**Q.5** With neat sketches, explain the constructional features and operation of Lancashire boiler. **(Refer section 2.2.1)**                                                                          **[10]**

**June 2013**

**Q.6** List out advantages and disadvantages of superheated steam.
**(Refer section 2.5)**                                                                                            **[4]**

**Q.7** Explain briefly air preheater, superheater and chimney with respect to boilers.
**(Refer section 2.3)**                                                                                            **[6]**

**Dec. 2013**

**Q.8** Name any four boiler mountings and give their functions.
**(Refer section 2.3)**                                                                                            **[2]**

*Steam Formation and Properties ends …*

# CHAPTER - 3

# TURBINES

**Syllabus : Steam Turbines :** Classification, Principle of operation of impulse and reaction turbines, Delaval's turbine, Parson's turbine. (No compounding of turbines).

**Gas Turbines :** Classification, Working principles and operations of open cycle and closed cycle gas turbines.

**Water Turbines :** Classification, Principles and operations of Pelton wheel, Francis turbine and Kaplan turbine.

| Section No. | Topic Name |
|:---:|:---|
| 3.1 | Steam Turbine |
| 3.2 | Gas Turbines |
| 3.3 | Hydraulic Turbines |
| 3.4 | Multiple Choice Questions with Answers |
| 3.5 | University Questions with Answers |

## 3.1 Introduction

- Power producing devices operates on a cycle and produces mechanical power output on the expense of supplied energy.

- These devices generally absorb thermal energy from the source and rejects some part of it to a sink, while doing so it produces work as per the laws of thermodynamics.

- **For example :** Boilers, Steam and Gas turbines, I.C. engines, Hydraulic turbines, etc.

- A turbine is defined as a rotary mechanical device which extracts energy from the fluid flow and converts it into useful work.

- A turbine mainly classified as steam turbine, gas turbine and hydraulic turbine.

## 3.2 Steam Turbine

- A steam turbine is a mechanical device that extracts thermal energy from pressurized steam and converts it into rotary motion.

- Steam turbine depends directly upon dynamic action of the steam.

- As per the Newton's second law of motion, the rate of change of momentum is caused in the steam by allowing high velocity jet of steam to pass over curved plate (blade) and the steam will impart a force to the blade.

- If the blade is free then it will rotate in the direction of applied force.

- The steam from the boiler is expanded in the nozzle where due to fall in pressure of steam, thermal energy of steam is converted into kinetic energy of steam.
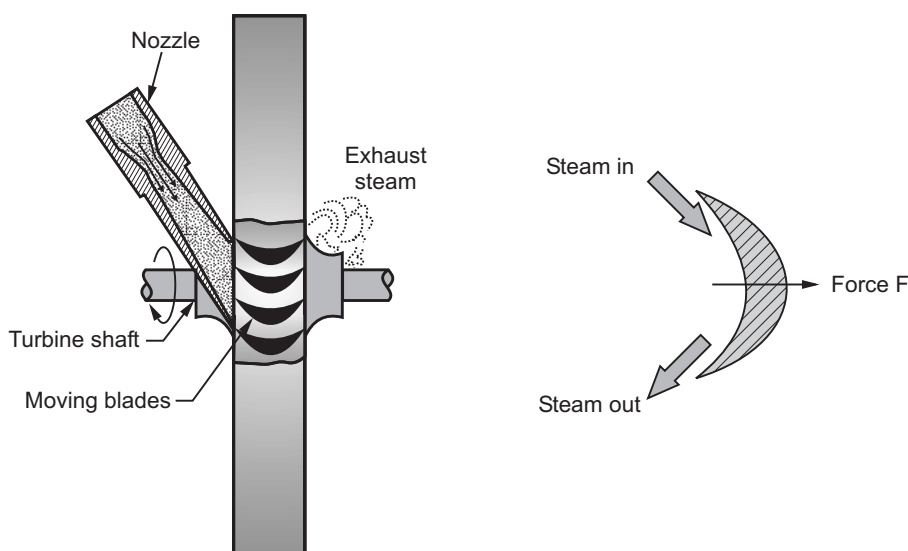


**Fig. 3.1 : Working principle of steam turbine**

- This high velocity jet of steam is impinged on the blades mounted on a shaft. Refer Fig. 3.1.

- The change in flow direction of steam causes a force to be exerted on the blades and due to rotation of these blades power is developed.

## 3.2.1 Types of Steam Turbine ☞ [ Dec. 2010, Dec. 2011, June 2013, Dec. 2013 ]

Steam turbines are mainly divided into two groups :

1. Impulse turbine (De-Laval turbine)
2. Reaction turbine (Parson's turbine)

### 1. Impulse Turbine

- In these turbines, the steam comes out at a very high vleocity through the fixed nozzle and impinges on the blades fixed on the periphery of a rotor. Refer Fig. 3.2 (a).

- The blades change the direction of the steam flow without changing its pressure.

- The resulting force due to the change in momentum causes the rotation of the turbine shaft.

- Fig. 3.2 (b) shows the blade arrangement for impulse turbine and the variation of pressure and velocity of steam passing through the turbine.

- Examples of impulse turbine are De-Laval turbine, Rateau turbine, Curties turbine.

- It is important to note that, in case of impulse turbine the shape of blades in *profile type.*

**(a) Working principle**    **(b) Arrangement of blades**
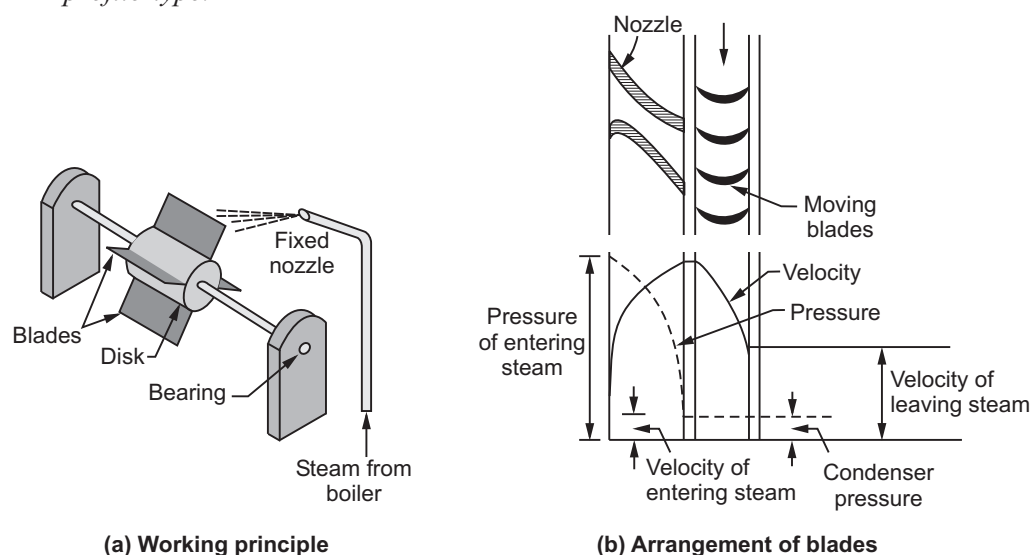
**Fig. 3.2 : Impulse turbine**

## 2. Reaction Turbine

- In these turbines, the high pressure steam from the boiler is passed through the nozzles as shown in Fig. 3.3 (a).
- When the steam comes out through these nozzles, the velocity of the steam increases relative to the rotating disc.
- This results in reacting force of the steam on nozzle which gives rotating motion to the disc and shaft.
- In these turbines steam expands both in fixed and moving blades continuously when the steam passes over them.
- Hence, pressure drop occurs gradually and continuously over both moving and fixed blades.
  For example, Parson's reaction turbine.
- Fig. 3.3 (b) shows the blade arrangement for reaction turbine and the variation of pressure and velocity of steam passing through the turbine.
- It is important to note that, in case of reaction turbine the shape of blades is *aerofoil.*



(a) Working principle        (b) Arrangement of blades
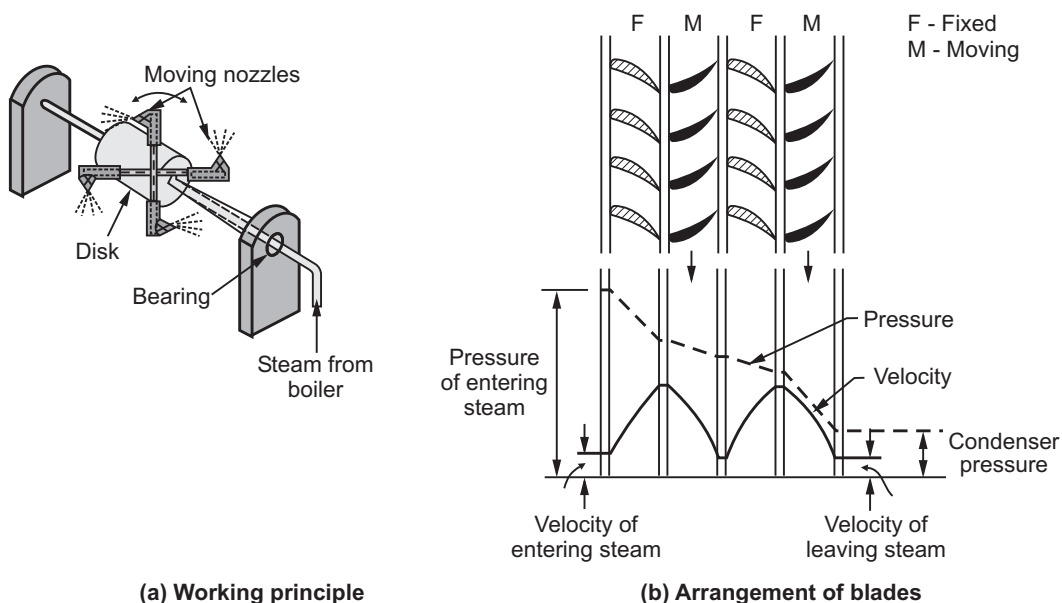
**Fig. 3.3 : Reaction turbine**

## 3.2.2 Advantages of Steam Turbine

Steam turbines offer following advantages :

- Steam turbine is highly simplified in operation and construction.
- The thermal efficiency of steam turbines is mush higher.

- It is compact and it has low weight to power ratio.
- It can operate at high speeds and greater range of speeds is possible.
- Due to absence of reciprocating parts, the vibrations and noise are greatly minimized.
- Steam turbine can take considerable over load.
- It can be designed in sizes ranging from a few kW to 1000 MW in a single unit.
- In steam turbines there is no condensation loss.
- Life of steam turbine is high.
- Initial cost, maintenance cost and installation cost are low.

### 3.2.3 Comparison between Impulse and Reaction Turbine

| Sr. No. | Impulse turbine | Reaction turbine |
|:---:|---|---|
| 1. | In these turbines, pressure drops only in nozzle and not in moving blades channel. | In these turbines, pressure drops in nozzle as well as in moving blades channel. |
| 2. | The blades are of profile shape. | The blades are of aerofoil shape. |
| 3. | Blade channel area is constant. | Blade channel area is varying. |
| 4. | By using these turbines much power cannot be developed. | Much power can be developed by using these turbines. |
| 5. | These turbines occupy less space for same power. | These tubines occupy more space for same power. |
| 6. | Velocity of steam is slightly higher. | Velocity of steam is lower. |
| 7. | Blade manufacturing is simple and less costly. | Blade manufacturing is difficult hence costly. |
| 8. | Efficiency of these turbines is low. | Efficiency of these turbines is high. |

## 3.3 Gas Turbines

- The working principle of gas turbines is almost similar to steam turbines; only the working fluid is gas instead of steam.
- Gas turbines represent the most satisfactory way of producing large quantities of power in a compact and self-contained unit.
- Sometimes, the thermal efficiency of gas turbines is increased by using a heat exchanger.

### 3.3.1 Classification of Gas Turbines ☞ **[ June 2012, Dec. 2013 ]**

Gas turbines may be classified as follows :

> 1. Constant pressure combustion gas turbine
>    a) Open cycle constant pressure gas turbine
>    b) Closed cycle constant pressure gas turbine
> 2. Constant volume combustion gas turbine

### 1. Open cycle constant pressure gas turbine

- An open cycle constant pressure gas turbine is shown in Fig. 3.4.
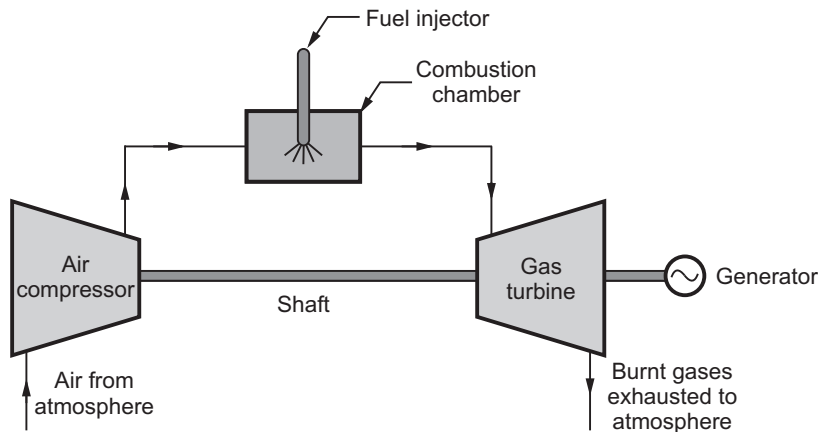


**Fig. 3.4 : Open cycle constant pressure gas turbine**

- It consists of an air compressor, combustion chamber and gas turbine.

- In these turbines, an air compressor and gas turbine are mounted on a common shaft.

- During the operation, fresh air is drawn into the compressor from the atmosphere and it is compressed to high pressure.

- This high pressure air is supplied to the combustion chamber where heat is added by injecting the fuel.

- Hence, the formed gases are allowed to expand in the turbine and it performs mechanical work by driving the turbine shaft.

- Some part of this developed power is used to run the compressor and remaining is considered as useful work.

- After expansion, the gases are exhausted to the atmosphere.

- The working fluid (mixture of air and fuel) must be continuously replaced beacuse it is exhausted to the atmosphere.

## 2. Closed cycle constant pressure gas turbine

- A closed cycle constant pressure gas turbine is shown in Fig. 3.5.
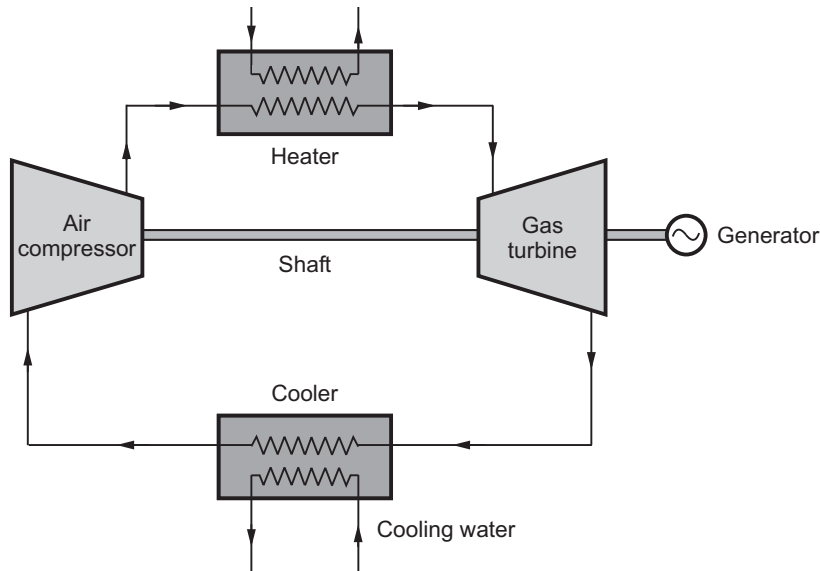


**Fig. 3.5 : Closed cycle constant pressure gas turbine**

- In addition to air compressor combustion chamber and gas turbine, it consists of heater and cooler.
- During the operation, the fluid is compressed in the compressor and the compressed fluid coming out of the compressor is heated in the heater by an external source and at constant pressure.
- This fluid expands in the turbine and power is developed.
- The expanded fluid coming out of the turbine is cooled to its original temperature in the cooler using external cooling source before fed to the compressor.
- Hence, the working fluid is continuously circulated in the circuit.

## Advantages of closed cycle gas turbine

- A high pressure can be maintained throughout the cycle with consequent reduction in volume of air.
- As the combustion is external, any type of fuel can be used.
- The working medium remains free from pollution of products.
- As the working circuit is closed, there is no loss of working medium.
- Thermal efficiency of these type of turbines is high.

### 3.3.2 Comparison between Open Cycle and Closed Cycle Gas Turbine

☞ **[ Dec. 2009, June 2013 ]**

| Sr. No. | Open cycle gas turbine | Closed cycle gas turbine |
|---|---|---|
| 1. | Maximum operating pressure of these turbines is less. | Maximum operating pressure of these turbines is high. |
| 2. | In these turbines, working fluid is air. | Working fluid is gas like helium, argon, air-fuel mixture, etc. |
| 3. | For given output size of plant is larger. | For given output size of plant is smaller. |
| 4. | Due to contaminated gases corrosion of blades takes place. | As there is indirect heating in the cycle, there is no corrosion of blades. |
| 5. | Commonly used fuels are kerosene, petrol, oil, etc. | It can use any type of fuel for its operation. |
| 6. | Cooling medium is not required. | Large amount of cooling water is required. |
| 7. | Weight and size of plant is small. | Weight and size of plant is high. |
| 8. | Low thermal efficiency. | High thermal efficiency. |

### 3.3.3 Comparison between Gas Turbine and Steam Turbine

| Sr. No. | Gas turbine | Steam turbine |
|---|---|---|
| 1. | For the operation of these turbines, boiler is not required. | Boiler is required for the operation of these turbines. |
| 2. | For given output less space is required. | It requires more space for given output. |
| 3. | Starting and power generation time is less. | Start and power generation time is more. |
| 4. | Weight to power ratio is less. | Weight to power ratio is high. |
| 5. | It is suitable for part loads and peak loads. | It is suitable only for part loads. |
| 6. | It does not require cooling water. | It requires large amount cooling water. |
| 7. | Thermal efficiency is low. | Thermal efficiency is high. |
| 8. | Capital cost and running cost is low. | Capital cost and running cost is high. |

### 3.3.4 Applications of Gas Turbines

Gas turbines are used in the following fields :

**i)** **Turbojet engine :** Energy turbojet and turbopropeller engine has a gas turbine.

**ii)** **Marine applications :** Gas turbines are mostly used in marine applications because of absence of boiler.

**iii)** **Railway engines :** The gas turbines are now also used in railway engines.

**iv)** **Supercharging :** In supercharging small gas turbine run by the hot flue gases drives supercharger for aviation gasoline engines.

**v)** **Electric power generation :** As gas turbines require less amount of water, now they are more popular then the steam turbines.

**vi)** **Industrial applications :** Gas turbines are also used in steel industries, chemical industries, oil industries, etc.

### 3.3.5 Advantages of Gas Turbine over I.C. Engine ☞ **[ June 2010 ]**

- Gas turbine has less moving parts than I.C. engine.
- Mechanical efficiency of gas turbine (95 %) is higher than that of I.C. engine (85 %)
- Gas turbine does not require flywheel like I.C. engine.
- Cheaper fuels can be used in the gas turbine.
- Gas turbines can be driven at high speed upto 40000 rpm.
- Work developed by the gas turbine is higher than the I.C. engine.
- As the pressure used in gas turbines is low (upto 5 bar) than I.C. engine (60 bar), the components of gas turbine can be made light in weight.

## 3.4 Hydraulic Turbines ☞ **[ June 2013 ]**

- Hydraulic or water turbines are the machines which use the energy of water (hydro-power) and convert it into mechanical energy.
- The mechanical energy developed by a turbine is used in running an electric generator which is coupled to the shaft of the turbine.
- Thus the electric generator develops power which is called as **hydroelectric power.**
- Generally, water turbine consists of a wheel called as *runner* or *rotor* having number of specially designed vanes or blades. The water with large amount of hydraulic energy strikes the runner and causes it to rotate. Hence mechanical energy is supplied to the generator coupled to runner which generates electrical energy.

## 3.4.1 Classification of Hydraulic Turbines ☞ [ June 2012 ]

Hydraulic turbines are classified on the basis of following :

**1. According to the action of water flowing through the turbine runners**
  a)  Impulse turbine          b) Reaction turbine

**2. According to the direction of flow of water in the turbine**
  a)  Tangential flow turbine    b) Radial flow turbine
  c)  Axial flow turbine          d) Mixed flow turbine

**3. According to the head and quantity of water required**
  a)  High head turbine          b) Medium head turbine
  c)  Low head turbine

**1. Impulse turbine**
  - In these turbines, all the available energy of water is converted into kinetic energy or velocity head by passing it through a nozzle provided at the end of penstock.
  - This high velocity water is impinged on a series of buckets of the runner thus causing it to revolve.
  - A casing is provided on the runner to prevent splashing and to guide the water discharged from the buckets to the tail race.
  - Commonly used impulse turbines are **Pelton wheel,** Girard turbine, Banki turbine, Jonval turbine, etc.

**2. Reaction turbine**
  - In these turbines, at the entrance to the runner, only a part of the available energy of water is converted into kinetic energy and substantial part is in the form of pressure energy.
  - The pressure at the inlet of turbine is much higher than the pressure at the outlet and varies throughout the passage of water through the turbine.
  - In these turbines, the runner is completely enclosed in air-tight casing and the passage is full of water throughout the operation.
  - The pressure difference between inlet and outlet of the runner is called as *reaction pressure* and hence these turbines are called **reaction turbines.**
  - Commonly used reaction turbines are **Francis turbine, Kaplan turbine,** Thomson turbine, Propeller turbine, etc.

## 3.4.2 Pelton Wheel (Impulse Turbine) ☞ [ June 2010, Dec. 2011 ]
  - This is the only impulse type of hydraulic turbine which is now commonly used.
  - It was first developed by Lester A. Pelton an American Engineer in 1880.
  - This turbine is most suitable for operating under high heads.

- An arrangement of a typical Pelton wheel is shown in Fig. 3.6.
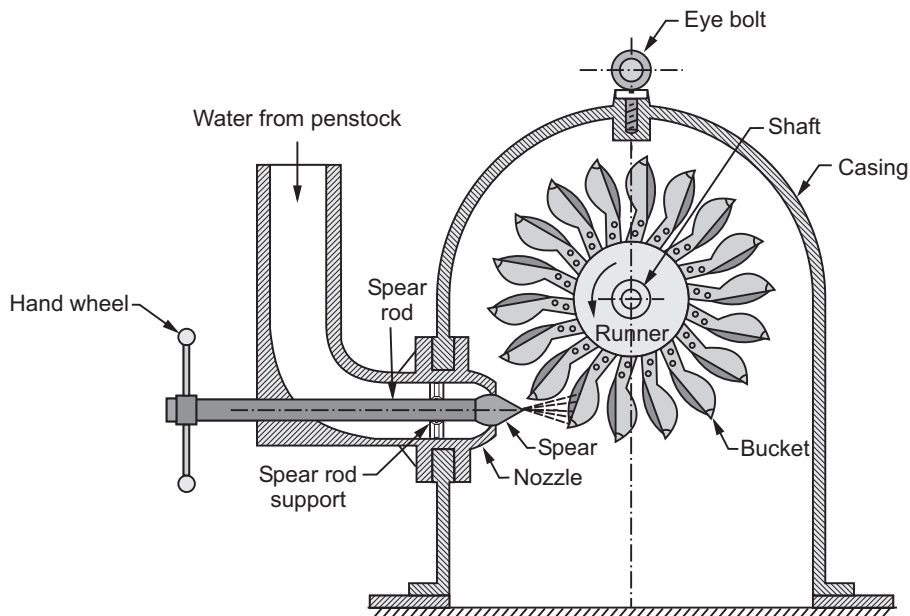
Fig. 3.6 : Pelton wheel

- The main elements of a Pelton wheel are :
  - Runner and buckets
  - Casing
  - Nozzle and spear assembly
- The water from reservoir flows through the penstock to the nozzle which converts pressure energy into kinetic energy.
- This high velocity jet (water) strikes the buckets or vanes on the outer periphery of runner.
- The buckets have a shape of double semi-ellipsoidal cups and each bucket is divided into two symmetrical parts by a sharp-edged ridge called as **splitter.** Refer Fig. 3.7.
- The jet of water impinges on the splitter which divides the jet into two equal portions, each of which flowing round the smooth inner surface and leaves at its outer edge.
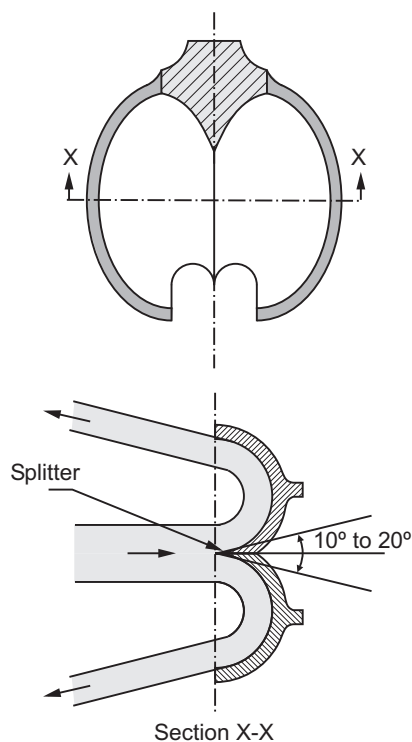
Fig. 3.7 : Shape of bucket

- Due to double cup-shaped buckets the axial thrust neutralize each other, being equal and opposite and the wheel bearings are not subjected to axial or end thrust.

- The back of the bucket is so shaped that as it swings downwards into the jet, no water is wasted by splashing.

- The buckets are generally made of cast iron, cast steel, bronze or stainless steel.

- The casing has no hydraulic function. It is provided only to prevent splashing of water, to lead the water to the tail race and it also act as a safeguard against accidents.

- In order to control the quantity of water striking the runner, the nozzle fitted at the end of penstock is provided with a spear which is fixed to the end of a rod.

- It may be operated manually by a wheel or automatically by a governor.

### 3.4.3 Francis Turbine (Reaction Turbine)          ☞ **[ Dec 2013 ]**

- Francis turbine is a mixed flow type of reaction turbine.

- It was invented by James B. Francis an American Engineer in 1849.

- In these turbines water enters the runner radially at the outer periphery and leaves axially at its centre.

- The main components of Francis turbine are :
  o Spiral or scroll casing
  o Runner and vanes
  o Guide mechanism
  o Draft tube

- The water from the pen stock enters a spiral casing which completely surrounds the runner.

- The casing is provided for an even distribution of water around the circumference of the turbine runner and maintains approximately constant velocity for the water so distributed.

- Fig. 3.8 shows the arrangement of Francis turbine.

- To keep the velocity of water constant throughout its path around the runner, the cross-sectional area of the cassing is gradually decreased. Generally, the casing is made of cast steel, steel, concrete, etc.

- From the scroll casing the water passes through a stay ring which consists of an upper and lower ring held together by series of fixed vanes called as **stay vanes**.

- The stay ring which is made of cast steel or cast iron directs the water from scroll casing to the guide vanes.

- From the speed ring water passes through a series of guide vanes provided around the periphery of the turbine runner.
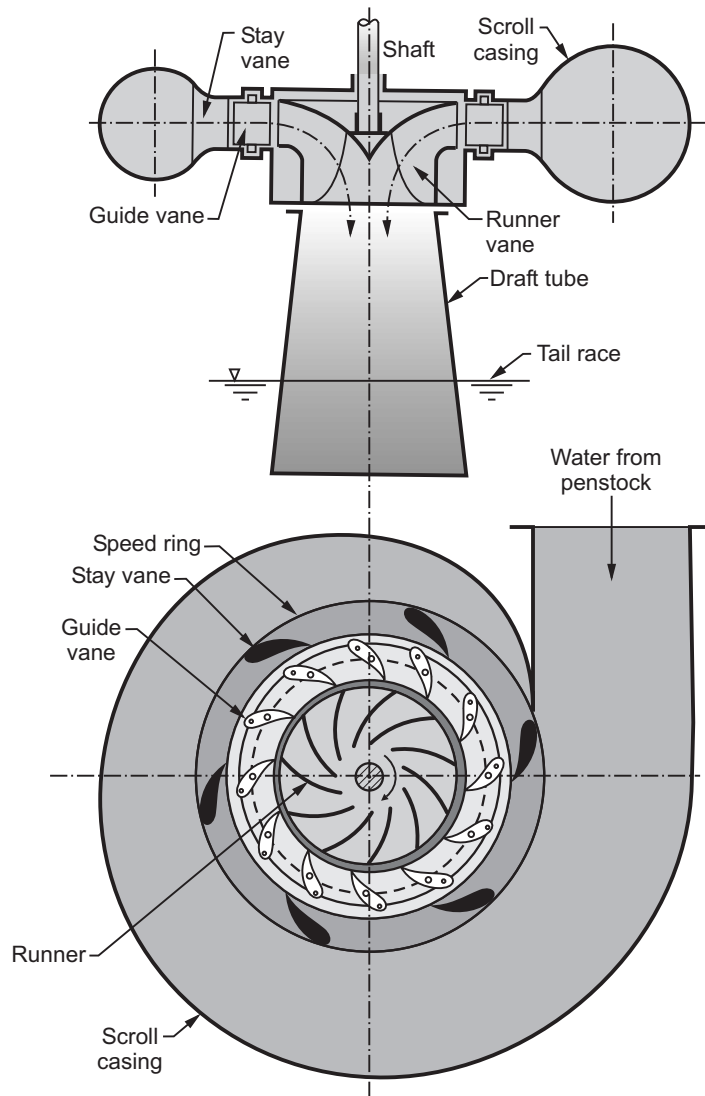
**Fig. 3.8 : Francis turbine**

- The guide vanes are of aerofoil shape and are used to regulate the quantity of water supplied to the runner and to direct the water on the runner at an appropriate angle.

- The guide vanes are operated either by means of a wheel or automatically by a governor.

- The vanes are so shaped that water enters the runner radially at the outer periphery and leaves axially at the inner periphery.

- The change in direction of water produces a circumferential force on the runner which makes it to rotate and produces useful output.

- After passing through the runner, the water flows to the tail race through a draft tube.
- A draft tube is a pipe or passage of gradually increasing cross-sectional area which connects the runner exit and tail race.
- It is always submerged below the level of water in the tail race.

## 3.4.4 Kaplan Turbine (Reaction Turbine)          ☞ **[ Dec. 2009 ]**
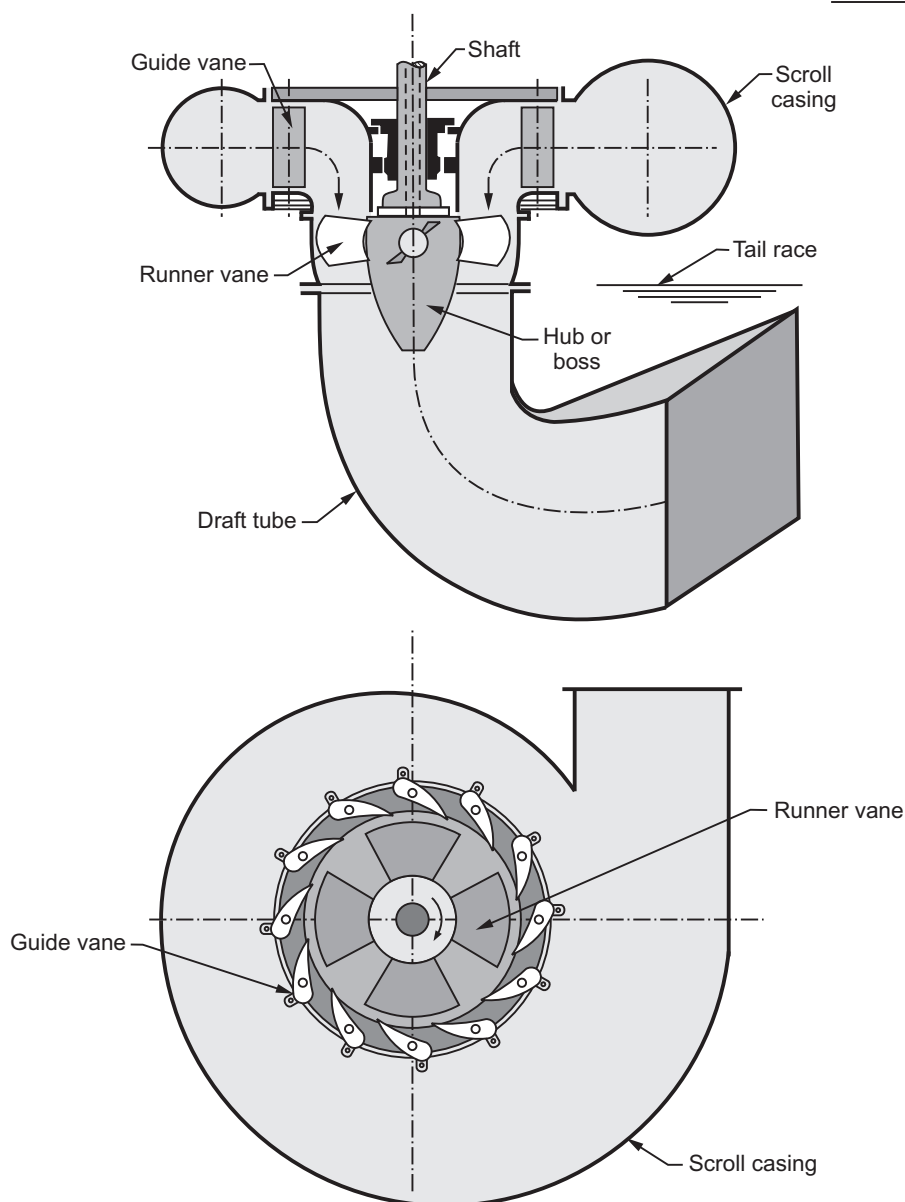
Fig. 3.9 : Kaplan turbine

- Kaplan turbine is an axial flow turbine which is suitable for low heads and hence it requires large quantity of water to develop large amount of power.
- It was developed by V. Kaplan an Australian Engineer.
- It operates in an entirely closed conduit from the head race to tail race.
- Fig. 3.9 shows the arrangement of Kaplan turbine.
- The main elements of Kaplan turbine are similar to Francis turbine.
- In these turbines, water turns between the guide vanes and runner at right-angle into the axial direction and then passes through the runner.
- The vanes attached to the hub or boss are so shaped that the water flows axially through the runner.
- The main advantage of Kaplan turbine is that, its runner blades can be turned about their own axis for adjusting the angle of inclination.
- The working principle of Kaplan turbine is similar to Francis turbine.

### 3.4.5 Comparison between Impulse Turbine and Reaction Turbine

| Sr. No. | Impulse turbine | Reaction turbine |
|---|---|---|
| 1. | The available water energy is converted into kinetic energy by using a nozzle. | Only some part of available energy is converted into kinetic energy in the guide vanes. |
| 2. | During the operation, pressure remains constant. | After entering at the runner, water undergoes chage in pressure and velocity. |
| 3. | Draft tube is not required for the operation. | Draft tube is required for the operation. |
| 4. | Water from the nozzles comes out in the form of jet which impinges on the buckets of runner. | Water is guided by the guide blades to flow over the vanes of aerofoil shape. |
| 5. | Water does not fill the bucket fully hence the air has easy access to the buckets. | Water completely fills all the passages between the blades. |
| 6. | It is always installed above the tail race. | It may be installed above or below the tail race. |
| 7. | These turbines are suitable for high heads. | These turbines are suitable for low heads. |
| 8. | Power is developed due to change in kinetic energy. | Power is developed due to change in pressure head. |

## Review Questions

1. *What is steam turbine ? What are its types ?*
2. *Explain impulse and reaction turbine with neat sketch.*
3. *What are the advantages of steam turbine?*
4. *Compare impulse and reaction steam turbine. (at least 6 points).*
5. *Explain the classification of gas turbines.*
6. *Explain the open cycle and closed cycle gas turbine (constant pressure type).*
7. *Compare open cycle and closed cycle gas turbines.*
8. *Compare gas turbine and steam turbine.*
9. *Explain the applications of gas turbines.*
10. *Classify hydraulic turbines.*
11. *Explain following types of hydraulic turbines :*
    *i) Kaplan turbine    ii) Francis turbine    iii) Pelton wheel*
12. *Compare impulse and reaction hydraulic turbines.*

## 3.5 Multiple Choice Questions with Answers

**Q.1**   In case of reaction turbine the shape of blades is _____ .

a) profile type                              b) aerofoil type

c) both (a) and (b)                         d) None of these              **[Ans. : b]**

**Q.2**   Life of steam turbine is _____ .

a) less                                        b) moderate

c) high                                        d) none of these              **[Ans. : c]**

**Q.3**   In _____ turbines pressure drops only in nozzle and not in moving blades channel.

a) impulse                                    b) reaction

c) both (a) and (b)                         d) none of these              **[Ans. : a]**

**Q.4**   Efficiency of impulse turbine is _____ than reaction turbine.

a) high                                        b) very high

c) equal                                       d) less                        **[Ans. : d]**

**Q.5** Maximum operating pressure of open cycle gas turbine is _____.

a) less                                 b) moderate

c) high                                 d) none of these             **[Ans. : a]**

**Q.6** In _____ maximum operating pressure is high.

a) open cycle gas turbines          b) closed cycle gas turbines

c) constant volume gas turbines      d) both (a) and (b)         **[Ans. : b]**

**Q.7** _____ is not a working fluid for closed cycle gas turbine.

a) Air-fuel mixture                  b) Helium

c) Argon                             d) Water                            **[Ans. : d]**

**Q.8** For _____ type of turbine cooling medium is not required.

a) open cycle                        b) closed cycle

c) both (a) and (b)                d) none of these             **[Ans. : a]**

**Q.9** _____ have low thermal efficiency.

a) Open cycle                        b) Closed cycle

c) Both (a) and (b)               d) None of these             **[Ans. : a]**

**Q.10** The thermal efficiency of closed cycle gas turbine is _____ .

a) less                                 b) moderate

c) high                                 d) none of these             **[Ans. : c]**

**Q.11** The weight to power ratio for steam turbine is _____ .

a) less                                 b) moderate

c) high                                 d) none of these             **[Ans. : c]**

**Q.12** In _____ turbines all the available energy of water is converted into kinetic energy.

a) impulse                             b) reaction

c) both (a) and (b)                d) none of these             **[Ans. : a]**

**Q.13** Pelton wheel is _____ turbine.

a) steam                               b) gas

c) hydraulic                          d) both (a) and (c)          **[Ans. : c]**

**Q.14** In pelton wheel, each bucket is divided into two symmetrical parts by a sharp-edged ridge called as _____.

a) spear                                b) eye bolt

c) splitter                             d) none of these             **[Ans. : c]**

**Q.15** Kaplan turbine is _____ .  ☞ **[ Dec. 2009 ]**

    a) impulse water turbine          b) steam turbine

    c) gas turbine          d) axial flow water turbine    **[Ans. : d]**

**Q.16** Pelton turbine is _____ .     ☞ **[ Dec. 2009, June 2011 ]**

    a) a reaction turbine          b) tangential flow turbine

    c) mixed flow turbine          d) a steam turbine       **[Ans. : b]**

**Q.17** A prime mover, which converts energy of steam into mechanical energy directly in the form of rotary motion is called as _____ .    ☞ **[ Dec. 2009 ]**

    a) steam engine          b) I.C. engine

    c) steam turbine          d) generator        **[Ans. : c]**

**Q.18** Most efficient prime mover is _____ .    ☞ **[ Dec. 2009 ]**

    a) I.C. engine          b) gas turbine

    c) steam turbine          d) steam engine      **[Ans. : c]**

**Q.19** The turbine in which steam expands completely in nozzles is called _____ .

                 ☞ **[ June 2010 ]**

    a) impulse turbine          b) Francis turbine

    c) reaction turbine          d) flow turbine        **[Ans. : a]**

**Q.20** Francis turbine is an example of _____ .    ☞ **[ June 2010 ]**

    a) impulse turbine          b) reaction turbine

    c) gas turbine          d) none of the above      **[Ans. : b]**

**Q.21** The thermal efficiency of open cycle gas turbine is _____ compared to close cycle gas turbine.    ☞ **[ June 2010 ]**

    a) low          b) high

    c) very high          d) medium        **[Ans. : a]**

**Q.22** _____ is an example of steam turbine.    ☞ **[ Dec. 2010 ]**

    a) Kaplan turbine          b) Pelton wheel

    c) Francis turbine          d) Parson's turbine       **[Ans. : d]**

**Q.23** Impulse steam turbine have _____ type of blades.    ☞ **[ Dec. 2010 ]**

    a) symmetrical profile          b) aerofoil profile

    c) unsymmetrical profile          d) none of these        **[Ans. : a]**

**Q.24** In Pelton wheel _____ energy is converted into mechanical energy.

☞ **[ Dec. 2010 ]**

    a) electrical                 b) solar

    c) hydraulic                d) wind             **[Ans. : c]**

**Q.25** _____ is an example for reaction turbine.     ☞ **[ Dec. 2010 ]**

    a) Kaplan turbine           b) Pelton wheel

    c) De-Lavel turbine         d) Curtis turbine      **[Ans. : a]**

**Q.26** In case of impulse steam turbine there is _____ .   ☞ **[ June 2011 ]**

    a) pressure drop in fixed and moving blades

    b) pressure drop only in moving blades

    c) pressure drop only in nozzles

    d) pressure drop only in fixed blades            **[Ans. : c]**

**Q.27** Mechanical efficiency of a gas turbine plant as compared to IC engine is _____.

☞ **[ June 2011 ]**

    a) higher        b) lower

    c) same         d) unpredictable           **[Ans. : a]**

**Q.28** In case of impulse water turbine, the entire hydro energy is converted into kinetic energy by passing the water through _____ .   ☞ **[ Dec. 2011 ]**

    a) tail race               b) runner

    c) nozzle                d) none of these        **[Ans. : c]**

**Q.29** The cross-section of a draft tube in a turbine _____.   ☞ **[ Dec 2011 ]**

    a) is uniform                  b) gradually decreases towards the outlet

    c) gradually increases towards the outlet

    d) none of these                     **[Ans. : c]**

**Q.30** _____ is an example of impulse turbine.   ☞ **[ June 2012 ]**

    a) De-Laval              b) Kaplan

    c) Francis               d) Lawn sprinkler      **[Ans. : a]**

**Q.31** A gas turbine as compared to diesel engine takes longer time to accelerate to full speed because _____ .   ☞ **[ June 2012 ]**

    a) gas turbine has lesser maximum pressure

b) gas turbine has larger rotating mass

c) gas turbine needs no water cooling

d) diesel engine has larger number of bearings                    **[Ans. : a]**

**Q.32**  Kaplan turbine is efficienct and preferred when _____.        ☞ **[ June 2012 ]**

a) low head and low discharge is available

b) low head and high discharge is available

c) high head and low discharge is available

d) high head and high discharge is available                    **[Ans. : b]**

**Q.33**  Cooling water is not needed in _____.            ☞ **[ June 2012 ]**

a) gas turbine plant              b) diesel engine plant

c) steam turbine plant            d) nuclear plant            **[Ans. : a]**

**Q.34**  _____ is an example of reaction turbine.            ☞ **[ Dec. 2012 ]**

a) De-Laval                    b) Kaplan

c) Flow                        d) Pelton wheel                **[Ans. : b]**

**Q.35**  Open cycle gas turbine uses _____ as the working substance. ☞ **[ Dec. 2012 ]**

a) ammonia                    b) nitrogen

c) air                        d) $CO_2$                    **[Ans. : c]**

**Q.36**  _____ is example of reaction water turbine.            ☞ **[ Dec. 2012 ]**

a) Pelton wheel                b) Francis

c) Kaplan                    d) Both (b) and (c)            **[Ans. : d]**

**Q.37**  An example of reaction turbine is _____.            ☞ **[ June 2013 ]**

a) Laval turbine              b) Curtis turbine

c) Zoelly turbine            d) Parson's turbine            **[Ans. : d]**

**Q.38**  The weight to power ratio of gas turbine is _____.        ☞ **[ June 2013 ]**

a) high                        b) less

c) moderate                    d) equal                    **[Ans. : b]**

**Q.39**  Draft tube is a _____ steel pipe.                ☞ **[ June 2013 ]**

a) closed                    b) open

c) converging                d) diverging                **[Ans. : d]**

**Q.40** Kaplan turbine is a _____ head turbine. ☞ **[ June 2013 ]**

    a) high                              b) low

    c) medium                     d) simple            **[Ans. : b]**

**Q.41** Steam turbine converts _____ into mechanical energy. ☞ **[ Dec. 2013 ]**

    a) kinetic energy              b) weight

    c) velocity                    d) potential          **[Ans. : a]**

**Q.42** Pelton wheel is example for _____ . ☞ **[ Dec. 2013 ]**

    a) a reaction turbine         b) tangential flow turbine

    c) mixed flow turbine        d) a steam turbine     **[Ans. : b]**

**Q.43** Combustion gas is directly converted into the mechanical power called as _____ . ☞ **[ Dec. 2013 ]**

    a) reaction turbine            b) impulse turbine

    c) open or closed gas turbine    d) steam turbine     **[Ans. : c]**

## 3.6 University Questions with Answers

### Dec. 2009

**Q.1** Differentiate between closed cycle and open cycle gas turbine.
**(Refer section 3.3.2)**     **[8]**

**Q.2** With a neat sketch, explain the construction and working of a Kaplan turbine. List advantages. **(Refer section 3.4.4)**     **[10]**

### June 2010

**Q.3** With a neat sketch, explain the working of Pelton wheel. **(Refer section 3.4.2)**     **[6]**

**Q.4** What are the advantages of gas turbines over I.C. engine. **(Refer section 3.3.5)**     **[6]**

### Dec. 2010

**Q.5** Explain with neat sketches, the working principles of impulse and reaction turbines. **(Refer section 3.2.1)**     **[10]**

<div align="center"><strong>Dec. 2011</strong></div>

**Q.6** Explain the working principle of impulse and reaction turbine.
**(Refer section 3.2.1)** [6]

**Q.7** Sketch and explain the working of a Pelton wheel. **(Refer section 3.4.2)** [10]

<div align="center"><strong>June 2012</strong></div>

**Q.8** With a neat sketch, explain construction and working of a closed cycle gas turbine plant. **(Refer section 3.3.1)** [6]

**Q.9** Classify water turbines. **(Refer section 3.4.1)** [4]

<div align="center"><strong>June 2013</strong></div>

**Q.10** With a neat sketch, explain working principle of an impulse turbine.
**(Refer section 3.2.1)** [6]

**Q.11** List any 4 differences between closed cycle and open cycle gas turbine.
**(Refer section 3.3.2)** [4]

**Q.12** Define radial flow, axial flow and mixed flow with respect to water turbine.
**(Refer section 3.4)** [6]

<div align="center"><strong>Dec. 2013</strong></div>

**Q.13** Explain the principle and working of reaction turbine. **(Refer section 3.2.1)** [6]

**Q.14** With the help of neat sketch, explain working of Francis turbine.
**(Refer section 3.4.3)** [6]

**Q.15** Explain the working principle of a gas turbine on closed cycle.
**(Refer section 3.3.1)** [4]

*Turbines ends …*

# Module - II

## CHAPTER - 4

# INTERNAL COMBUSTION (I.C.) ENGINES

**Syllabus :** Classification, I.C. engines parts, 2 stroke and 4 stroke petrol engines, 4 stroke diesel engines. P-V diagrams of Otto and Diesel cycles. Problems on indicated power, Brake power, Indicated thermal efficiency, Brake thermal efficiency, Mechanical efficiency and specific fuel consumption, [Numericals on IC engines].

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| 4.1 | Internal Combustion (I.C.) Engines |
| 4.2 | Four Stroke Petrol Engines (S.I. Engines) |
| 4.3 | Four Stroke Diesel Engines (C.I. Engines) |
| 4.4 | Comparison of Petrol Engine and Diesel Engine |
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## 4.1 Internal Combustion (I.C.) Engines

- Any machine which derives heat energy from the combustion of fuel (chemical energy of fuel) and convert part of this energy into mechanical work is called as **heat engine.**

- These heat engines may be externally combustion type or internally combustion type.

- In case of external combustion engines, the combustion of fuel takes place outside the cylinder.

  **For example :** Steam engines, steam and gas turbines, air engines, etc.

- In case of internal combustion engines, the combustion of fuel in the presence of air takes place inside the cylinder and produced gases act on piston to develop the power.

  **For example :** Petrol engines, diesel engines, gas engines, etc.

- Internal combustion (I.C.) engines are commonly used in vehicles, locomotives and in various industrial applications.

### 4.1.1 Classification of I.C. Engines

I.C. engines are classified as follows :

**1. According to the cycle of operation**

   a) **Four stroke engines :** In these engines cycle is completed in two revolution of crank.

   b) **Two stroke engines :** In these engines cycle is completed in one revolution of crank.

**2. According to the nature of thermodynamic cycle**

   a) Constant volume or Otto cycle.

   b) Constant pressure or diesel cycle.

   c) Partly Otto and partly diesel cycle or dual cycle.

**3. According to the method of ignition**

   a) **Spark Ignition (S.I.) engines :** In spark ignition or **petrol engines,** air-fuel mixture supplied by carburettor is ignited by producing spark.

   b) **Compression Ignition (C.I.) engines :** In compression ignition or **diesel engines** air is compressed to higher pressure and in fine atomised form fuel is injected in combustion chamber. Hence air-fuel mixture is ignited without producing spark.

**4. According to the number of cylinders**

   a) Single cylinder engines

   b) Multi-cylinder engines

## 5. According to the type of cooling system

a) **Air cooled engines :** For cooling purpose air is used.

b) **Water cooled engines :** Water jackets are provided around the cylinder to cool the engine.

## 6. According to the speed of engine

a) Low speed engines

b) Medium speed engines

c) High speed engines

## 7. According to the lubrication method

a) Wet sump lubrication

b) Dry sump lubrication

c) Pressure lubrication

## 8. According to the fuel used

a) Petrol engines

b) Diesel engines

c) Gas engines

## 9. According to the field of operation

a) Automotive engines

b) Stationary engines

c) Locomotive engines

d) Marine engines

## 10. According to the arrangement of cylinder (Refer Fig. 4.1)

a) **Vertical engines :** In these engines, cylinder is in vertical position.

b) **Horizontal engines :** In these engines, cylinder is in horizontal position.

c) **V-engines :** In these engines, two cylinders are arranged at an angle connected to a common crank.

d) **Radial engines :** In these engines 4 to 6 cylinders are placed radially and equally spaced and connected to a common crank.

e) **Opposed cylinder engines :** In these engines, cylinders are arranged on opposite side of a common crank.

f) **Opposed piston engines :** In these engines, single cylinder houses two pistons, each of which drives separate crank.

**(a) Vertical engine**

**(b) Horizontal engine**

**(c) V - engine**

**(d) Radial engine**

**(e) Opposed cylinder engine**

**(f) Opposed piston engine**
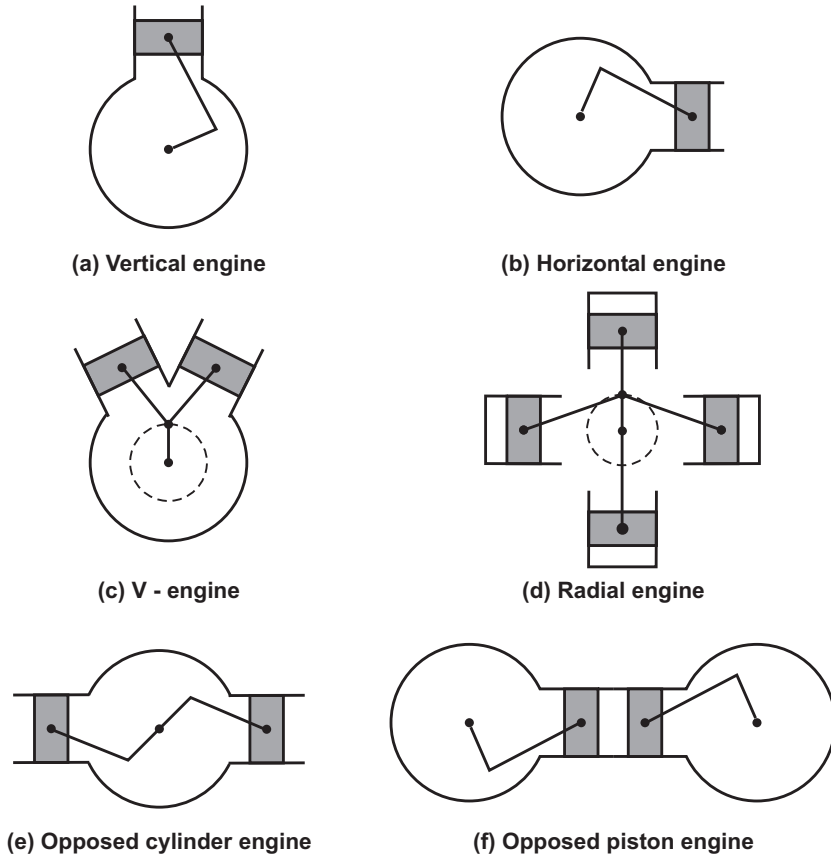
**Fig. 4.1 : Arrangement of cylinder in I.C. engine**

## 4.1.2 I.C. Engine and its Components
☞ **[ June 2013 ]**

Fig. 4.2 shows reciprocating I.C. engine and its components. The main components of this 4-stroke petrol engine are as follows :

| | |
|---|---|
| 1. Cylinder | 2. Piston |
| 3. Crank and crankshaft | 4. Connecting rod |
| 5. Spark plug | 6. Inlet and exhaust valve |
| 7. Crank pin | 8. Gudgeon pin |
| 9. Cylinder head | 10. Piston rings |
| 11. Suction and exhaust manifold | 12. Carburettor |

1. **Cylinder :** It is the main body of an I.C. engine in which piston reciprocates to develop power. It has to withstand very high pressures (upto 75 bar) and temperatures (upto 2400 ºC), because the the combustion takes place in the cylinder. It may be air cooled or water cooled. It is generally made of cast iron or alloy steel.
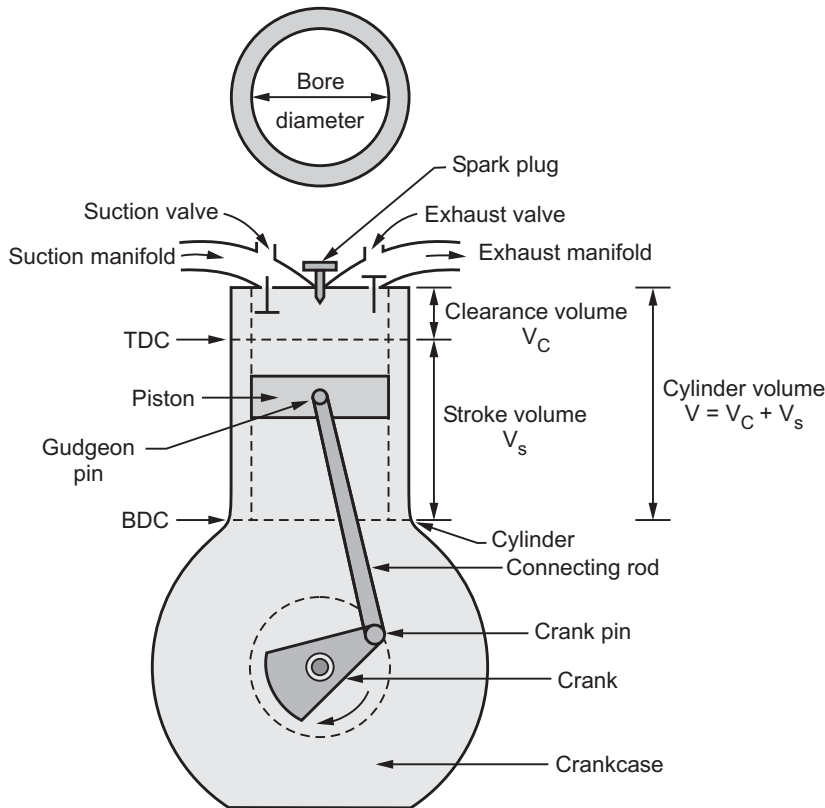
**Fig. 4.2 : Four stroke I.C. engine (petrol) and its components**

2. **Piston :** It is used to compress the charge (air-fuel mixture) during compression stroke and to transmit the gas force to the connecting rod and then crank during power stroke.

3. **Crank and crankshaft :** Crank is the integral part of the crankshaft and crankshaft is the backbone of the engine, crankshaft is supported in main bearings and it has a heavy wheel called as **flywheel** to control the fluctuation of torque.

4. **Connecting rod :** It is a rod of circular or rectangular cross section. Its small end is connected to the piston and big end is connected to the crank. It converts reciprocating motion of pistion into rotary motion of crankshaft.

5. **Spark plug :** It is used to initiate the spark for the combustion of air-fuel mixture in petrol engines.

6. **Inlet and exhaust valve :** Inlet valve controls the admission of the charge during suction stroke and exhaust valve is used for the removal of exhaust gases after doing work on the pistion.

7. **Crank pin and Gudgeon pin :** Crank pin is used to connect big end of connecting rod to the crank and gudgeon pin is used to connect small end of connecting rod to the piston.

8. **Cylinder head :** It is used for closing the one end of the cylinder. It houses inlet and exhaust valves through which charge is taken inside the cylinder and burned gases are exhausted to the atmosphere from the cylinder.

9. **Piston rings :** Piston rings are housed in the circumferential grooves provided on the outer surface of the piston. It gives tight fit between the pistion and cylinder hence prevents the leakage of high pressure gases.

10. **Suction and exhaust manifold :** Suction manifold is the passage which carries the charge from carburettor to the engine where as exhaust manifold is the passage which carries the exhaust gases from the exhaust valve to the atmosphere.

11. **Carburettor :** It is used to supply the uniform air-fuel mixture to the cylinder of petrol engine through the intake manifold. It is controlled by a throttle valve.

## 4.1.3 Terminology used in I.C. Engines

In addition to the above components of I.C. engine, certain standard terminology used in I.C. engine is as follows :

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1. Bore                        2. Stroke
3. Top Dead Centre (T.D.C.)    4. Bottom Dead Centre (B.D.C.)
5. Clearance volume            6. Swept volume
7. Compression ratio
```

1. **Bore :** It is the inside diameter of the cylinder.

2. **Stroke :** It is the maximum distance travelled by the piston in the cylinder in one direction. It is generally twice the radius of crank.

3. **Top Dead Centre (T.D.C.) :** It is the extreme position of the piston at the top of the cylinder. For horizontal engines it is called as inner dead centre (I.D.C.).

4. **Bottom Dead Centre (B.D.C.) :** It is the extreme position of the piston at the bottom of the cylinder. For horizontal engines it is called as outer dead centre (O.D.C.).

5. **Clearance volume :** It is the volume contained in the cylinder above the top of the piston when it is at T.D.C. It is denoted by $V_c$.

6. **Swept volume :** It is the volume swept by the piston in moving between TDC and BDC. It is denoted by $V_s$.

7. **Compression ratio :** It is the ratio of the volume when the piston is at BDC to the volume when the piston is at TDC. It is denoted by r.

## 4.2 Four Stroke Petrol Engines (S.I. Engines) ☞ [ June 2010, Dec. 2013 ]

- In a four stroke cycle engine, the cycle is completed in *two revolutions* of crankshaft and four strokes are performed.

> 1. Suction stroke 2. Compression stroke
> 3. Expansion/Power stroke 4. Exhaust stroke

- Each stroke consists of $180^o$ of crankshaft rotation, hence the cycle consists of $720^o$ of crankshaft rotation for one cycle.

- Four stroke cycle engine consists of following strokes (Refer Fig. 4.3) :



**(a) Suction stroke**

**(b) Compression stroke**

E.V. = Exhaust valve
I.V. = Inlet valve
S.P. = Spark plug

**(c) Expansion or power stroke**
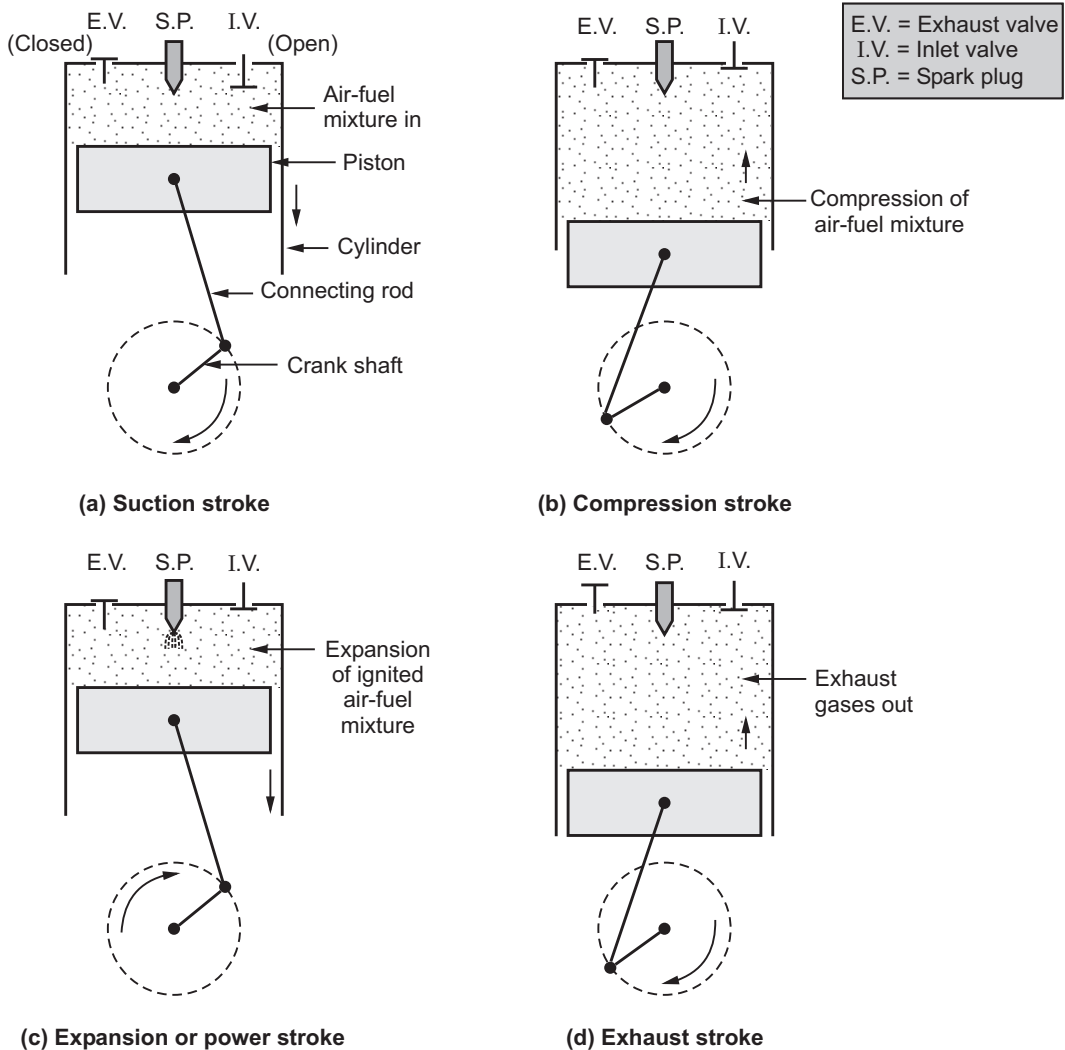
**(d) Exhaust stroke**

**Fig. 4.3 : Four stroke petrol (S.I.) engine**

**1. Suction stroke**

- This stroke starts when the piston is at TDC and about to move downwards.
- *During this stroke inlet valve remains open and exhaust valve remains closed.*
- Due to low pressure created by downward moving piston, the charge (air-fuel mixture) is drawn into the cylinder.
- At the end of this stroke the inlet valve closes.

**2. Compression stroke**

- During this stroke, the compression of fresh sucked charge takes place by the return stroke (BDC to TDC) of piston.
- *During this stroke, both inlet and exhaust valve remains closed.*
- Just before completion of compression stroke a charge is ignited by a spark plug and combustion takes place.

**3. Expansion or power stroke**

- The products of combustion exerts pressure on the piston hence forcing it to move downwards i.e. TDC to BDC.
- *During this stroke, both inlet and exhaust valve remains closed.*
- Power is developed during expansion of gases hence this stroke is also called as **power stroke.**
- During power stroke, both temperature and pressure decreases.

**4. Exhaust stroke**

- *At the end of power stroke the exhaust valve opens but the inlet valve remains closed.*
- During this stroke piston moves from BDC to TDC and burnt gases inside the cylinder are exhausted.
- At the end of this stroke exhaust valve closes but some residual gases remain in the cylinder.
- In this way, again the inlet valve opens and the new cycle starts.

> **Note :** *Each cycle of four stroke engine completes the above strokes in two crank rotations. One revolution of crankshaft occurs during the suction and compression strokes and the other revolution during the expansion and exhaust stroke.*

## 4.3 Four Stroke Diesel Engines (C.I. Engines)          ☞ [ Dec. 2010 ]

The working of four stroke diesel engine is similar to four stroke petrol engine, except the following two major points :

- In C.I. engines the air is only drawn during the suction stroke instead of air-fuel mixture drawn in S.I. engines.

- ○ In C.I. engines the fuel is injected by using injector into the cylinder and the high pressure and temperature mixture is burnt. Hence there is no need of spark plug.
- Diesel engine cycle consists of following four strokes (Refer Fig. 4.4) :

---
| 1. Suction stroke | 2. Compression stroke |
| 3. Expansion/Power stroke | 4. Exhaust stroke. |
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(a) Suction stroke

(b) Compression stroke

(c) Expansion or power stroke
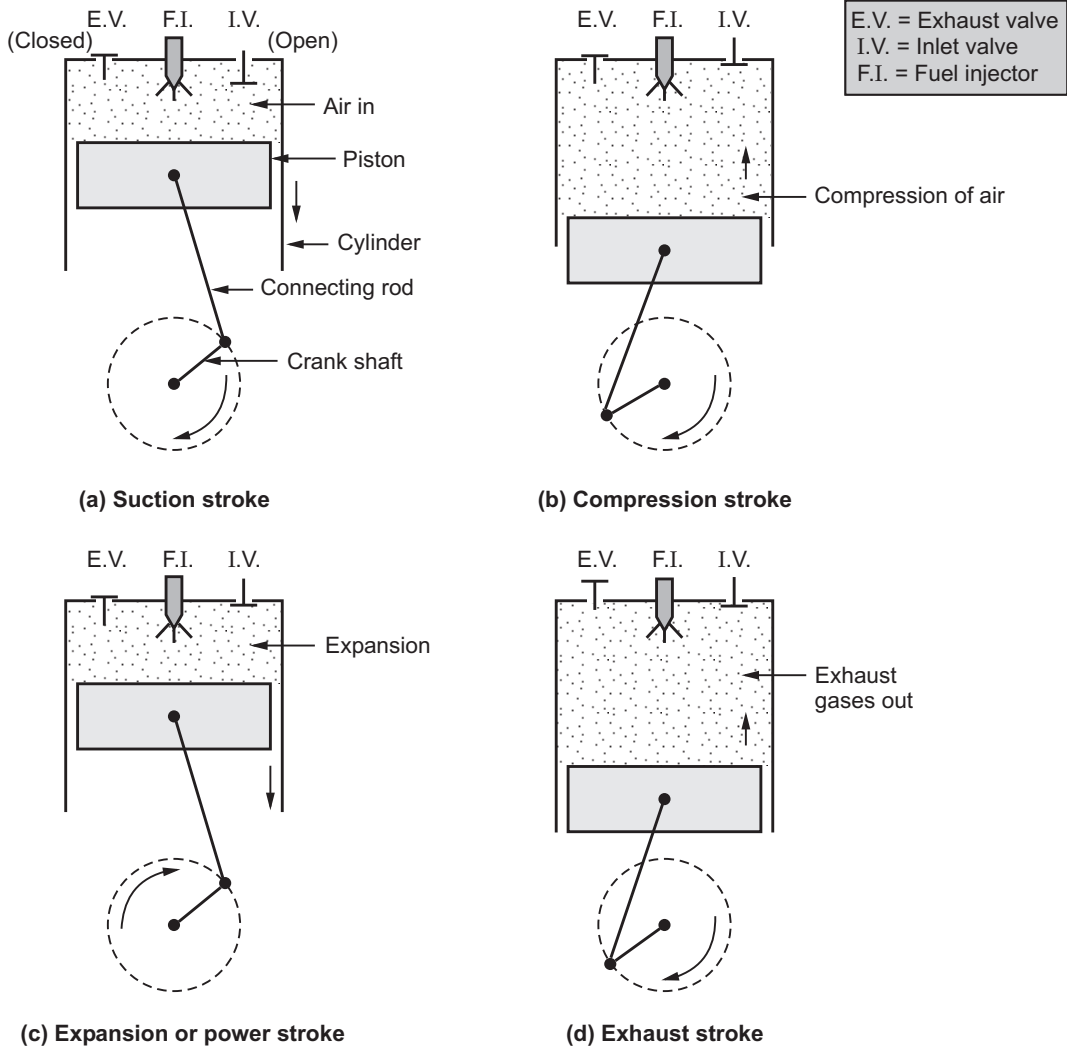
(d) Exhaust stroke

**Fig. 4.4 : Four stroke diesel (C.I.) engine**

## 1. Suction stroke

- During this stroke air is drawn into the cylinder and piston moves from TDC to BDC.

- The exhaust valve remains closed during this stroke.

**2. Compression stroke**

- During this stroke the piston moves from BDC to TDC and both the valves remain closed.

- The air sucked during the suction stroke is compressed hence there is rise in the pressure and temperature of the air.

- Before the end of this stroke, a fine spray of fuel is injected into the compressed air which is at high temperature and hence combustion takes place.

**3. Expansion or power stroke**

- During this stroke both the valves remain closed and the piston moves from TDC to BDC.

- The heat energy released by the combustion of fuel results in rise in pressure of the gases which drives the piston downwards. Hence, power is developed.

**4. Exhaust stroke**

- In this stroke exhaust valve is opened and inlet valve remains closed and the piston moves from BDC to TDC.

- The upward movement of the piston forces the burnt gases out of the cylinder through the exhaust valve.

## 4.4 Comparison of Petrol Engine and Diesel Engine

The comparison between four stroke petrol and four stroke diesel engines is as follows :

| Sr. No. | Petrol (S.I.) engines | Diesel (C.I.) engines |
|---|---|---|
| 1. | Petrol engine works on Otto cycle. | Diesel engine works on Diesel cycle. |
| 2. | In these engines, air-fuel mixture is sucked during suction stroke. | In these engines, only air is sucked during suction stroke. |
| 3. | Fuel supply is controlled by throttle valve in the carburettor. | Fuel supply is controlled by fuel pump. |
| 4. | For ignition, spark plug is required. | Spark plug is not required. |

| 5. | Compression ratio is low (about 6 to 12). | Compression ratio is high (about 14 to 22). |
|---|---|---|
| 6. | Due to low compression ratio, efficiency of these engines is low. | Due to high compression ratio, efficiency of these engines is high. |
| 7. | Due to low compression ratio, starting of these engines is easy. | Due to high compression ratio, starting of these engines is difficult. |
| 8. | Petrol engine is light in weight. | Diesel engine is heavier due to high pressure. |
| 9. | Due to light weight these engines can rotate at high speed. | Due to heavy weight these engines cannot rotate at high speed. |
| 10. | The operation of these engines is silent. | The operation of these engines is noisy. |
| 11. | Running cost is more since it uses costlier fuel. | Running cost is low since it uses cheaper fuel. |
| 12. | Initial cost is low. | Initial cost is high. |
| 13. | These engines are used in light duty vehicles like motor cycles, scooters, cars, etc. | These engines are used in heavy duty vehicles like buses, trucks, etc. |

## 4.5 Two Stroke Petrol Engines (S.I. Engines)

☞ **[ Dec. 2011, June 2012, Dec. 2012 ]**

- In four stroke engines, there is one power stroke in one cycle i.e. in two revolutions of crankshaft.

- In two stroke engines the suction and exhaust strokes are eliminated. Also there are no inlet and exhaust valves, instead of that these engines have inlet and exhaust ports.

- A piston of these engines is given a specific crown shape which helps to prevent the loss of fresh incoming charge which can be escaped alongwith the gases through exhaust port.

- A two stroke petrol engine consists of following strokes (Refer Fig. 4.5) :

  1. First stroke
  2. Second stroke

**(a) First stroke**



**(b) Second stroke**
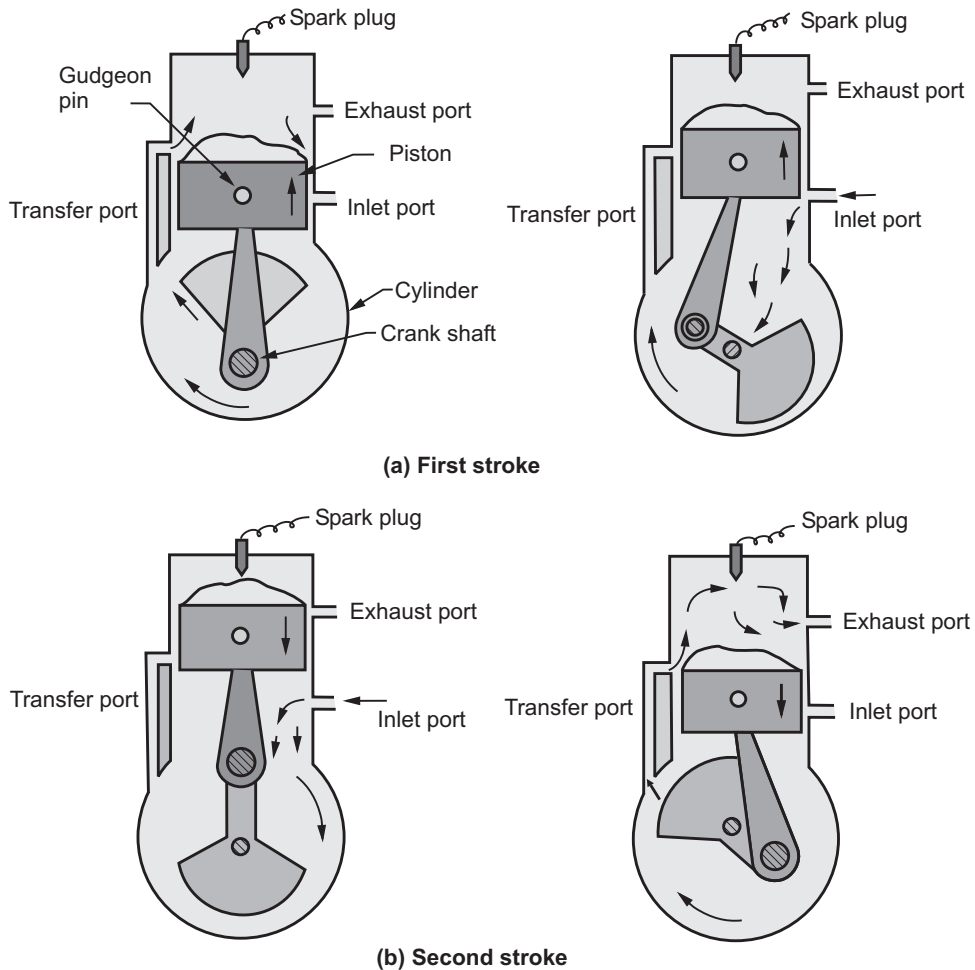
**Fig. 4.5 : Two stroke petrol (S.I.) engine**

**1. First stroke**

- Initially the piston is at BDC. The arrangement of the ports is such that the piston performs two operations simultaneously.

- When the piston starts rising from BDC it closes the transfer port and exhaust port and the already existing charge is compressed.

- At that time, vacuum is created in the crankcase which is gas tight.

- As soon as the inlet port is uncovered the fresh air is sucked in the crankcase and the charging is continued untill the crankcase is filled.

- At the end of this first stroke piston reaches TDC.

**2. Second stroke**

- In this stroke, piston moves from TDC to BDC.

- Before the completion of compression stroke, the compressed charge is ignited using spark plug and the gas pressure is exerted on the crown of the piston.
- This pressure forces the piston in downward direction which produces some useful work.
- The downward movement of piston closes the inlet port and compresses the charge already sucked in the crankcase. This fresh charge is transferred on the top side of the piston through transfer port.
- At that time, exhaust port opens and burnt gases are escaped.

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**Note :** *The difference between two stroke petrol engine and diesel engine is similar to the difference between four stroke petrol engine and diesel engine.*

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## 4.6 Comparison between Two Stroke and Four Stroke Engines

☞ **[ June 2013, Dec. 2013 ]**

| Sr. No. | Two stroke engine | Four stroke engine |
|---|---|---|
| 1. | The cycle is completed in one revolution of crankshaft. | The cycle is completed in two revolutions of crankshaft. |
| 2. | Power stroke is obtained in every revolution of crankshaft. | Power stroke is obtained in every two revolutions of crankshaft. |
| 3. | Due to one power stroke in one revolution, power produced for same size of engine is more. | Due to one power stroke for two revolutions, power produced for same size of engine is small. |
| 4. | In these engines ports are present. | Instead of ports these engines contains valves. |
| 5. | Due to simplicity and light weight, its initial cost is low. | Due to complication and heavy weight, its initial cost is high. |
| 6. | The piston is having crown shape or dome shape. | The crown of the piston is flat. |
| 7. | Low thermal efficiency. | High thermal efficiency. |
| 8. | It consumes more amount of lubricating oil. | It consumes less amount of lubricating oil. |
| 9. | During the operation it produces more noise. | It produces less noise during the operation. |
| 10. | These type of engines are used in scooters, mopeds, etc. | These type of engines are used in cars, buses, trucks, etc. |

## 4.7 Otto Cycle or Constant Volume Cycle ☞ [ June 2011 ]

- To analyse the I.C. engine performance which may uses petrol, gas etc. as a fuel, the Otto cycle is used.

- The Otto cycle is the theoretical constant volume cycle for the spark ignition engine.

- Fig. 4.6 shows the p-V diagram for an Otto cycle.
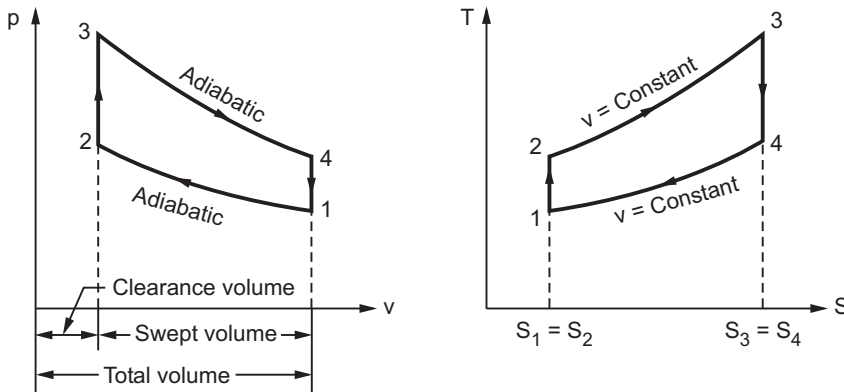


**Fig. 4.6 : Otto cycle**

- In the p-V diagram of an Otto cycle, the processes 0 - 1 and 1 - 0 are induction and exhaust process. The work during these processes is equal and opposite and hence cancel each other. Therefore, both the processes are neglected.

- **Process 1 - 2 :** This process represents reversible adiabatic compression process. In this process the entropy remains constant i.e. $S_1 = S_2$. No heat transfer takes place during this process. Here, the piston moves from bottom dead centre to top dead centre.

- **Process 2 - 3 :** This process represents the constant volume heat addition process. In an I.C. engine it is equivalent to burning of fuel by an electric spark and heat is generated.

- **Process 3 - 4 :** This process represents reversible adiabatic expansion process. In this stroke, piston moves outward from top dead centre to bottom dead centre. No heat transfer takes place during this process.

- **Process 4 - 1 :** This process represents constant volume heat rejection process. In actual engine, during this process the exhaust valve opens at 4 and brings down the pressure upto point 1.

## 4.8 Diesel Cycle                                    ☞ **[ Dec. 2010 ]**

- To analyse the performance of I.C. engine, Dr. R. Diesel introduced this cycle.
- The Diesel cycle is the theoretical cycle used for the compression ignition engine or diesel engines.
- The only difference between the Otto cycle and Diesel cycle is that the heat addition during the Diesel cycle is carried out by constant pressure.
- Hence, the Diesel cycle is sometimes reffered as constant pressure cycle. Refer Fig. 4.7.



**(a) p-v diagram**               **(b) T-S diagram**
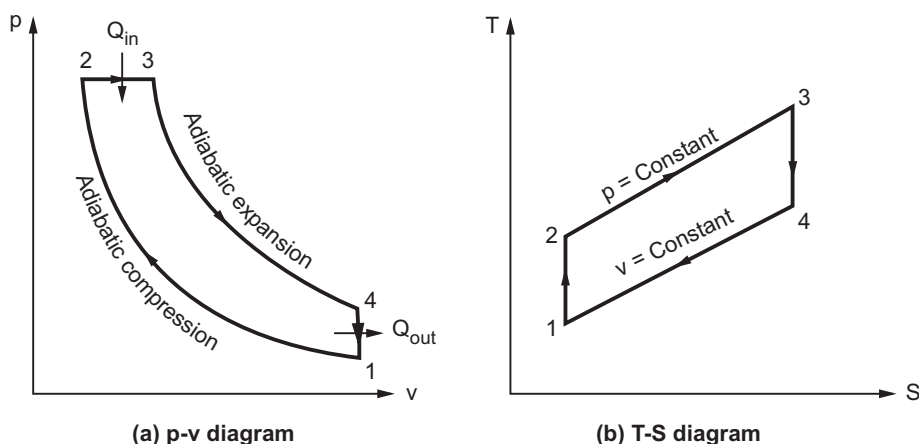
**Fig. 4.7 : Diesel cycle**

- **Process 1 - 2 :** This process represents reversible adiabatic i.e. isentropic compression process. The air is compressed through the compression ratio $V_1 / V_2$
- **Process 2 - 3 :** This process represents constant pressure heat addition process where air expands from volume $V_2$ to $V_3$. In actual engine, the heat addition takes place by injecting fuel which self ignites due to high temperature of compressed air and combustion of fuel takes place at constant pressure.
- **Process 3 - 4 :** Point 3 represents the cut off point of fuel injection. The process 3 - 4 represents the reversible adiabatic i.e. isentropic expansion.
- **Process 4 - 1 :** This process represents heat rejection at constant volume process and hence the cycle completed.

## 4.9 Performance of an I.C. Engine

- I.C. engine have got lot of importance due to transportation demand therefore, it is necessary to have efficient engine performance.

- The engine performance can be measured using various performance parameters as follows :

  1. Power and Mechanical efficiency
  2. Mean effective pressure and torque
  3. Specific output
  4. Volumetric efficiency
  5. Air fuel ratio
  6. Specific fuel consumption
  7. Thermal efficiency and heat balance
  8. Exhaust smoke and other emissions
  9. Specific weight

## 1. Power and Mechanical Efficiency

### i) Indicated Power :

- It is defined as the total power developed during the combustion of fuel in combustion chamber.
- It is denoted by letters I.P. and is given by,

$$\text{I.P.} = \frac{n \times \text{imep} \times l \times A \times N}{60 \times 1000}, \text{ kW}$$

where,

$n$ = No. of cylinders

imep = Indicated mean effective pressure in N/m$^2$

$l$ = Length of stroke in m

$A$ = Area of the piston in m$^2$

$N$ = Speed in rpm

$N$ = $\dfrac{N}{2}$ for four stroke engine

  = N for two stroke engine

### ii) Brake Power :

- It is defined as the power developed at the output shaft by an engine.
- It is denoted by B.P. and is given by,

$$\text{B.P.} = \frac{2 \times \pi \times N \times T}{60 \times 1000}, \text{ kW}$$

where,

$N$ = Speed in rpm

$T$ = Torque in Nm

### iii) Frictional Power :

- It is the difference between the indicated power and brake power.
- It is denoted by F.P. and is given by,

$$F.P. = I.P. - B.P.$$

### iv) Mechanical Efficiency :

- It is the ratio of brake power to indicated power.
- It is denoted by $\eta_m$ and is given by,

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

## 2. Mean effective pressure and torque

### i) Mean effective pressure (m.e.p.) :

- It is the hypothetical pressure which acts during the power stroke on the piston.
- If the mean effective pressure is based on the indicated power then it is known as indicated mean effective pressure (i.m.e.p.).
- If the mean effective pressure is based on the brake power then it is known as brake mean effective pressure (b.m.e.p.).

## 3. Specific Output

- Specific output is defined as the brake power per unit piston displacement. It is given by,

$$\text{Specific output} = \frac{B.P.}{A \times l}$$

## 4. Volumetric Efficiency

- Volumetric efficiency is defined as the actual volume of charge taken during suction stroke to the swept volume of piston.

## 5. Air-fuel ratio

- It is the ratio of mass of air to the mass of fuel in air fuel mixture.

## 6. Specific fuel consumption (s.f.c.)

- It is the mass of fuel consumed per kW of power developed per hour.
- It represents the criteria for economical power production and it is given by,

$$s.f.c. = \frac{\dot{m}_f}{B.P.} \text{, kg / kWh}$$

## 7. Thermal Efficiency

- Thermal efficiency is the ratio of power developed to the energy supplied by fuel.
- The indicated thermal efficiency is given by,

$$\eta_{in.th.} = \frac{I.P.}{\dot{m}_f \times C.V.}$$

- The brake thermal efficiency is given by,

$$\eta_{br.th.} = \frac{B.P.}{\dot{m}_f \times C.V.}$$

where,     $\dot{m}_f$ = Mass of fuel in kg/sec

C.V. = Calorific value of fuel

## 4.10 Solved Examples

**Example 4.1 :** *Following data are collected from a 4-stroke single cylinder oil engine at full load. Bore = 200 mm, stroke = 280 mm, speed = 300 rpm, indicated mean effective pressure = 5.6 bar, torque on the brake drum = 250 Nm, oil consumed = 4.2 kg / hour, calorific value of oil = 41,000 kJ/kg. Determine mechanical efficiency, indicated thermal efficiency and brake thermal efficiency.* ☞ **[ Dec. 2009, 10 Marks ]**

**Solution :  Given data :**

d = 200 mm = 0.2 m, $l$ = 280 mm = 0.28 m,

N = 300 rpm, imep = 5.6 bar = $5.6 \times 10^5$ N/m$^2$, T = 250 Nm,

$\dot{m}_f$ = 4.2 kg/hr = $\dfrac{4.2}{3600}$ kg/sec. = $1.6666 \times 10^{-3}$ kg/sec, C.V. = 41000 kJ/kg, n = 1

**To find :**  i) $\eta_m$  ii) $\eta_{in.th.}$  iii) $\eta_{br.th.}$

**Step 1 :  Calculate the mechanical efficiency of oil engine**

1) Brake Power (B.P.)

$$B.P. = \frac{2\pi \times N \times T}{60 \times 1000} = \frac{2\pi \times 300 \times 250}{60 \times 1000} = 7.8539 \text{ kW}$$

2) Indicated Power (I.P.)

$$I.P. = \frac{n \times imep \times l \times A \times (N/2)}{60 \times 1000}$$

$$= \frac{1 \times 5.6 \times 10^5 \times 0.28 \times \left(\dfrac{\pi}{4}\right) \times (0.2)^2 \times \left(\dfrac{300}{2}\right)}{60 \times 1000} = 12.3150 \text{ kW}$$

Mechanical efficiency $\eta_m = \dfrac{\text{B.P.}}{\text{I.P.}} \times 100 = \dfrac{7.8539}{12.3150} \times 100 = $ **63.77 %**                    …Ans.

**Step 2 :  Calculate the indicated thermal efficiency of oil engine**

$\eta_{\text{in.th.}} = \dfrac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}} \times 100 = \dfrac{12.3150}{1.6666 \times 10^{-3} \times 41,000} \times 100 = $ **25.74 %**                    …Ans.

**Step 3 :  Calculate the brake thermal efficiency of oil engine**

$\eta_{\text{br.th.}} = \dfrac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}} = \dfrac{7.8539}{1.6666 \times 10^{-3} \times 41000} \times 100 = $ **17.24 %**                    …Ans.

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**Example 4.2 :** *A four stroke diesel engine has a piston diameter 250 mm and stroke 400 mm. The mean effective pressure is 4 bar and the speed is 500 rpm. The diameter of the brake drum is 1000 mm and the effective brake load is 400 N. Find indicated power, brake power and frictional power.*                    ☞ **[ June 2010, 10 Marks ]**

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**Solution :  Given data :**

d = 250 mm = 0.25 m, *l* = 400 mm = 0.4 m, imep = 4 bar = $4 \times 10^5$ N/m$^2$, N = 500 rpm,

$d_b$ = 1000 mm = 1 m, (W − S) = 400 N, n = 1

**To find :**  i) I.P. ii) B.P. iii) F.P.

**Step 1 :  Calculate the indicated power of diesel engine**

$$\text{I.P.} = \frac{n \times \text{imep} \times l \times A \times \left(\dfrac{N}{2}\right)}{60 \times 1000}$$

∴                    **I.P.** $= \dfrac{1 \times 4 \times 10^5 \times 0.4 \times \left(\dfrac{\pi}{4}\right) \times 0.25^2 \times \left(\dfrac{500}{2}\right)}{60 \times 1000} = $ **32.7249 kW**  …Ans.

**Step 2 :  Calculate the brake power of diesel engine**

**B.P.** $= \dfrac{(W - S)\, \pi\, d_b\, N}{60 \times 1000} = \dfrac{400 \times \pi \times 1 \times 500}{60 \times 1000} = $ **10.4719 kW**                    …Ans.

**Step 3 :  Calculate the frictional power of diesel engine**

**F.P.** = I.P. − B.P. = 32.7249 − 10.4719 = **22.2529 kW**                    …Ans.

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**Example 4.3 :** *A single cylinder four stroke engine runs at 1000 rpm has a bore of 115 mm and has a stroke of 140 mm. The brake load is 6 kg at 600 mm radius and the mechanical efficiency is 80 %. Calculate brake power and the mean effective pressure.*

☞ **[ Dec. 2010, 6 Marks ]**

**Solution : Given data :**

n = 1, N = 1000 rpm, d = 115 mm = 0.115 m, $l$ = 140 mm = 0.14 m

m = 6 kg, r = 600 mm = 0.6 m, $\eta_m$ = 80 % = 0.8

**To find :** i) B.P. ii) mep

**Step 1 : Calculate the brake power of engine**

$$\text{B.P.} = \frac{2\pi NT}{60 \times 1000} = \frac{2\pi \times 1000 \times 6 \times 9.81 \times 0.6}{60 \times 1000}$$

∴         **B.P. = 3.6982 kW**                                                   **…Ans.**

**Step 2 : Calculate the mean effective pressure of engine**

$$\eta_m = \frac{\text{B.P.}}{\text{I.P.}} \qquad \therefore \quad 0.8 = \frac{3.6982}{\text{I.P.}}$$

∴         I.P. = 4.6228 kW

$$\text{I.P.} = \frac{n \times \text{mep} \times l \times A \times (N/2)}{60 \times 1000}$$

$$4.6228 = \frac{1 \times \text{mep} \times 0.14 \times \left(\dfrac{\pi}{4}\right) \times 0.115^2 \times \left(\dfrac{1000}{2}\right)}{60 \times 1000}$$

∴         **mep = 381485 N/m$^2$   or   3.814 bar**                         **…Ans.**

**Example 4.4 :** *The following observations were recorded during a test on 4-stroke diesel engine :*
*Bore = 200 mm, Stroke = 250 mm, Mean effective pressure = 0.6 MPa.*
*Brake drum diameter = 1.2 m, Net brake load = 500 N, Speed of crank shaft = 600 rpm*
*Find i) Indicating power ii) Brake power iii) Friction power iv) Mechanical efficiency.*

☞ **[ June 2011, 10 Marks ]**

**Solution : Given data :**

d = 200 mm = 0.2 m, $l$ = 250 mm = 0.25 m, N = 600 rpm

imep = 0.6 MPa = 0.6 × 10$^6$ N/m$^2$, d$_b$ = 1.2 m,  (W − S) = 500 N

**To find :** i) I.P. ii) B.P. iii) F.P. iv) $\eta_m$

**Step 1 :** **Calculate the indicating power of diesel engine**

$$\text{I.P.} = \frac{n \times \text{imep} \times l \times A \times (N/2)}{60 \times 1000}$$

$$\text{I.P.} = \frac{1 \times 0.6 \times 10^6 \times 0.25 \times \left(\frac{\pi}{4}\right) \times (0.2)^2 \times \left(\frac{600}{2}\right)}{60 \times 1000} = \textbf{23.5619 kW} \quad \textbf{…Ans.}$$

**Step 2 :** **Calculate the brake power of diesel engine**

$$\text{B.P.} = \frac{(W - S)\,\pi\,d_b N}{60 \times 1000} = \frac{500 \times \pi \times 1.2 \times 600}{60 \times 1000} = \textbf{18.8495 kW} \quad \textbf{…Ans.}$$

**Step 3 :** **Calculate the frictional power of diesel engine**

$$\text{F.P.} = \text{I.P.} - \text{B.P.} = 23.5619 - 18.8495 = \textbf{4.7123 kW} \quad \textbf{…Ans.}$$

**Step 4 :** **Calculate the mechanical efficiency of diesel engine**

$$\eta_m = \frac{\text{B.P.}}{\text{I.P.}} \times 100 = \frac{18.8495}{23.5619} \times 100 = \textbf{79.99 \%} \quad \textbf{…Ans.}$$

---

**Example 4.5 :** *A single cylinder 4-stroke I.C. engine has bore = 180 mm, stroke = 200 mm, a rated speed = 300 rpm. Torque on the brakedrum = 200 N-m, mean effective pressure = 6 bar. It consumes 4 kg of fuel per hour. The calorific value of fuel = 42,000 kJ/kg. Determine B.P, I.P, brake thermal efficiency and mechanical efficiency.*

☞ **[ Dec 2011, 8 Marks ]**

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**Solution :** **Given data :**

n = 1, d = 180 mm = 0.18 m, $l$ = 200 mm = 0.2 m, N = 300 rpm

T = 200 N-m, mep = 6 bar = $6 \times 10^5$ N/m$^2$, $\dot{m}_f$ = 4 kg/hr = $\dfrac{4}{3600}$ = $1.1111 \times 10^{-3}$ kg/sec

C.V. = 42,000 kJ/kg

**To find :** i) B.P. ii) I.P. iii) $\eta_{br.th.}$ iv) $\eta_m$

**Step 1 :** **Calculate the brake power of I.C. engine**

$$\text{B.P.} = \frac{2\pi NT}{60 \times 1000} = \frac{2 \times \pi \times 300 \times 200}{60 \times 1000} = \textbf{6.2831 kW} \quad \textbf{…Ans.}$$

**Step 2 :  Calculate the indicated power of I.C. engine**

$$\text{I.P.} = \frac{n \times \text{mep} \times l \times A \times \dfrac{N}{2}}{60 \times 1000}$$

$\therefore$  **I.P.** $= \dfrac{1 \times 6 \times 10^5 \times 0.2 \times \left(\dfrac{\pi}{4}\right) \times (0.18)^2 \times \left(\dfrac{300}{2}\right)}{60 \times 1000} = $ **7.6340 kW**    ...Ans.

**Step 3 :  Calculate the brake thermal efficiency of I.C. engine**

$$\eta_{\text{br.th.}} = \frac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}} \times 100 = \frac{6.2831}{1.1111 \times 10^{-3} \times 42000} \times 100 = \textbf{13.46 \%}  \qquad \textbf{...Ans.}$$

**Step 4 :  Calculate the mechanical efficiency of I.C. engine**

$$\eta_m = \frac{\text{B.P.}}{\text{I.P.}} \times 100 = \frac{6.2831}{7.6340} \times 100 = \textbf{82.30 \%}  \qquad \textbf{...Ans.}$$

---

**Example 4.6 :** *A single cylinder two stroke petrol engine develops 7.5 kW at 2500 rpm. The mean effective pressure on the piston is 8 bar and mechanical efficiency is 80 %. Calculate the diameter and stroke of the cylinder if stroke to bore ratio is 1.5. Also calculate the fuel consumption rate if brake thermal efficiency is 28 %. The calorific value of the fuel is 43900 kJ/kg.*  ☞ **[ June 2012, 10 Marks ]**

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**Solution :  Given data :**

B.P. = 7.5 kW, N = 2500 rpm, mep = 8 bar = $8 \times 10^5$ N/m$^2$,

$\eta_m$ = 80 % = 0.8, $l/d$ = 1.5,  $\eta_{\text{br.th}}$ = 28 % = 0.28, C.V. = 43900 kJ/kg, n = 1

**To find :**  i) d   ii) $l$   iii) Fuel consumption rate ($\dot{m}_f$)

**Step 1 :  Calculate the bore and stroke length of petrol engine**

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

$\therefore$  $0.8 = \dfrac{7.5}{\text{I.P.}}$    $\therefore$  I.P. = 9.375 kW

Also,  $\text{I.P.} = \dfrac{n \times \text{mep} \times l \times A \times N}{60 \times 1000}$

$\therefore$  $9.375 = \dfrac{1 \times 8 \times 10^5 \times 1.5\, d \times \dfrac{4}{\pi} \times (d^2) \times 2500}{60 \times 1000}$

$\therefore$ $\qquad$ $d^3$ = $2.3873 \times 10^{-4}$

$\therefore$ $\qquad$ **d = 0.0620 m** or **62 mm** $\qquad$ **…Ans.**

$\therefore$ $\qquad$ **$l$** = 1.5 d = 1.5 × 62 = **93 mm** $\qquad$ **…Ans.**

**Step 2 : Calculate the fuel consumption rate of petrol engine**

$$\eta_{br.th.} = \frac{B.P.}{\dot{m}_f \times C.V.}$$

$\therefore$ $\qquad$ $0.28 = \dfrac{7.5}{\dot{m}_f \times 43900}$

$\therefore$ $\qquad$ **$\dot{m}_f$ = 0.000610 kg/sec** or **2.1965 kg/hr** $\qquad$ **…Ans.**

---

**Example 4.7 :** *A 4-stroke two cylinder petrol engine develops 30 kW at 2500 rpm. The mean effective pressure on the piston is 8 bar and mechanical efficiency is 80 %. Calculate the diameter and stroke of the cylinder if stroke to bore ratio is 1.5. Also calculate the fuel consumption rate if brake thermal efficiency is 28 %. The calorific value of the fuel is 43900 kJ/kg.* ☞ **[ Dec. 2012, 8 Marks ]**

---

**Solution : Given data :**

$\quad$ n = 2, B.P. = 30 kW, N = 2500 rpm, mep = 8 bar = $8 \times 10^5$ N/m$^2$,

$\eta_m$ = 80 % = 0.8, $l$/d = 1.5, $\eta_{br.th.}$ = 28 % = 0.28, C.V. = 43900 kJ/kg

**To find :** i) $l$ ii) d iii) $\dot{m}_f$

**Step 1 : Calculate the bore and stroke length of petrol engine**

$$\eta_m = \frac{B.P.}{I.P.} \qquad \therefore \ 0.8 = \frac{30}{I.P.} \qquad \therefore \ I.P. = 37.5 \text{ kW}$$

Also, $\qquad$ $I.P. = \dfrac{n \times mep \times l \times A \times \left(\dfrac{N}{2}\right)}{60 \times 1000}$

$\therefore$ $\qquad$ $37.5 = \dfrac{2 \times 8 \times 10^5 \times 1.5 \times d \times \left(\dfrac{\pi}{d}\right) \times d^2 \times \left(\dfrac{2500}{2}\right)}{60 \times 1000}$

$\therefore$ $\qquad$ $d^3$ = $9.5492 \times 10^{-4}$

$\therefore$ $\qquad$ **d = 0.0984 m** or **98.4745 mm** $\qquad$ **…Ans.**

$\therefore$ $\qquad$ **$l$** = 1.5 d = 1.5 × 98.4745 = **147.7117 mm** $\qquad$ **…Ans.**

---

**Step 2 :  Calculate the fuel consumption rate of petrol engine**

$$\eta_{br.th.} = \frac{B.P.}{\dot{m}_f \times C.V.}$$

$\therefore \quad 0.28 = \dfrac{30}{\dot{m}_f \times 43900} \quad \therefore \ \dot{m}_f = \textbf{0.00244 kg/sec} \quad \textbf{or} \ \ \textbf{8.7862 kg/hr} \qquad \textbf{...Ans.}$

---

**Example 4.8 :** *A 6-cylinder,  4-stroke IC engine develops 50 kW indicated power at mep of 700 kPa. The bore and stroke length indicated are 70 mm and 100 mm respectively. If the engine speed is 3700 rpm, find the average misfires per unit time.*

☞ **[ June 2013, 6 Marks ]**

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**Solution :  Given data :**

n = 6, I.P. = 50 kW, imep = 700 kPa = $7 \times 10^5$ N/m$^2$,

d = 70 mm = 0.07 m, $l$ = 100 mm = 0.1 m, N = 3700 rpm

**To find :** Average number of misfires per unit time

**Step 1 :  Calculate the average number of misfires per minute of I.C. engine**

$$I.P. = \frac{n \times imep \times l \times A \times \left(\dfrac{N}{2}\right)}{60 \times 1000}$$

$$\therefore \qquad 50 = \frac{6 \times 7 \times 10^5 \times 0.1 \times \left(\dfrac{\pi}{4}\right) \times 0.07^2 \times \left(\dfrac{N}{2}\right)}{60 \times 1000}$$

$\therefore \qquad N = 3712$ rpm

Actual number of fires in one minute $= \dfrac{3712}{2} \times 6 = 11136$

Expected number of fires in one minute $= \dfrac{3700}{2} \times 6 = 11100$

**Average number of misfires per minute** $= \dfrac{11136 - 11100}{6} = \textbf{6}$ \qquad **...Ans.**

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**Example 4.9 :** *The power output of an I.C. engine is measured by a rope brake dynamometer. The brake pulley diameter is 900 mm and rope diameter is 50 mm. The net load on brake is 500 N. Engine running at 1200 rpm and consumes fuel at a rate of 6 kg/hr. Calorific value of fuel is 43900 kJ/kg. Calculate brake specific fuel consumption and brake thermal efficiency.*

---

**Solution :  Given data :**

$d_b$ = 900 mm = 0.9 m, $d_r$ = 50 mm = 0.05 m, (W − S) = 500 N

N = 1200 rpm, $\dot{m}_f$ = 6 kg/hr, C.V. = 43900 kJ/kg

**To find :**  i) bsfc ii) $\eta_{br.th.}$

**Step 1 :  Calculate the brake specific fuel consumption of an I.C. engine**

$$B.P. = \frac{(W-S) \times \pi \times (d_b + d_r) \times N}{60 \times 1000}$$

$$= \frac{500 \times \pi \times (0.9 + 0.05) \times 1200}{60 \times 1000} = \mathbf{29.8451 \ kW} \qquad \textbf{...Ans.}$$

$$bsfc = \frac{\dot{m}_f}{B.P.} = \frac{6}{29.8451} = \mathbf{0.2010 \ kg/kWh} \qquad \textbf{...Ans.}$$

**Step 2 :  Calculate the brake thermal efficiency of an I.C. engine**

$$\eta_{br.th.} = \frac{B.P.}{\dot{m}_f \times C.V.} \times 100 = \frac{29.8451}{\left(\dfrac{6}{3600}\right) \times 43900} \times 100 = \mathbf{40.79 \ \%} \qquad \textbf{...Ans.}$$

---

**Example 4.10 :** *For a single cylinder four-stroke I.C. engine brake drum diameter = 1 m, rope diameter = 50 mm, crankshaft speed = 400 rpm, spring balance reading = 10 kg, load suspended on brake drum = 100 kg rate of the fuel consumed = 48 kg/hr, calorific value of fuel = 44000 kJ/kg. Determine the brake power and brake thermal efficiency.*

---

**Solution :  Given data :**

$d_b$ = 1 m, $d_r$ = 0.05 m, N = 400 rpm, S = 10 kg, W = 100 kg

$\dot{m}_f$ = 4 kg/hr, C.V. = 44000 kJ/kg

**To find :**  i) B.P. ii) $\eta_{br.th.}$

**Step 1 :  Calculate the brake power of I.C. engine**

$$\text{Effective radius, R} = \frac{d_b + d_r}{2} = \frac{1 + 0.05}{2} = 0.525 \text{ m}$$

Net load on brake drum = (W − S) × 9.81 = (100 − 10) × 9.81

$$(W - S) = 882.9 \text{ N}$$

$$B.P. = \frac{2\pi NT}{60 \times 1000}$$

$$\therefore \qquad \textbf{B.P.} \;=\; \frac{2\pi \times 400 \times 882.9 \times 0.525}{60 \times 1000} = \textbf{19.4159 kW} \qquad \qquad \textbf{...Ans.}$$

**Step 2 : Calculate the brake thermal efficiency of I.C. engine**

$$\eta_{\text{br.th.}} \;=\; \frac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}} \times 100 = \frac{19.4159}{\left(\dfrac{4}{3600}\right) \times 44000} \times 100 = \textbf{39.7145 \%}$$

$$\textbf{...Ans.}$$

---

**Example 4.11 :** *A four cylinder four stroke S.I. engine has mean effective pressure of 8 bar. The engine develops 30 kW power and 80 % mechanical efficiency. The bore diameter and stroke are 300 mm and 150 mm respectively. The fuel consumption rate is 5 kg / hr and calorific value of fuel is 43900 kJ/kg. Calculate the rated speed of engine and indicated thermal efficiency.*

---

**Solution : Given data :**

d = 300 m = 0.3 m, $l$ = 450 mm = 0.45 m, $\dot{m}_f$ = 5 kg/hr

B.P. = 30 kW, mep = 8 bar = $8 \times 10^5$, $\eta_m$ = 80 % = 0.8

C.V. = 43900 kJ/kg, n = 4

**To find :** i) N    ii) $\eta_{\text{in.th.}}$

**Step 1 : Calculate the rated speed of S.I. engine**

$$\eta_m \;=\; \frac{\text{B.P.}}{\text{I.P.}} \qquad \therefore \quad 0.8 = \frac{30}{\text{I.P.}} \qquad \therefore \quad \text{I.P.} = 37.5 \text{ kW}$$

$$\text{I.P.} \;=\; \frac{n \times \text{mep} \times l \times \text{A} \times (\text{N}/2)}{60 \times 1000}$$

$$\therefore \qquad 37.5 \;=\; \frac{4 \times 8 \times 10^5 \times 0.45 \times \left(\dfrac{\pi}{4}\right) \times (0.3)^2 \times (\text{N}/2)}{60 \times 1000}$$

$$\therefore \qquad \textbf{N} \;=\; \textbf{44.2097 rpm} \qquad \qquad \textbf{...Ans.}$$

**Step 2 : Calculate indicated thermal efficiency of S.I. engine**

$$\eta_{\textbf{br.th.}} \;=\; \frac{\text{I.P.}}{\dot{m}_f \times \text{C.V.}} \times 100 = \frac{37.5}{\left(\dfrac{5}{3600}\right) \times 43900} \times 100 = \textbf{61.50 \%} \quad \textbf{...Ans.}$$

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**Example 4.12 :** *A 6 cylinder four stroke I.C. engine is to develop 100 kW indicated power at 600 rpm. The stroke to bore ratio is 1.5. The mean effective pressure is 6 bar. Mechanical efficiency is 85 %. Calculate the bore and stroke, and if fuel consumption rate is 9 kg/hr and calorific value of fuel is 44,000 kJ/kg. Calculate brake thermal efficiency*

**Solution :  Given data :**

n = 6, I.P. = 100 kW, N = 600 rpm, $l/d$ = 1.5, mep = 6 bar = $6 \times 10^5$ N/m$^2$

$\eta_m$ = 85 % = 0.85, $\dot{m}_f$ = 9 kg/hr, n = 6

**To find :**  i) $l$   ii) d  iii) $\eta_{br.th.}$

**Step 1 :  Calculate the bore and stroke of I.C. engine**

$$\eta_m = \frac{B.P.}{I.P.} \quad \therefore \quad 0.85 = \frac{B.P.}{100} \quad \therefore \quad B.P. = 85 \text{ kW}$$

$$B.P. = \frac{n \times mep \times l \times A \times N/2}{60 \times 1000}$$

$$\therefore \qquad 85 = \frac{6 \times 6 \times 10^5 \times 1.5 \times d \times \left(\dfrac{\pi}{4}\right) \times d^2 \times (600/2)}{60 \times 1000}$$

$$\therefore \qquad d^3 = 4.0083 \times 10^{-3}$$

$$\therefore \qquad \mathbf{d = 158.85 \text{ mm}} \qquad\qquad\qquad \textbf{…Ans.}$$

$$l = 1.5 \text{ d} = 1.5 \times 158.85 = \mathbf{238.275 \text{ mm}} \qquad \textbf{…Ans.}$$

**Step 2 :  Calculate the brake thermal efficiency of I.C. engine**

$$\eta_{\textbf{br.th.}} = \frac{B.P.}{\dot{m}_f \times C.V.} \times 100 = \frac{85}{\left(\dfrac{9}{3600}\right) \times 44000} \times 100 = \mathbf{77.27 \%} \textbf{ …Ans.}$$

**Example 4.13 :** *In a trial of single cylinder oil engine, the following observations were made : Oil consumption = 8 kg/hr, C.V. of fuel = 43900 kJ/kg, speed = 1500 rpm, torque on brake drum = 250 Nm. Calculate i) Brake power ii) Brake specific fuel consumption iii) Brake thermal efficiency.*

**Solution :  Given data :**

$\dot{m}_f$ = 8 kg/hr, C.V. = 43900 kJ/kg, N = 1500 rpm, T = 250 Nm

**To find :** i) B.P. ii) bsfc iii) $\eta_{br.th.}$

**Step 1 :** **Calculate the brake power of oil engine**

$$\text{B.P.} = \frac{2\pi NT}{60 \times 1000} = \frac{2 \times \pi \times 1500 \times 250}{60 \times 1000} = \textbf{39.2699 kW} \qquad \textbf{…Ans.}$$

**Step 2 :** **Calculate the brake thermal specific consumption of oil engine**

$$\text{bsfc} = \frac{\dot{m}_f}{\text{B.P.}} = \frac{8}{39.2699} = \textbf{0.2037 kg/kWh} \qquad \textbf{…Ans.}$$

**Step 3 :** **Calculate the brake thermal efficiency of oil engine**

$$\eta_{br.th.} = \frac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}} \times 100$$

$$= \frac{39.2699}{\left(\dfrac{8}{3600}\right) \times 43900} \times 100 = \textbf{40.2538 \%} \qquad \textbf{…Ans.}$$

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**Example 4.14 :** *The following results refer to a test on I.C. engine : Indicative power = 42 kW, frictional power = 7 kW, engine speed = 1800 rpm, specific fuel consumption per B.P. = 0.30 kg/kWh, calorific value of fuel used = 43000 kJ/kg. Calculate i) Mechanical efficiency ii) Brake thermal efficiency iii) Indicated thermal efficiency.*

☞ **[ GTU : 2008 ]**

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**Solution : Given data :**

I.P. = 42 kW, F.P. = 7 kW, N = 1800 rpm, sfc = 0.30 kg/kWh

C.V. = 43,000 kJ/kg

**To find :** i) $\eta_m$ ii) $\eta_{br.th.}$ iii) $\eta_{in.th.}$

**Step 1 :** **Calculate the mechanical efficiency of I.C. engine**

$$\text{B.P.} = \text{I.P.} - \text{F.P.} = 42 - 7 = 35 \text{ kW}$$

$$\eta_m = \frac{\text{B.P.}}{\text{I.P.}} \times 100 = \frac{35}{42} \times 100 = \textbf{83.3334 \%} \qquad \textbf{…Ans.}$$

**Step 2 :** **Calculate the brake thermal efficiency of I.C. engine**

$$\text{sfc} = \frac{\dot{m}_f}{\text{B.P.}} \quad \therefore \quad 0.30 = \frac{\dot{m}_f}{35} \quad \therefore \quad \dot{m}_f = 10.5 \text{ kg/h}$$

$$\eta_{\text{br.th.}} = \frac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}} \times 100 = \frac{35}{\left(\dfrac{10.5}{3600}\right) \times 43000} \times 100 = \textbf{27.90 \%}$$

…Ans.

**Step 3 : Calculate the indicated thermal efficiency of I.C. engine**

$$\eta_{\text{in.th.}} = \frac{\text{I.P.}}{\dot{m}_f \times \text{C.V.}} \times 100 = \frac{42}{\left(\dfrac{10.5}{3600}\right) \times 43000} \times 100 = \textbf{33.48 \%} \text{ …Ans.}$$

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**Example 4.15 :** *The following observations were recorded during a test of a single cylinder oil engine : Bore = 300 mm, stroke = 450 mm, speed = 300 rpm, mep = 6 bar, net brake load = 1.5 kN, brake drum diameter = 1.8 m, brake rope diameter = 2 cm. Calculate i) Brake power ii) Indicative power iii) Mechanical efficiency.* ☞ **[ GTU : 2009 ]**

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**Solution : Given data :**

d = 300 mm = 0.3 m, $l$ = 450 mm = 0.45 m, N = 300 rpm, mep = 6 bar = $6 \times 10^5$ N/m$^2$,

(W − S) = 1.5 kN, $d_b$ = 1.8 m, $d_r$ = 2 cm = 0.02 m

**To find :** i) B.P. ii) I.P. iii) $\eta_m$

**Step 1 : Calculate the brake power of oil engine**

$$\text{B.P.} = \frac{(W - S) \times \pi \times N \times (d_b + d_r)}{60 \times 1000}$$

$$= \frac{1.5 \times 10^3 \times \pi \times 300 \times (1.8 + 0.02)}{60 \times 1000} = \textbf{42.8827 kW} \qquad \text{…Ans.}$$

**Step 2 : Calculate the indicated power of oil engine**

$$\text{I.P.} = \frac{n \times \text{mep} \times l \times A \times (N/2)}{60 \times 1000}$$

$$= \frac{1 \times 6 \times 10^5 \times 0.45 \times (\pi/4) \times 0.3^2 \times (300/2)}{60 \times 1000}$$

$$\text{I.P.} = \textbf{47.7129 kW} \qquad \text{…Ans.}$$

**Step 3 : Calculate the mechanical efficiency of oil engine**

$$\eta_m = \frac{\text{B.P.}}{\text{I.P.}} \times 100 = \frac{42.8827}{47.7129} \times 100 = \textbf{89.8764 \%} \qquad \text{…Ans.}$$

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**Example 4.16 :** *The following readings were taken during the test of a single cylinder four-stroke oil engine : Cylinder diameter = 250 mm, stroke = 400 mm, mep = 6.5 bar, engine speed = 250 rpm, load on brake = 1080 N, effective diameter of the brake = 1.5 m, fuel used per hour = 10 kg. C.V. of fuel = 44300 kJ/kg. Calculate, i) Indicated power ii) Brake power iii) Mechanical efficiency iv) Indicated thermal efficiency.* ☞ **[ GTU : 2009 ]**

**Solution : Given data :**

d = 250 mm = 0.25 m, $l$ = 400 mm = 0.4 m, mep = 6.5 bar = $6.5 \times 10^5$ N/m$^2$,

N = 250 rpm, (W – S) = 1080 N, $d_b$ = 1.5 m, $\dot{m}_f$ = 10 kg/h, C.V. = 44300 kJ/kg

$$r_b = \frac{d_b}{2} = \frac{1.5}{2} = 0.75 \text{ m}$$

**To find :** i) I.P. ii) B.P. iii) $\eta_m$ iv) $\eta_{in.th.}$

**Step 1 : Calculate the indicated power of oil engine**

$$\textbf{I.P.} = \frac{n \times mep \times l \times A \times (N/2)}{60 \times 1000}$$

$$= \frac{1 \times 6.5 \times 10^5 \times 0.4 \times \left(\frac{\pi}{4}\right) \times (0.25)^2 \times (250/2)}{60 \times 1000}$$

$$= \textbf{26.5890 kW} \qquad \qquad \textbf{…Ans.}$$

**Step 2 : Calculate the brake power of oil engine**

$$\textbf{B.P.} = \frac{2\pi NT}{60 \times 1000} = \frac{2\pi \times 250 \times 1080 \times 0.75}{60 \times 1000} = \textbf{21.2057 kW} \qquad \textbf{…Ans.}$$

**Step 3 : Calculate the mechanical efficiency of oil engine**

$$\eta_\textbf{m} = \frac{\text{B.P.}}{\text{I.P.}} \times 100 = \frac{21.2057}{26.5890} \times 100 = \textbf{74.1745 \%} \qquad \textbf{…Ans.}$$

**Step 4 : Calculate the indicated thermal efficiency of oil engine**

$$\eta_\textbf{in.th.} = \frac{\text{I.P.}}{\dot{m}_f \times \text{C.V.}} \times 100 = \frac{26.5890}{\left(\dfrac{10}{3600}\right) \times 44300} \times 100 = \textbf{21.6073 \%} \qquad \textbf{…Ans.}$$

**Example 4.17 :** *For a four stroke single cylinder engine, load on brake drum = 50 kg, diameter of brake drum = 1250 mm, spring balance reading = 7 kg, engine speed = 450 rpm, fuel consumption = 4 kg/hr, C.V. of fuel = 43,000 kJ/kg. Determine i) Indicated thermal efficiency ii) Brake thermal efficiency. Assume mechanical efficiency is 70 %.* ☞ **[ GTU : 2010 ]**

**Solution :  Given data :**

W = 50 kg,  $d_b$ = 1250 mm = 1.25 m, S = 7 kg, N = 450 rpm, $\dot{m}_f$ = 4 kg/hr

C.V. = 43,000 kJ/kg, $\eta_m$ = 70 % = 0.7

**To find :**  i) $\eta_{in.th.}$  ii) $\eta_{br.th.}$

**Step 1 :  Calculate the indicated thermal efficiency of an engine**

$$T = (W - S) \times 9.81 \times \frac{d_b}{2}$$

$$T = (50 - 7) \times 9.81 \times \frac{1.25}{2}$$

$$B.P. = \frac{2\pi \, NT}{60 \times 1000} = \frac{2\pi \times 450 \times (50 - 7) \times 9.81 \times \left(\dfrac{1.25}{2}\right)}{60 \times 1000} = 12.4239 \text{ kW}$$

$$\eta_m = \frac{B.P.}{I.P.} \quad \therefore \quad 0.7 = \frac{12.4239}{I.P.} \quad \therefore \quad I.P. = 17.7484 \text{ kW}$$

$$\eta_{\textbf{in.th.}} = \frac{I.P.}{\dot{m}_f \times C.V.} \times 100 = \frac{17.7484}{\left(\dfrac{4}{3600}\right) \times 43000} \times 100 = \textbf{37.1479 \%} \qquad \textbf{...Ans.}$$

**Step 2 :  Calculate the brake thermal efficiency of an engine**

$$\eta_{\textbf{br.th.}} = \frac{B.P.}{\dot{m}_f \times C.V.} \times 100 = \frac{12.4239}{\left(\dfrac{4}{3600}\right) \times 43000} \times 100 = \textbf{26.0035 \%} \qquad \textbf{...Ans.}$$

---

**Example 4.18 :**  *During testing of a single cylinder two-stroke petrol engine, following data were obtained : brake torque = 640 Nm, cylinder diameter = 21 cm, speed = 350 rpm, stroke = 28 cm, mep = 5.6 bar, oil consumption = 8.16 kg/hr, C.V. = 42705 kJ/kg. Determine i) Mechanical efficiency ii) Indicted thermal efficiency iii) Brake thermal efficiency and iv) Brake specific fuel consumption.* ☞ **[ GTU : 2010 ]**

**Solution :  Given data :**

T = 640 Nm, d = 21 cm = 0.21 m, N = 350 rpm, $l$ = 28 cm = 0.28 m,

mep = 5.6 bar = 5.6 × 10$^5$ N/m$^2$, $\dot{m}_f$ = 8.16 kg/hr, C.V. = 42705 kJ/kg

**To find :**  i) $\eta_m$  ii) $\eta_{in.th.}$  iii) $\eta_{br.th.}$  iv) bsfc

**Step 1 :  Calculate the mechanical efficiency of petrol engine**

$$\text{I.P.} = \frac{n \times \text{mep} \times l \times A \times N}{60 \times 1000}$$

$$= \frac{1 \times 5.6 \times 10^3 \times 0.28 \times \left(\dfrac{\pi}{4}\right) \times (0.21)^2 \times 350}{60 \times 1000} = 31.6804 \text{ kW}$$

$$\text{B.P.} = \frac{2\pi NT}{60 \times 1000} = \frac{2 \times \pi \times 350 \times 640}{60 \times 1000} = 23.4572 \text{ kW}$$

$$\eta_{m} = \frac{\text{B.P.}}{\text{I.P.}} \times 100 = \frac{23.4572}{31.6804} \times 100 = \mathbf{74.0433 \%} \qquad \textbf{…Ans}$$

**Step 2 :  Calculate the indicated thermal efficiency of petrol engine**

$$\eta_{\text{in.th.}} = \frac{\text{I.P.}}{\dot{m}_f \times \text{C.V.}} \times 100$$

$$= \frac{31.6804}{\left(\dfrac{8.16}{3600}\right) \times 42705} \times 100 = \mathbf{32.7283 \%} \qquad \textbf{…Ans.}$$

**Step 3 :  Calculate the brake thermal efficiency of petrol engine**

$$\eta_{\text{br.th.}} = \frac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}} \times 100$$

$$= \frac{23.4572}{\left(\dfrac{8.16}{3600}\right) \times 42705} \times 100 = \mathbf{24.2331 \%} \qquad \textbf{…Ans.}$$

**Step 4 :  Calculate the brake specific fuel consumption of petrol engine**

$$\textbf{bsfc} = \frac{\dot{m}_f}{\text{B.P.}} = \frac{8.16}{23.4572} = \mathbf{0.3478 \text{ kg/kWh}} \qquad \textbf{…Ans.}$$

---

**Example 4.19 :** *A four cylinder, four stroke petrol engine develops 200 kW brake power at 2500 rpm. Stroke to bore ratio is 1 : 2. If mean effective pressure is 10 bar and mechanical efficiency is 81 %, calculate bore and stroke of the engine. Also calculate the indicated thermal efficiency and brake thermal efficiency if 65 kg/hr of petrol is consumed having calorific value of 42000 kJ/kg.* ☞ **[ GTU : 2011 ]**

---

**Solution : Given data :**

B.P. = 200 kW, $l/d$ = 1.2, mep = 10 bar = $10 \times 10^5$ N/m$^2$, n = 4

$\eta_m$ = 81 % = 0.81, $\dot{m}_f$ = 65 kg/hr, C.V. = 42000 kJ/kg, N = 2500 rpm

**To find :** i) $l$  ii) d  iii) $\eta_{in.th.}$  iv) $\eta_{br.th.}$

**Step 1 : Calculate the bore and stroke of the petrol engine**

$$\eta_m = \frac{B.P.}{I.P.} \quad \therefore \quad 0.81 = \frac{200}{I.P.} \quad \therefore \quad I.P. = 246.9135 \text{ kW}$$

$$I.P. = \frac{n \times mep \times l \times A \times (N/2)}{60 \times 1000}$$

$$\therefore \quad 246.9135 = \frac{4 \times 10 \times 10^5 \times 1.2 \times d \times \left(\frac{\pi}{d}\right) \times d^2 \times (2500/2)}{60 \times 1000}$$

$$\therefore \quad d^3 = 3.1438 \times 10^{-3}$$

$$\therefore \quad \mathbf{d = 0.1469 \text{ m} \quad or \quad 146.9 \text{ mm}} \qquad \text{...Ans}$$

$$l = 1.2 \text{ d} = 1.2 \times 146.9 = \mathbf{175.7921 \text{ mm}} \qquad \text{...Ans.}$$

**Step 2 : Calculate the indicated thermal efficiency of petrol engine**

$$\eta_{in.th.} = \frac{I.P.}{\dot{m}_f \times C.V.} \times 100 = \frac{246.9135}{\left(\frac{65}{3600}\right) \times 42000} \times 100 = \mathbf{32.56 \%} \text{...Ans.}$$

**Step 3 : Calculate the brake thermal efficiency of petrol engine**

$$\eta_{br.th.} = \frac{B.P.}{\dot{m}_f \times C.V.} \times 100 = \frac{200}{\left(\frac{65}{3600}\right) \times 42000} \times 100 = \mathbf{26.3736 \%}$$

$$\text{... Ans.}$$

**Example 4.20 :** *A four cylinder, two stroke engine develops 30 kW at 2500 rpm. The mean effective pressure of each cylinder is 800 kPa and mechanical efficiency is 80 %. Calculate brake power and mass flow rate of fuel if l / d = 1.5, brake thermal efficiency = 28 % and calorific value of fuel is = 44000 kJ/kg.* ☞ **[ GTU : 2011 ]**

**Solution : Given data :**

n = 4, I.P. = 30 kW, N = 2500 rpm, mep = 800 kPa,

$\eta_m$ = 80 % = 0.8, $l/d$ = 1.5, $\eta_{br.th.}$ = 28 %, = 0.28 C.V. = 44000 KJ/kg

**To find :** i) B.P. ii) $\dot{m}_f$

**Step 1 : Calculate the brake power of the engine**

$$\eta_m \; = \; \frac{B.P.}{I.P.} \quad \therefore \quad 0.8 = \frac{B.P.}{30} \quad \therefore \quad \textbf{B.P. = 24 kW} \qquad \textbf{...Ans.}$$

**Step 2 : Calculate the mass flow rate of the engine**

$$\eta_{br.th.} \; = \; \frac{B.P.}{\dot{m}_f \times C.V.}$$

$$\therefore \qquad 0.28 \; = \; \frac{24}{\dot{m}_f \times 44000}$$

$$\therefore \qquad \dot{m}_f \; = \; \textbf{0.00194 kg/s or 7.0129 kg/hr} \qquad \textbf{...Ans.}$$

## 4.11 Multiple Choice Questions

**Q.1** Petrol engine works on _____ cycle .

    a) joule      b) otto      c) diesel      d) all of these

    **[Ans. : b]**

**Q.2** _____ is used to compress the charge during compression stroke.

    a) Crank      b) Connecting rod    c) Piston      d) None of these

    **[Ans. : c]**

**Q.3** _____ is called as the backbone of the engine.

    a) Piston      b) Connecting rod    c) Crank      d) Crank shaft

    **[Ans. : d]**

**Q.4** _____ is used to connect small end of the connecting rod to piston.

    a) Crank      b) Crank pin      c) Gudgeon pin      d) None of these

    **[Ans. : c]**

**Q.5** Clearance volume is the volume contained in the cylinder above the top of piston when _____ .

    a) it is at T.D.C.                     b) it is at B.D.C.

    c) it is in between T.D.C. to B.D.C.      d) none of these      **[Ans. : a]**

**Q.6** In four stroke petrol engine, each stroke consists of _____ of crankshaft rotation.

a) 360º            b) 0º            c) 180º            d) 720º

**[Ans. : c]**

**Q.7** For four-stroke petrol engines, the cycle consists _____ of crankshaft rotation for one cycle.

a) 360º            b) 0º            c) 180º            d) 720º

**[Ans. : d]**

**Q.8** For S.I. engine during _____ stroke both inlet and outlet valves remains closed.

a) suction        b) compression    c) expansion      d) exhaust

**[Ans. : b]**

**Q.9** At the end of _____ stroke exhaust valve opens but the inlet valve remains closed.

a) suction        b) compression    c) expansion      d) exhaust

**[Ans. : d]**

**Q.10** In C.I. engine, fuel supply is controlled by _____.

a) throttle valve    b) spark plug    c) fuel pump     d) none of these

**[Ans. : c]**

**Q.11** For S.I. engine, compression ratio is _____.

a) low                              b) high

c) moderate                        d) equal to C.I. engine      **[Ans. : a]**

**Q.12** The efficiency of S.I. engine is _____ than C.I. engine.

a) less                            b) higher

c) moderate                        d) equal to C.I. engine      **[Ans. : a]**

**Q.13** For light duty vehicles _____ type of engines are used.

a) S.I.                            b) C.I.

c) both S.I and C.I.               d) None of these             **[Ans. : a]**

**Q.14** In two stroke petrol engine piston is given a _____ shape.

a) circular                        b) crown

c) cylindrical                     d) None of these             **[Ans. : b]**

**Q.15** The Otto's cycle is the theoretical _____ cycle of the spark ignition engine.

a) constant volume                 b) constant pressure

c) both constant volume and constant pressure

d) None of these                                               **[Ans. : a]**

**Q.16** For I.C. engine mechanical efficiency $\eta_m = \underline{\hspace{2cm}}$ .

a) $\dfrac{\text{B.P.}}{\dot{m}_f \times \text{C.V.}}$      b) $\dfrac{\text{B.P.}}{\text{I.P.}}$      c) $\dfrac{\text{I.P.}}{\dot{m}_f \times \text{C.V.}}$      d) $\dfrac{\text{I.P.}}{\text{B.P.}}$    **[Ans. : b]**

**Q.17** For S.I. engine compression ratio varies between $\underline{\hspace{2cm}}$ .

a) 6 to 12                    b) 14 to 22

c) 20 to 30                 d) none of these      **[Ans. : a]**

**Q.18** For C.I. engine compression ratio varies between $\underline{\hspace{2cm}}$ .

a) 6 to 12                    b) 14 to 22

c) 20 to 30                 d) none of these      **[Ans. : b]**

**Q.19** Specific fuel consumption of four-stroke engine is $\underline{\hspace{2cm}}$ than two-stroke engine.

a) high                        b) low

c) equal                      d) moderate      **[Ans. : b]**

**Q.20** The ratio of brake power to indicated power is $\underline{\hspace{2cm}}$ .

a) volumetric efficiency        b) relative efficiency

c) thermal efficiency           d) mechanical efficiency      **[Ans. : d]**

**Q.21** In two-stroke engine, power is developed $\underline{\hspace{2cm}}$ .    ☞ **[ Dec. 2009 ]**

a) in every revolution         b) once in 2 revolutions

c) at half the revolution       d) in every stroke      **[Ans. : a]**

**Q.22** In diesel engine, during suction stroke $\underline{\hspace{2cm}}$ is sucked in the cylinder.

☞ **[ Dec. 2009 ]**

a) air-fuel mixture           b) fuel - air mixture

c) air                       d) diesel      **[Ans. : c]**

**Q.23** Scavenging is employed in $\underline{\hspace{2cm}}$ .    ☞ **[ Dec. 2009 ]**

a) 4-stroke petrol engine      b) 4-stroke diesel engine

c) 2-stroke petrol or diesel engine    d) in all types of engines      **[Ans. : c]**

**Q.24** Flywheel is used $\underline{\hspace{2cm}}$ .    ☞ **[ Dec. 2009 ]**

a) to increase speed         b) to reduce fuel consumption

c) to make speed uniform      d) to increase torque      **[Ans. : c]**

**Q.25** The heart of an engine is _____ .   ☞ **[ June 2010 ]**

    a) valves                      b) connecting rod

    c) flywheel                 d) cylinder          **[Ans. : d]**

**Q.26** _____ is the thermodynamic cycle which is not followed by an I.C. engine.

                                                             ☞ **[ June 2010 ]**

    a) Diesel cycle              b) Brayton cycle

    c) Otto cycle               d) Dual cycle        **[Ans. : b]**

**Q.27** _____ is the type of motion of the connecting rod in an I.C. engine.

                                                             ☞ **[ June 2010 ]**

    a) Oscillation              b) Reciprocation

    c) Rotation                d) Vibration         **[Ans. : b]**

**Q.28** In a two-stroke cycle engine, there is a power stroke every _____ revolutions of the crank shaft.                 ☞ **[ June 2010 ]**

    a) two                         b) four

    c) one                         d) three             **[Ans. : c]**

**Q.29** A petrol engine works on _____ thermodynamic cycle.    ☞ **[ Dec. 2010 ]**

    a) otto cycle               b) diesel cycle

    c) dual combustion cycle      d) sterling cycle      **[Ans. : a]**

**Q.30** In four-stroke engines, number of rotations of the crankshaft to complete a cycle are _____ .                              ☞ **[ Dec. 2010 ]**

    a) 1                           b) 2

    c) 4                           d) 6                 **[Ans. : b]**

**Q.31** The part of an engine which stores energy during power stroke and suply the same for the other three strokes is, _____ .      ☞ **[ Dec. 2010 ]**

    a) piston                  b) crank

    c) connecting rod         d) flywheel          **[Ans. : d]**

**Q.32** In diesel engines, heat is supplied at constant _____ .      ☞ **[ Dec. 2010 ]**

    a) temperature             b) pressure

    c) volume                  d) area               **[Ans. : b]**

**Q.33** The combustion of fuel in petrol engine takes place at _____ . ☞ **[ June 2011 ]**

a) constant pressure                b) constant volume

c) constant temperature            d) none of these          **[Ans. : b]**

**Q.34** In C.I. engine, during suction stroke _____ is sucked into the cylinder.

☞ **[ June 2011 ]**

a) diesel                          b) diesel and air mixture

c) diesel and petrol mixture       d) air                    **[Ans. : d]**

**Q.35** In a four stroke C.I. engine, during suction stroke,_____ . ☞ **[ Dec. 2011 ]**

a) only air is sucked in           b) only diesel is sucked in

c) both air and diesel is sucked in   d) either diesel or air is sucked in

**[Ans. : a]**

**Q.36** In two-stroke engine, the number of revolutions made by the crank to complete one cycle is, _____ . ☞ **[ Dec. 2011 ]**

a) 1              b) 2              c) 3              d) 4      **[Ans. : a]**

**Q.37** The brake power of an engine is always _____ than indicated power.

☞ **[ Dec. 2011 ]**

a) equal to                        b) less than

c) greater than                    d) reciprocal of          **[Ans. : b]**

**Q.38** The inner diameter of engine cylinder is called as _____ . ☞ **[ Dec. 2011 ]**

a) stroke                          b) clearance

c) bore                            d) pitch                  **[Ans. : c]**

**Q.39** The overall efficiency of an I.C. engine is _____ . ☞ **[ June 2012 ]**

a) mechanical efficiency           b) brake thermal efficiency

c) indicated thermal efficiency    d) none of these          **[Ans. : b]**

**Q.40** The air-fuel ratio in a petrol engine is governed by _____ . ☞ **[ June 2012 ]**

a) injector                        b) governor

c) carburetor                      d) flywheel               **[Ans. : c]**

**Q.41** The ratio of speed of the camshaft to speed of the crankshaft in four-stroke cycle engine is _____ . ☞ **[ June 2012 ]**

a) 1 : 2　　　　　　　　　　　b) 2 : 1

c) 1 : 1　　　　　　　　　　　d) none of these　　　**[Ans. : a]**

**Q.42** For the same speed and power, the size of the flywheel of a four stroke petrol engine is _____ . ☞ **[ June 2012 ]**

a) same as that of two-stroke petrol engine

b) larger than that of two-stroke petrol engine

c) smaller than that of two-stroke petrol engine

d) all of these　　　**[Ans. : b]**

**Q.43** The motion of piston is _____ . ☞ **[ Dec. 2012 ]**

a) rotary　　　　　　　　　　b) oscillatory

c) rectilinear　　　　　　　　d) circular　　　**[Ans. : b]**

**Q.44** Diesel engine is also called as _____ . ☞ **[ Dec. 2012 ]**

a) four-stroke engine　　　　b) two-stroke engine

c) C.I. engine　　　　　　　d) S.I. engine　　　**[Ans. : c]**

**Q.45** The power measured in the crankshaft of engine is _____ . ☞ **[ Dec. 2012 ]**

a) indicated power　　　　　b) brake power

c) horse power　　　　　　　d) torque　　　**[Ans. : b]**

**Q.46** _____ is fed into diesel engine through inlet valve. ☞ **[ Dec. 2012 ]**

a) Fuel　　　　　　　　　　b) Diesel

c) Air-fuel mixture　　　　　d) Air　　　**[Ans. : d]**

**Q.47** Flywheel is used as an energy _____ . ☞ **[ June 2013 ]**

a) receiver　　　　　　　　　b) reservoir

c) mixer　　　　　　　　　　d) multiplier　　　**[Ans. : b]**

**Q.48** Mechanical efficiency of a four-stroke engine is _____ . ☞ **[ June 2013 ]**

a) medium　　　　　　　　　b) high

c) low　　　　　　　　　　　d) balanced　　　**[Ans. : c]**

**Q.49** The output shaft of I.C. engine is _____ . ☞ **[ June 2013 ]**

    a) camshaft                        b) crankshaft

    c) rotary shaft                     d) axial shaft        **[Ans. : b]**

**Q.50** In C.I. engine, charge means _____ . ☞ **[ June 2013 ]**

    a) air and fuel                     b) only fuel

    c) air and water                   d) only air          **[Ans. : a]**

**Q.51** Otto cycle engine is an example of _____ . ☞ **[ Dec. 2013 ]**

    a) petrol engine                   b) diesel engine

    c) dual engine                     d) all of these       **[Ans. : a]**

**Q.52** Four-stroke engine has power stroke in _____ .

    a) every cycle                     b) every alternate cycle

    c) every third cycle

    d) in all the revolution of the crank shaft      ☞ **[ Dec. 2013 ]**

                                                  **[Ans. : a]**

**Q.53** In two-stroke petrol engine compression ratio is _____ . ☞ **[ Dec. 2013 ]**

    a) 1 : 22          b) 1 : 11          c) 1 : 1         d) 1 : 80 **[Ans. : b]**

**Q.54** Diesel engine is also called as _____ . ☞ **[ Dec. 2013 ]**

    a) constant volume cycle              b) dual cycle

    c) constant pressure cycle           d) all of these       **[Ans. : c]**

## 4.12 University Questions with Answers

### June 2010

**Q.1** With neat sketches, explain the working principle of a four stroke petrol engine. **(Refer section 4.2)**         **[8]**

### Dec. 2010

**Q.2** With a neat sketch, explain the working principle of a four stroke diesel engine with the p-V diagram. **(Refer sections 4.3 and 4.8)**     **[10]**

**June 2011**

**Q.3** Name the thermodynamic cycle in petrol engine. Draw the p-V diagram of the same indicating various process. **(Refer section 4.7)** [6]

**Dec. 2011**

**Q.4** With neat sketches, explain the working of two stroke petrol engines. **(Refer section 4.5)** [8]

**June 2012**

**Q.5** Explain with a neat sketch, working of a two stroke petrol engine. **(Refer section 4.5)** [6]

**Dec. 2012**

**Q.6** With neat sketches, explain the working of two stroke petrol engines. **(Refer section 4.5)** [8]

**June 2013**

**Q.7** List out any four differences beween two-stroke and four-stroke engines. **(Refer section 4.6)** [4]

**Q.8** Draw a schematic diagram of I.C. engine and name the parts. **(Refer section 4.1.2)** [6]

**Dec. 2013**

**Q.9** Explain with a neat figure four-stroke petrol engine. **(Refer section 4.2)** [8]

**Q.10** List out any four differences beween two-stroke and four-stroke engines. **(Refer section 4.6)** [4]

**Q.11** Give advantages of two-stroke engine over four-stroke engine. **(Refer section 4.6)** [4]

*Internal Combustion (I.C.) Engines ends ...*

# Module - III

## Chapter - 5

# MACHINE TOOLS AND AUTOMATED MACHINE TOOL OPERATIONS

**Syllabus :** Turning, Facing, Knurling, Thread cutting, Taper turning by swivelling the compound rest, Drilling, Boring, Reaming, Tapping, Counter sinking, Counter boring. Plane milling, End milling, Slot milling. (No sketches of machine tools, Sketches to be used only for explaining operations. Students to be shown the available machine tools in the machine shop of the college before explaining the operations).

# 5.1 Introduction

- **Machine tools** are defined as the machines used for carrying out metal cutting processes (removing the material from the workpiece in the form of chips by using cutting tools) and surface finishing processes (imparting good surface finish to the already machined workpiece, with the negligible removal of the material).

- Machine tool is a power driven machine used for producing the components of required shape and size with desired accuracy and surface finish by removing the material from the workpieces.

- The shapes which are commonly produced through the machine tools used for metal cutting processes are flat, cylindrical, spherical or combination of two or all of them.

- For performing the operations successfully, every machine tool has to perform following functions :
  - Hold, support and guide the workpiece to be machined.
  - Hold, support and guide the cutting tool used for machining.
  - Impart the motion to the cutting tool or workpiece or both of them for producing the desired shape of the workpiece.
  - Regulate the cutting speed and feeding movement between the cutting tool and workpiece.

## 5.1.1 Classification of Machine Tools

- All the machine tools which are employed in machine shop may be classified as follows :

  1. According to the desired purpose.
  2. According to the size of chip removed.

### 1. According to the desired purpose

- The machine tools which are designed to perform only some specified operations so as to produce identical items in large quantity come under this category.

- The machine tools which come under this category are as follows :
  (i)   Single-purpose machine tool      (ii)  Multi-purpose machine tool
  (iii) Special purpose machine tool

### 2. According to the size of chip removed

#### *a) Machine tools producing larger sized chips*

- These machine tools are used for producing the components of required shape and size with desired accuracy by removing the material in the form of comparatively larger sized chips.

```
                        ┌──────────────────┐
                        │  Machine tools   │
                        └──────────────────┘
```

**According to the desired purpose**
(i)   Single-purpose machine tool
(ii)  Multi-purpose machine tool
(iii) Special purpose machine tool

**According to the size of chip removed**
*a) Machine tools producing larger sized chips*
(i)   Lathe machine
(ii)  Drilling machine
(iii) Milling machine
(iv)  Shaping machine, etc.
*b) Machine tools producing chips of very small size*
(i)   Grinding machine
(ii)  Lapping machine
(iii) Honing machine
(iv)  Polishing machine, etc.

**Fig. 5.1 : Classification of machine tools**

- In these type of machine tools for removing the material from the workpiece cutting tools are used.

- The machine tools which come under this category are as follows :
  (i)  Lathe machine         (ii) Drilling machine
  (iii) Milling machine      (iv) Shaping machine, etc.

### b) Machine tools producing chips of very small size

- These machine tools are used for producing the components with good surface finish and high accuracy by removing the materal in the form of chips of very small size.

- In these type of machine tools, for removing the material from the workpiece abrasives are used.

- The machine tools which come under this category are as follows :
  (i)  Grinding machine  (ii) Lapping machine
  (iii) Honing machine   (iv) Polishing machine, etc.

**Lathe Machine**

## 5.2 Lathe Machine

- **Lathe machine** is known as the mother of all the machine tools.

- It is one of the most widely used machine tool.

- Lathe was the first machine tool which came into being as a useful machine for metal cutting.

## 5.2.1 Working Principle of Lathe Machine

- Lathe is a machine tool which holds the workpiece securely between the two rigid and strong supports, called as centres or in a chuck or face plate, while the workpiece revolves.

- The cutting tool is rigidly held and supported in a tool post and is fed against the revolving workpiece.

- While the workpiece revolves about its own axis, the tool is made to move in parallel or at an inclination with the axis of a material to be cut.

- Hence, the main function of a lathe is to remove metal from a workpiece to give it desired shape and size.

- The material from the workpiece is removed in the form of chips.

- Fig. 5.2 shows the working principle of the lathe machine.
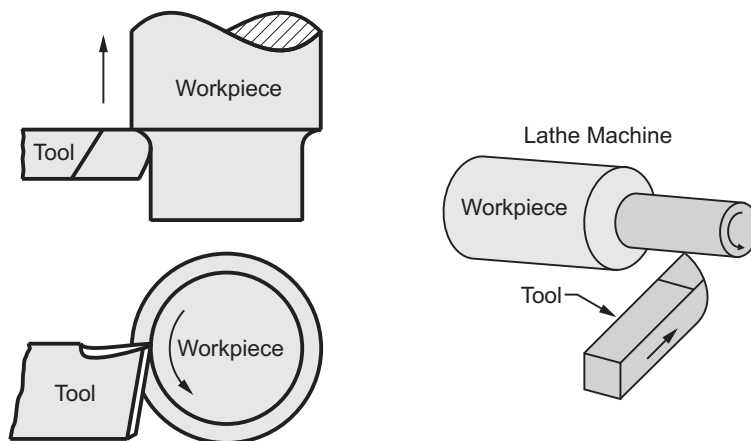


**Fig. 5.2 : Working principle of lathe machine**

- Also, to cut the material properly, the tool material should be harder than the workpiece material.

## 5.2.2 Basic Elements of Lathe Machine                ☞ [ June 2013 ]

- Fig. 5.3 shows the actual lathe machine which consists of following principal parts :

| | |
|---|---|
| a) Bed | b) Headstock |
| c) Tailstock | d) Carriage |
| e) Feed mechanism | f) Thread cutting mechanism (lead screw) |
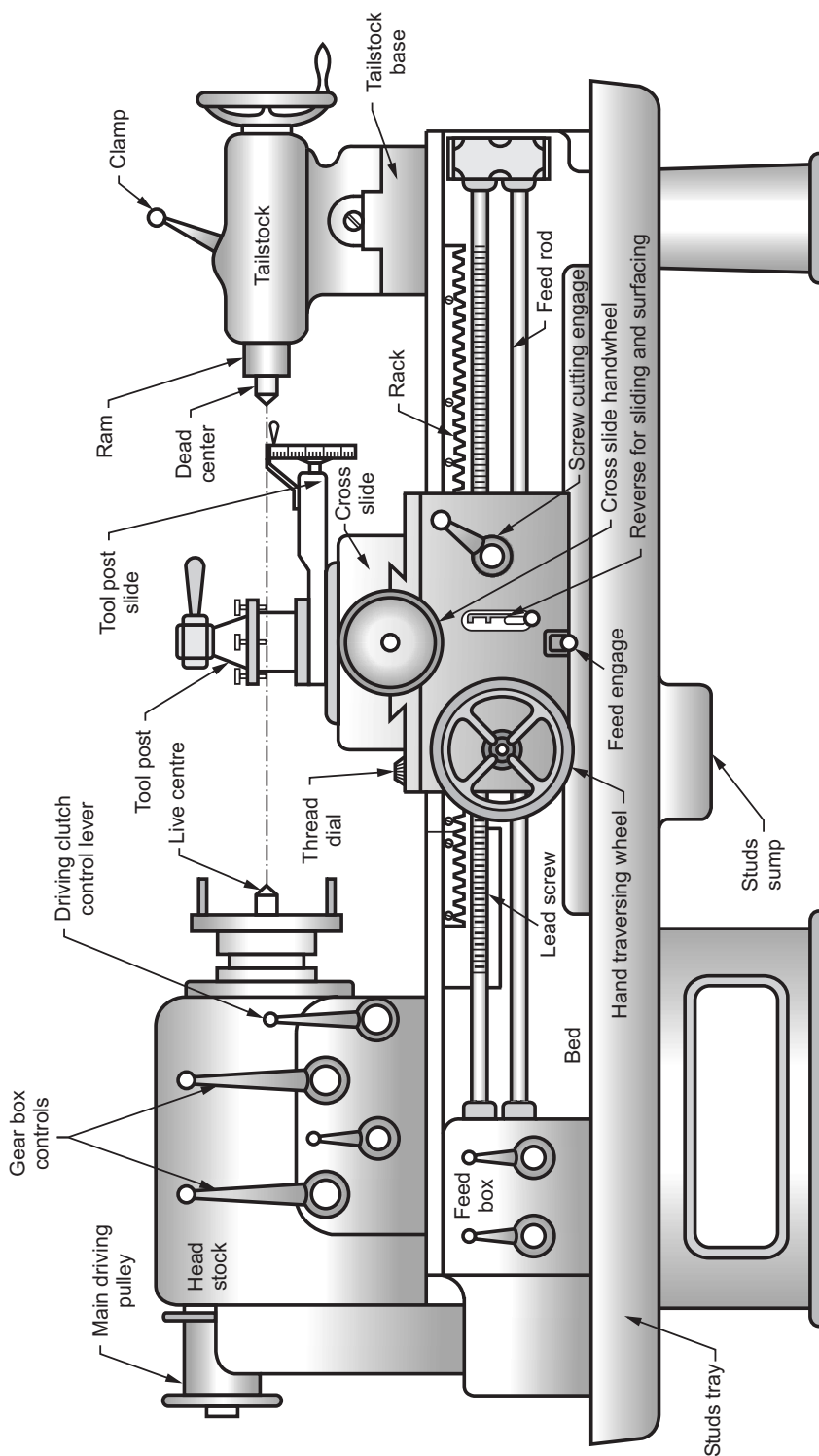
**Fig. 5.3 : Lathe machine**

**a) Bed :**

- It acts as a base of the machine on which, different fixed and operating parts of the lathe are mounted.

- The headstock and tailstock are mounted on either end of the bed and the carriage rests on the lathe bed and slides on it.

- Also, it has to withstand various forces exerted on the cutting tool during the operation.

- Usually, lathe bed is made up of cast iron alloyed with nickel and chromium.

**Functions of lathe bed :**

- It is used to support all the elements of lathe and to withstand cutting forces during the operation.

**b) Headstock :**

- The headstock is a box-like casting mounted permanently on the bed to the left hand end of the machine.

- The headstock supports the spindle (hollow rotating shaft used to hold the workpiece) and contains a gear-box by which the spindle may be rotated at various speeds.

**Functions of the headstock :**

- ○ To support the spindle.

- ○ To carry driving mechanism for the workpiece.

- ○ To give multiple speeds to the spindle.

**c) Tailstock :**

- Tailstock is also called as **loose headstock** or **puppet head**.

- Tailstock is situated at the right hand end of the bed and can be moved on the innerways of the bed.

**Functions of the tailstock :**

- ○ To support the other end of the workpiece when it is being machined between centres.

- ○ To hold a tool for performing operations such as drilling, reaming, tapping, etc.

- ○ To turn a taper on the workpiece by using tailstock set-over method.

**d) Carriage :**

- The lathe carriage is located between the headstock and tailstock of the lathe.

- It can be moved left or right between the headstock and tailstock either by handwheel or power-feed.

- It carries the cutting tool and precisely controls its movements.

**Functions of the carriage :** It is used for supporting, guiding and feeding the tool against the workpiece during the operation on the lathe.

- The different parts of carriage are tabulated as follows :

**Table 5.1 : Parts of a carriage**

| i) Saddle | It slides along the bedways of the lathe and supports the cross-slide, compound rest and tool post. |
|---|---|
| ii) Cross-slide | It is mounted on the top of the saddle and moves in a direction perpendicular to the axis of the main spindle. |
| iii) Compound rest | It is supported on the cross-slide and consists of a graduated circular base called as swivel plate which enables cross-slide to swivel at any required angle in a horizontal plane. |
| iv) Tool post | It is located on the top of the compound rest and used to hold the tool or tool holder in a convenient working position. |
| v) Apron | It is bolted to the front of the saddle. It houses the gears and controls for the carriage and feed mechanism. |

**e) Feed mechanism :**
- The movement of the tool relative to the workpiece is known as **feed.**
- The lathe tool can have longitudinal, cross and angular feed.
- The feed mechanism has various units through which motion is transmitted from the headstock spindle to the carriage.

**Functions of feed mechanism :** It is used to transmit the motion from headstock spindle to the carriage by using various units.

**f) Thread cutting mechanism (Lead screw) :**
- Lead screw is a long threaded shaft which is used as a master screw and it is brought into operation only when threads have to be cut.
- In all other time, it is disengaged from the gear box and remains stationary.
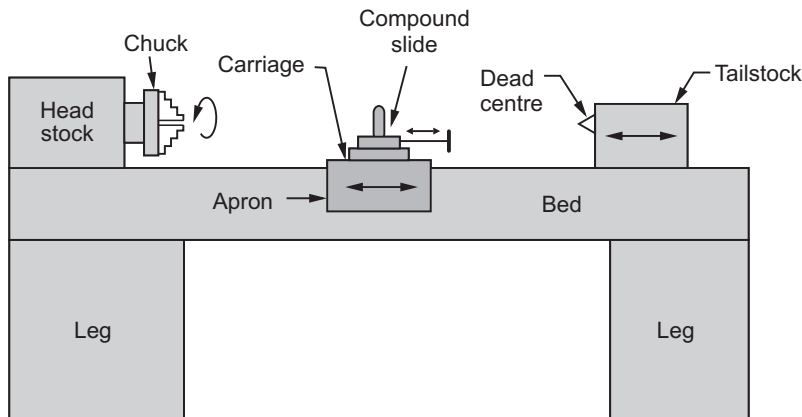


**Fig. 5.4 : Block diagram of a lathe machine**

**Functions of thread cutting mechanism :** It uses the rotation of the lead screw to traverse the tool along the workpiece for producing screw threads. It consists of pair of half-nuts which are capable of moving in or out of mesh with the lead screw.

Fig. 5.4 shows the block diagram of a lathe machine.

## 5.2.3 Specifications of Lathe Machine   ☞ **[ June 2011, Dec. 2012 ]**

In order to specify the size of a lathe, following specifications should be included (Refer Fig. 5.5) :

(a) **Height of the centres :** It is measured from the lathe bed.

(b) **The length between centres :** It is the maximum length of the workpiece that can be mounted between centres.

(c) **The length of bed :** It includes the length of headstock and tailstock.

(d) **The swing diameter over bed :** It is the largest diameter of the workpiece that revolves without touching the bed.

(e) **Swing diameter over carriage :** It is the largest diameter of the workpiece that can revolve over the lathe saddle. It is always less than swing diameter over the bed.

(f) **Maximum bar diameter :** It is the  maximum diameter of bar stock that passes through the hole of  the headstock spindle.

(g) **Spindle speed**.

(h) **Spindle nose diameter**.

(i) **Lead screw pitch**.

(j) **Motor horse power and R.P.M**.
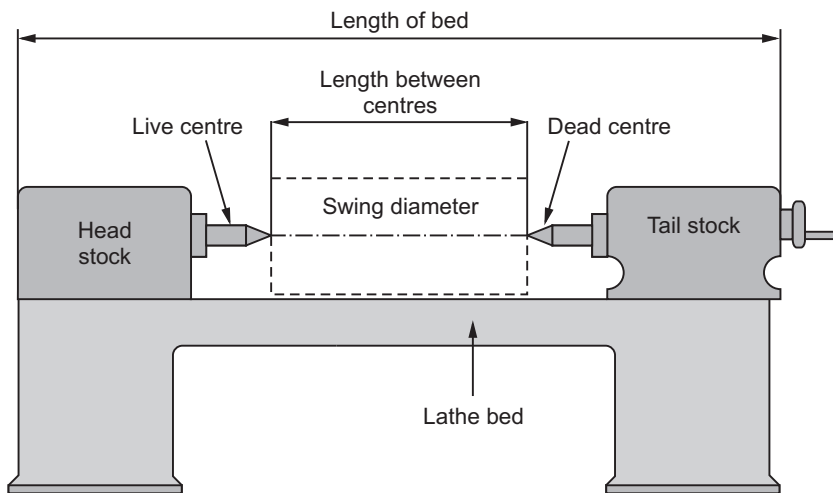


**Fig. 5.5 : Specification of lathe machine**

## 5.2.4 Lathe Machine Operations
☞ **[ Dec. 2010 ]**

The different operations performed on a lathe are as follows :

| | | |
|---|---|---|
| 1. Straight turning | 2. Step turning | 3. Eccentric turning |
| 4. Taper turning | 5. Facing | 6. Drilling |
| 7. Reaming | 8. Boring | 9. Knurling |
| 10. Thread cutting | 11. Counter-boring | 12. Counter-sinking |
| 13. Tapping | | |

**1. Straight turning :**

- This operation is performed for producing a cylindrical surface by removing the excess material from the workpiece.

- The cutting tool is held in the tool post and fed into the rotating work parallel to the lathe axis. Refer Fig. 5.6.

- It may be rough turning or finish turning.

- The tool used in this operation is called as **turning tool.**
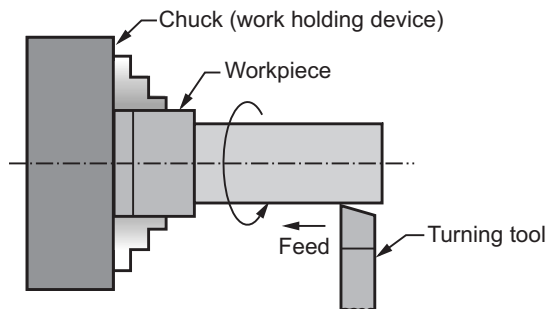


**Fig. 5.6 : Straight turning**

**2. Step turning :**

- Step turning is also called as **shoulder turning**.

- When workpiece of different diameters are turned, the surface formed from one diameter to the other is called as shoulder. Refer Fig. 5.7.
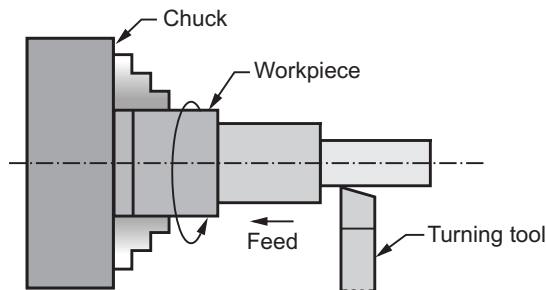


**Fig. 5.7 : Step turning**

- The machining of this part of the workpiece is known as shoulder turning.

## 3. Eccentric turning :

- If a cylindrical workpiece has two separate axis of rotation one being out of centre to the other, then the workpiece is called as **eccentric**.

- The turning of different surfaces of the workpiece is known as eccentric turning. Refer Fig. 5.8.
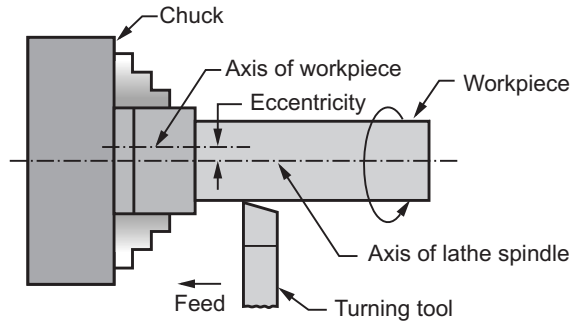


**Fig. 5.8 : Eccentric turning**

- For eccentric turning, the workpiece is first mounted on its true centre and turned, then it is remounted on the offset centre and the eccentric surfaces are machined.

## 4. Taper turning :

- In taper turning, workpiece is rotated on the lathe axis and tool is fed at an angle to the axis of rotation of the workpiece.

- The tool is mounted on the compound rest which is attached to circular base.

- A circular base is graduated in degrees which can be swivelled and clamped at any required angle. Refer Fig. 5.9.
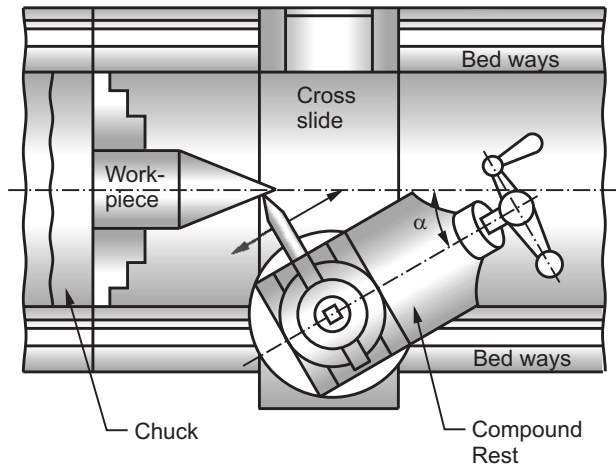


**Fig. 5.9 : Taper turning**

## 5. Facing :

- It is the operation of machining the ends of a workpiece to produce a flat surface with the axis.

- It involves feeding of the tool perpendicular to the axis of rotation of the workpiece. Refer Fig. 5.10.
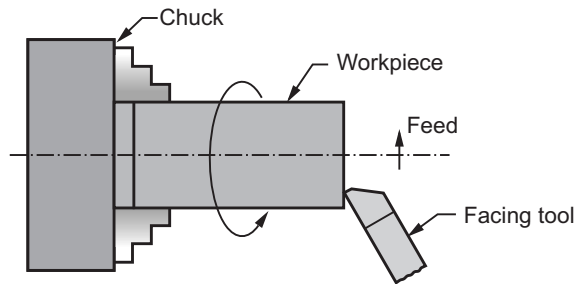


**Fig. 5.10 : Facing**

- The tool used for facing is properly ground and mounted in a tool holder of the tool post.

## 6. Drilling :

- Drilling is the process of producing cylindrical hole in the workpiece.

- In this operation, workpiece is held in a chuck or suitable device like face plate and the drill (tool) is held in the tailstock.

- During operation, the drill is fed by rotating the handwheel of the tailstock in clockwise direction. Refer Fig. 5.11.

- First a shorter length is drilled by using smaller and shorter drill, followed by producing the required diameter with the help of correct drill size.

- At the end of operation, the drill is taken out by rotating the handwheel of tailstock in anticlockwise direction.
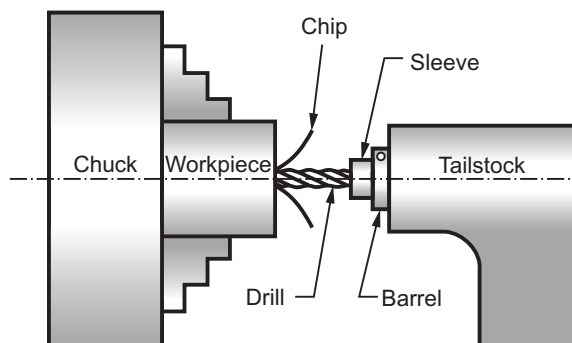


**Fig. 5.11 : Setup for drilling on a lathe**

## 7. Reaming :

- Reaming is a finishing operation because a very small amount of material is removed during the operation.

- For performing reaming a multi-teeth tool is used, which is called as ρεαμερ.

- During the operation, the workpiece is held in a chuck or face plate and the reamer shank is fitted in a sleeve or inserted in the tapered hole of the tailstock spindle. Refer Fig. 5.12.
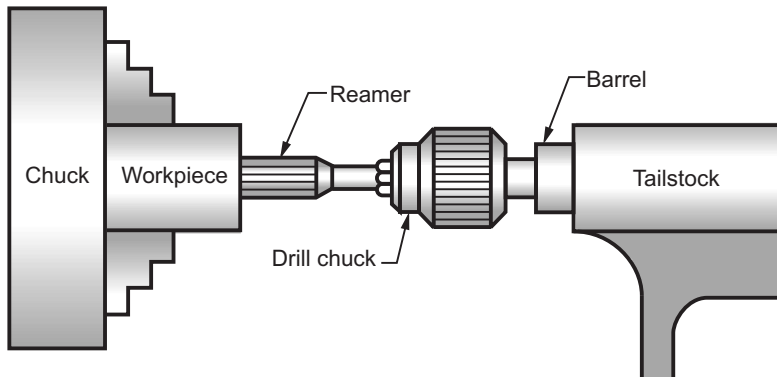


**Fig. 5.12 : Setup for reaming on a lathe**

## 8. Boring :

- It is an operation which is employed for machining internal surfaces, hence also called as **internal turning.**

- Boring is done to enlarge the already drilled hole and bring them to the exact required size.

- Generally, a single point solid boring tool is used for this purpose, which may be either rough or finish.
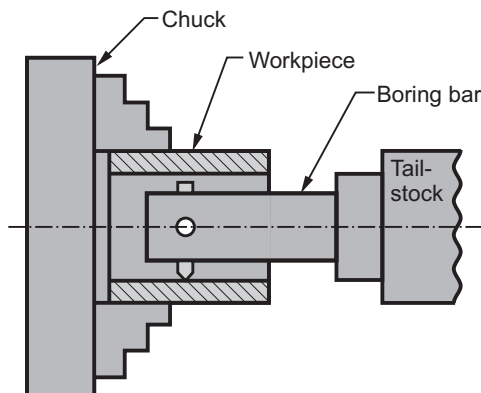


**Fig. 5.13 : Use of boring bars**

## 9. Knurling :

- Outer surfaces of some components such as dumbels, handles, measuring instruments and tools, gauges, etc. are generally provided with rolled impressions on them.

- These depressions are provided for better grip as compared to smooth surface.

- These indentations are known as knurls and the corresponding surface is known as **knurled surface.**

- The operation performed for producing this knurled surface is called as knurling.

- The tool used for knurling is termed as **knurling tool**, which consists of a straight shank fitted with one or two knurling wheels at its front. Refer Fig. 5.14 (a) and (b).



|  (a) Knurling | (b) Knurling tool |
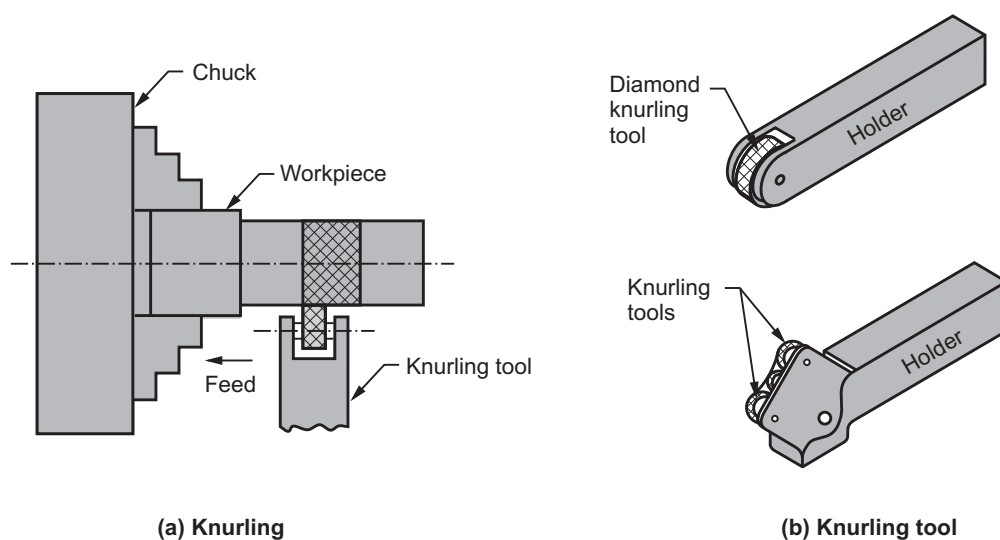
**Fig. 5.14**

## 10. Thread cutting :

- Cutting screw threads on a centre lathe is called as thread cutting.

- In thread cutting, helical grooves are produced on a cylindrical or conical surface by feeding the tool longitudinally when the workpiece is revolved between the centres (live centre and dead centre).

- For thread cutting, it is necessary that, for every revolution of the workpiece the tool should move parallel to the axis of workpiece by a distance equal to the lead of the screw to be cut.

- The motion is transmitted from the lathe spindle to the change gears and finally to the lead screw. Refer Fig. 5.15.
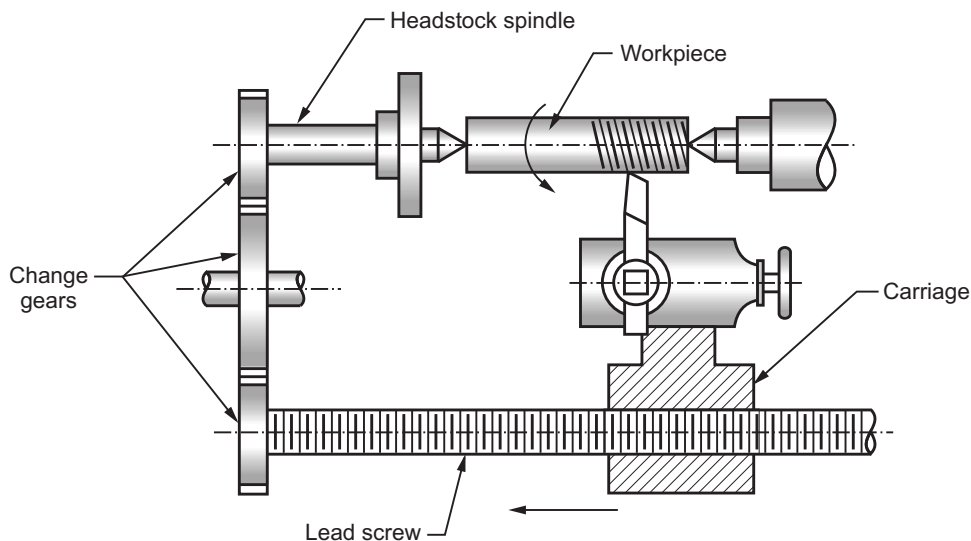
**Fig. 5.15 : Lathe setting for thread cutting**

## 11. Counter-boring :

- The operation which is used for enlarging only limited portion of the hole is called as **counter-boring** and the tool used for this purpose is called as **counterbore**.
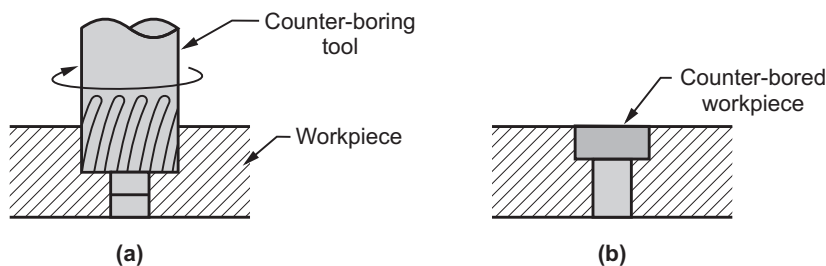


**Fig. 5.16 : Counter-boring operation**

- Fig. 5.16 shows counterboring operation in which the enlarged hole forms a square shoulder with the original hole.

- The cutting edges of counterbore may have straight or spiral teeth.

## 12. Counter-sinking :

- Countersinking operation is used for enlarging the end of a hole and to give it a conical shape for a short distance.

- Fig. 5.17 shows countersinking operation in which the tool used is called as countersunk.

- The standard countersinks have the included angles of 60°, 82° or 90° and cutting edges of tool are at the conical surface.

(a)  (b)
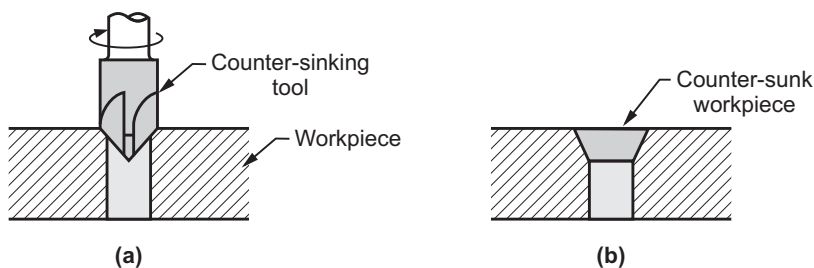
**Fig. 5.17 : Counter-sinking operation**

## 13. Tapping :

- Tapping is an operation of cutting internal threads by using a cutting tool called as **tap**.

- For tapping purpose, the machine should be equipped with a reversible motor or some other reversing mechanism.

- A tap is considered as a bolt with accurate threads cut on it and the threads act as cutting edges which are hardened and ground.

- Fig. 5.18 shows tapping operation in which the tap is screwed into the hole and metal is removed.
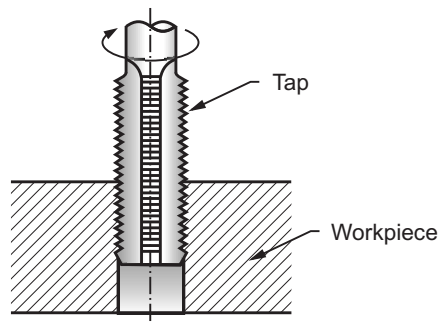


**Fig. 5.18 : Tapping operation**

## 5.2.5 Taper Turning by Swivelling Compound Rest

☞ **[ June 2012, Dec. 2013 ]**

- In this method, workpiece is rotated on the lathe axis and tool is fed at an angle to the axis of rotation of the workpiece.

- The tool is mounted on the compound rest which is attached to the circular base.

- A circular base is graduated in degrees, which can be swivelled and clamped at any required angle. Refer Fig. 5.19.

- Once the compound rest is set at the required half taper angle, rotation of the compound slide screw will cause the tool to be fed at that angle and corresponding taper is generated.

- Due to limited movement of compound rest, this method is suitable only for turning short taper.

- The compound rest can be swivelled at 45º on either side of the lathe axis; hence steep taper can also be turned.

- The tool movement is purely controlled by hand which gives low production capacity and poorer surface finish.
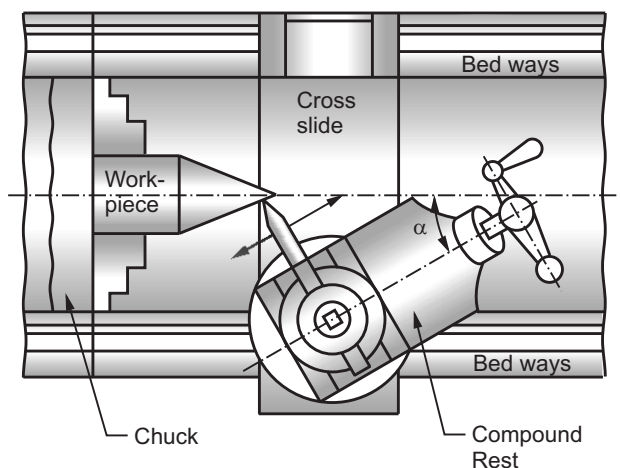
**Fig. 5.19 : Turning taper by swivelling the compound rest**

- The half angle of taper is calculated by,

$$\tan \alpha = \frac{D - d}{2l}$$

| **Milling Machine** |

## 5.3  Milling Machine

- Milling is the machining process in which the metal removal takes place due to the cutting action of a revolving cutter when workpiece is fed past it.
- The revolving cutter is held on a spindle or arbor and the workpiece is clamped on the machine table.
- During the process, to produce the desired shape, the cutter removes the metal in the form of chips from the workpiece surface.
- The machine tool on which the milling operation is performed is called as **Milling machine.**
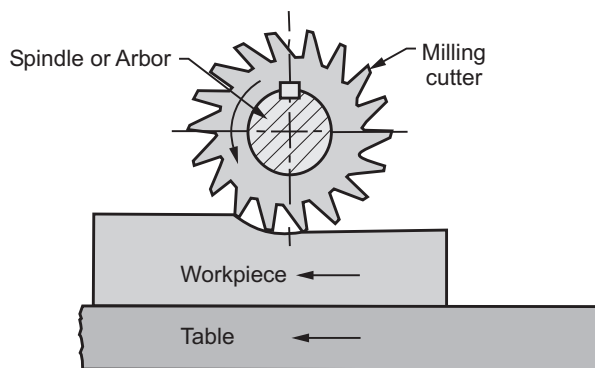


**Fig. 5.20 : Working principle of a milling machine**

- Also, the workpiece can be fed in a vertical, longitudinal or cross direction. Fig. 5.20 shows the working principle of a milling machine.

## 5.3.1 Basic Elements of Milling Machine

Column and knee type milling machine is the most commonly used type of milling machine. Fig. 5.21 shows block diagram of column and knee type milling machine. It consists of following basic elements.

| | |
|---|---|
| 1. Base | 2. Column |
| 3. Knee | 4. Table |
| 5. Saddle | 6. Over-arm |
| 7. Arbor | |

**1. Base :**

- Base is a heavy casting and provided at the bottom of the machine.
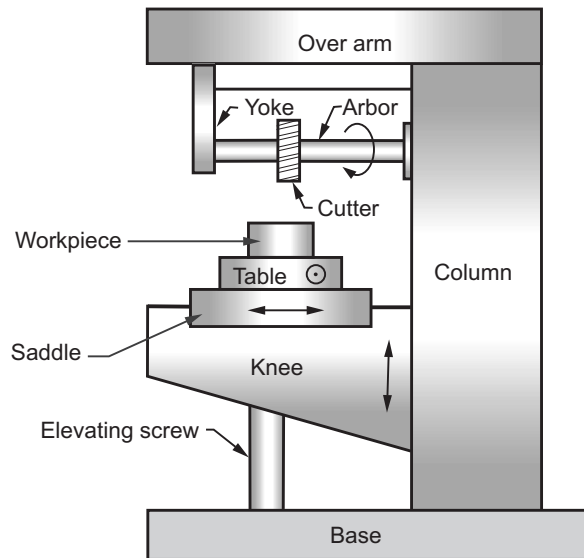


**Fig. 5.21 : Column and knee type milling machine**

- It acts as a load taking member for all other parts of the machine and a reservoir for the coolant.

- It also carries an elevating screw which supports and moves the knee.

**2. Column :**

- Column is important part of a milling machine because on the column many parts and controls are fitted.

- Front face of the column consists of vertical parallel guideways in which knee slides up and down.

- On the top of the column, over-arm is supported.

## 3. Knee :

- Knee is a rigid casting which is capable of sliding up and down along the guideways provided on front face of the column.
- With the movement of the knee, the table height or distance between the cutter and workpiece can be adjusted.

## 4. Table :

- The table acts as a support for the workpiece. It is mounted on the saddle.
- To accommodate the clamping bolts for fixing the workpiece, the top surface of the table carries T-slots.
- Longitudinal (along the length) feed is provided to the table by using hand wheel ($\leftrightarrow$), vertical feed is provided by raising or lowering the knee ($\updownarrow$) and cross feed by moving the saddle ($\bullet$).

## 5. Saddle :

- Saddle is the intermediate part between the table and knee which acts as a support for the table.
- To provide cross feed to the table, the saddle can be adjusted crosswise along the guideways provided on the top of the knee.

## 6. Over-arm :

- It is a heavy suppart provided on the top of the milling machine.

## 7. Arbor :

- Arbor is used for holding the milling cutters during the operations.
- One end of the arbor is supported by the over-arm and other end is by the yoke.

## 5.3.2  Milling Machine Operations                     ☞ **[ Dec. 2013 ]**

- A large variety of components can be machined on a milling machine which involves various types of operations. These operations can be broadly classified as follows :

  1. Plain or slab milling
  2. Slot and groove milling
  3. End milling

## 1. Plain or slab milling :

- It is used for machining a flat, plain, horizontal surface which is parallel to the axis of cutter. Refer Fig. 5.22.
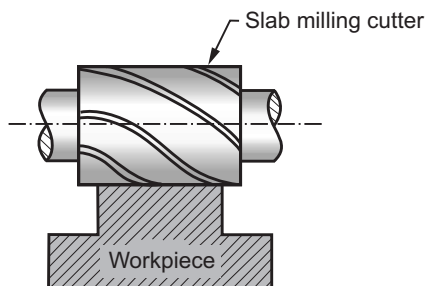
**Fig. 5.22 : Plain or slab milling**

- During the operation, the workpiece and cutter are secured properly on the machine; and by rotating the vertical feed screw of the table and machine, the depth of cut is adjusted.

- Following two methods are commonly used for performing this operation : a) Up milling b) Down milling

**a) Up milling :**

- Up milling is also called as **conventional milling.**

- In this method, cutter rotates in a direction opposite to that in which the workpiece is fed. Refer Fig. 5.23 (a).



**(a) Up or conventional milling**          **(b) Down or climb milling**
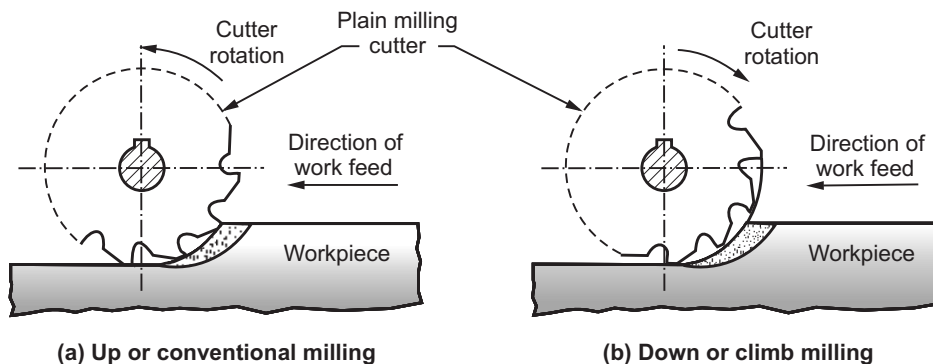
**Fig. 5.23**

**b) Down milling :**

- Down milling is also called as **climb milling**.

- In this method, the direction of rotation of the cutter and the direction of workpiece fed is same. Refer Fig. 5.23 (b).

**2. Slot and groove milling :**

- Slot milling is the operation of producing slots in solid workpieces.

- These slots can be of different shapes such as plain slots, T-slots, dovetail slots, etc. Refer Fig. 5.24.
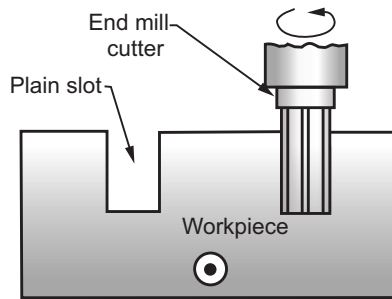
**Fig. 5.24 : Milling a plain slot by using an end mill cutter**

- Groove milling is the operation of producing grooves of various shapes like plain grooves, curved grooves, V-grooves, etc.

**3. End milling :**

- This operation is used to machine and produce a flat surface or a pair of flat surfaces by using an end milling cutter.
- Fig. 5.25 shows the end milling operation in which flat surface is produced with the help of an end milling cutter.
- The surfaces produced may be horizontal, vertical or inclined with respect to the top of the machine table.
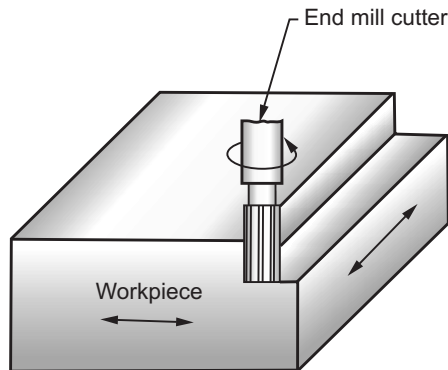


**Fig. 5.25 : End milling**

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## Review Questions

*1. What is meant by machine tool ? What are its different types ?*

*2. What is lathe machine ? Explain its working principle with neat sketch.*

*3. What are the basic elements of lathe machine ? Explain the function of each.*

*4. Explain the specifications of lathe machine.*

---

5. *What are the different operations that can be performed on a lathe machine ?*

6. *Explain the following lathe operations with neat sketch :*

   *i) Step turning          ii) Facing          iii) Reaming*

   *iv) Knurling          v) Parting*

7. *What are the basic elements of milling machine ? Explain their functions.*

## 5.4 Multiple Choice Questions with Answers

**Q.1**  Machine tools are used for _____.

a)  metal cutting only          b) surface finishing only

c) metal cutting and surface finishing d) none of the above          **[Ans. : c]**

**Q.2**  _____ machine is known as mother of all the machine tools.

a) Lathe          b) Drilling

c) Grinding          d) Milling          **[Ans. : a]**

**Q.3**  In lathe machine during the operation workpiece _____ .

a) rotates          b) reciprocates

c) oscillates          d) stationary          **[Ans. : a]**

**Q.4**  The main function of lathe machine is _____ .

a)  to provide surface finish on the component

b) to join two components

c) to bend the components

d) to remove material from the component and give it desired shape and size.

**[Ans. : d]**

**Q.5**  The main function of lathe bed is _____ .

a) to support the spindle

b) to guide the cutting tool

c) to support all the elements and withstand cutting forces during the operation

d) to transmit motion from headstock to spindle          **[Ans. : c]**

**Q.6**  The lathe carriage is located between _____ .

a) toolpost and chuck          b) headstock and tailstock (centres)

c) toolpost and tailstock          d) toolpost and headstock          **[Ans. : b]**

**Q.7** _____ is performed for producing cylindrical surface by removing the material from the workpiece.

a) Straight turning          b) Taper turning

c) Facing          d) Drilling          **[Ans. : a]**

**Q.8** In _____ workpiece is rotated on lathe axis and tool is fed at an angle to the axis of rotation of the workpiece.

a) taper turning          b) straight turning

c) step turning          d) eccentric turning          **[Ans. : a]**

**Q.9** Which of the following is not a part of milling machine ?

a) Base          b) Knee

c) Apron          d) Arbor          **[Ans. : c]**

**Q.10** In milling machine the workpiece can be fed in _____ direction.

a) vertical          b) longitudinal

c) cross          d) All of these          **[Ans. : d]**

**Q.11** _____ acts as load taking member for all other parts and a reservoir for the coolant in milling machine.

a) Bed          b) Column

c) Table          d) both (a) and (b)          **[Ans. : a]**

**Q.12** _____ is used for machining a flat surface which is parallel to the axis of cutter.

a) Plain milling          b) Slot milling

c) End milling          d) both (a) and (b)          **[Ans. : a]**

**Q.13** Up milling is also called as _____ milling.

a) Climb          b) End

c) Conventional          d) Slot          **[Ans. : c]**

**Q.14** Down milling is also called as _____ milling.

a) Climb          b) End

c) Conventional          d) Slot          **[Ans. : a]**

**Q.15** _____ is the intermediate part between the table and knee which acts as a support for the table.

a) Bed          b) Column

c) Saddle          d) Arbor          **[Ans. : c]**

**Q.16** In a lathe _____ operation cannot be performed. ☞ **[ June 2010 ]**

    a) thread cutting                   b) reaming

    c) boring                          d) planning            **[Ans. : d]**

**Q.17** Knurling is an operation of producing _____. ☞ **[ June 2010 ]**

    a) Flat surfaces                   b) Screw threads

    c) Diamond shaped pattern       d) Conical surfaces     **[Ans. : c]**

**Q.18** _____ is the process of generating internal threads. ☞ **[ June 2010 ]**

    a) Tapping                    b) Turning

    c) Milling                      d) Knurling            **[Ans. : a]**

**Q.19** _____ is the finishing operation to produce a flat round surface around already drilled hole. ☞ **[ June 2010 ]**

    a) Spot facing                  b) Tapping

    c) Counter sinking             d) None of these       **[Ans. : c]**

**Q.20** The device used to support the cutting tool in milling machine is called _____ . ☞ **[ June 2010 ]**

    a) arbor                      b) saddle

    c) table                        d) column            **[Ans. : a]**

**Q.21** Milling machine can be specified by _____ . ☞ **[ June 2010 ]**

    a) cutter size                   b) table size

    c) machine height             d) none of these       **[Ans. : a]**

**Q.22** Carriage is a part of a _____. ☞ **[ Dec. 2010 ]**

    a) milling machine            b) drilling machine

    c) grinding machine         d) lathe machine       **[Ans. : d]**

**Q.23** A machine operation performed on a lathe, to obtain flat surface at the end of the work piece is called _____. ☞ **[ Dec. 2010 ]**

    a) turning                     b) facing

    c) knurling                   d) taper turning       **[Ans. : b]**

**Q.24** Tapping operation is performed to obtain _____. ☞ **[ Dec. 2010 ]**

    a) external threads            b) internal threads

    c) tapered hole                d) cylindrical hole      **[Ans. : b]**

**Q.25** _____ is not a part of carriage assembly. ☞ **[ June 2011 ]**

    a) Apron                          b) Compound slide

    c) Tool post                   d) Tail stock         **[Ans. : d]**

**Q.26** _____ is the operation of separating a piece of finished work from bar stock.

                                                            ☞ **[ June 2011 ]**

    a) Parting          b) Facing        c) Turning       d) Knurling **[Ans. : a]**

**Q.27** _____ is the process of enlarging already drilled hole. ☞ **[ Jue 2011 ]**

    a) Reaming        b) Boring        c) Tapping       d) Spot facing

                                                                 **[Ans. : b]**

**Q.28** _____ is the process of generating internal threads. ☞ **[ June 2011 ]**

    a) Reaming        b) Boring        c) Tapping       d) Drilling    **[Ans. : c]**

**Q.29** To drill a hole on a lathe, a drill bit is held in the _____. ☞ **[ Dec. 2011 ]**

    a) tool post                          b) tailstock spindle

    c) head stock                  d) compound rest      **[Ans. : b]**

**Q.30** Horizontal shaft used to mount milling cutter is _____. ☞ **[ Dec. 2011 ]**

    a) spindle                           b) connecting rod

    c) saddle                       d) arbor            **[Ans. : d]**

**Q.31** Which of the following parts is not present in lathe ? ☞ **[ June 2012 ]**

    a) Spindle        b) Knee          c) Bed           d) Slide     **[Ans. : b]**

**Q.32** Which of the following operation can be carried out on lathe ?

    a) Knurling                         b) Counter boring

    c) Boring                      d) All of these       ☞ **[ June 2012 ]**

                                                                  **[Ans. : d]**

**Q.33** _____ is the operation of enlarging a hole by a single point cutting tool.

                                                            ☞ **[ June 2012 ]**

    a) Reaming                       b) Counter sinking

    c) Boring                      d) All of these          **[Ans. : c]**

**Q.34** _____ objects are produced in an engine lathe. ☞ **[ Dec. 2012 ]**

    a) Plane          b) Curved       c) Circular      d) None of these

                                                                  **[Ans. : d]**

**Q.35** Taper turning is a method of producing _____ on the workpiece.

☞ **[ Dec. 2010 ]**

    a) tapping        b) reaming      c) taper        d) boring    **[Ans. : d]**

**Q.36** Milling cutter is a _____.           ☞ **[ Dec. 2012 ]**

    a) multipoint cutting tool       b) abrasive cutter

    c) single point cutting tool      d) metal removing machine    **[Ans. : a]**

**Q.37** Milling is a _____ .           ☞ **[ Dec. 2012 ]**

    a) metal removal process       b) metal cutting processor

    c) metal joining process         d) none of these      **[Ans. : a]**

**Q.38** Compound slide swiveling method is used to produce _____ . ☞ **[ June 2013 ]**

    a) hole           b) threads      c) knurl        d) taper    **[Ans. : d]**

**Q.39** Function of the lathe is to _____.       ☞ **[ Dec 2013 ]**

    a) produce cylindrical parts      b) produce key holes

    c) produce slots           d) all of these       **[Ans. : d]**

## 5.5 University Questions with Answers

**Dec. 2010**

**Q.1** With a neat sketch, explain the following operations :
1) Counter boring    2) Knurling    3) Taper turning. **(Refer section 5.2.4)**    **[9]**

**June 2011**

**Q.2** List the specifications of a lathe. **(Refer section 5.2.3)**       **[4]**

**June 2012**

**Q.3** With a neat sketch, explain the taper turning on lathe by swivelling of compound slide. **(Refer section 5.2.5)**       **[6]**

**Dec. 2012**

**Q.4** Explain with a schematic diagram, show how a centre lathe is specified.
**(Refer section 5.2.3)**       **[8]**

**June 2013**

**Q.5** Differentiate between cross-slide and compound slide. **(Refer section 5.2.2)** **[4]**

**Dec. 2013**

**Q.6** With a neat sketch, explain the taper turning on lathe by swivelling of compound slide. **(Refer section 5.2.5)** **[8]**

**Q.7** Explain any two milling operations. **(Refer section 5.3.2)** **[2]**

*Machine Tools and Automated Machine Tool Operations ends …*

## Module - III

# CHAPTER - 6

# ROBOTICS AND AUTOMATION

> **Syllabus : Robotics :** Introduction, Classification based on robots configuration; Polar, Cylindrical, Cartesian coordinate and spherical. Application, Advantages and disadvantages.
>
> **Automation :** Definition, Types - Fixed, Programmable and flexible automation. NC / CNC machines : Basic elements with simple block diagrams, Advantages and disadvantages.

| Section No. | Topic Name |
|---|---|
| 6.1 | Introduction to Robotics |
| 6.2 | Parts of the Robot |
| 6.3 | Classification of Robots |
| 6.4 | Advantages of Robots |
| 6.5 | Disadvantages / Limitations of Robots |
| 6.6 | Applications of Robots |
| 6.7 | Introduction to Automation |
| 6.8 | Types of Automation |
| 6.9 | Necessity of NC Machine Tool |
| 6.10 | Numerical Control (NC) Machine Tool |
| 6.11 | Computerized Numerical Control (CNC) Machine Tool |
| 6.12 | Comparison of NC and CNC System |
| 6.13 | Multiple Choice Questions with Answers |

## 6.1 Introduction to Robotics

- Robotics is a branch of mechanical engineering which brings together several engineering fields and skills.
- It includes use of mechanical, electrical, electronics, computer science that deals with the design, construction, operation and applications of robots.
- The evolution of automated machines that can replace human in dangerous environments or manufacturing processes, the concept of robotics has arised.
- The word robotics was derived from the word robot, which was introduced by Karel Capek, a Czech writer in 1920.
- The idea of robotics has established and developed from engineers and inventors from ancient civilizations.
- Following are the stages in the development of robots :
  - First generation robots are dumb robots. These robots have kind of mechanical construction and does not include any sensors to give feedback and correct the action.
  - Second generation robots are clever robots. These robots have an electrical aspect in the working movements and includes wires, sensors, circuits, motors batteries, etc.
  - Third generation robots are intelligent robots and includes level of computer programming. They are based on the concept of artificial intelligence.

## 6.2 Parts of the Robot

- A robot is a machine which resembles to human or animal and can be controlled electronically to carry out a variety of physical tasks.
- A typical robot shown in Fig. 6.1 consist of following essential elements :

  > (i)   Robot Controller Unit (RCU)
  > (ii)  Manipulator
  > (iii) Tooling or End effectors

### i) Robot Controller Unit (RCU)

- The robot controller unit may be installed in the manipulator or may have installed individually in separate cabinet.
- It is a part of a robot that determines the robot movements.
- The robot controller is fed with the program instructions. Controller converts this input program to suitable signals.
- Signals actuate the manipulator to perform the desired tasks.
- The controller first carry out the motions of the manipulator in the desired sequence at the specific points.

- RCU first stores these positions at specific points and sequences the data in the memory and then interfaces with manufacturing operation.
- RCU is computer based unit provided with Programmable Logic Controller (PLC).

## ii) Manipulator

- All the moving and actuating parts of the robot except gripper are included in the manipulator.
- A series of joints and mechanical linkages forms the manipulator, which can actuate on receiving signals from RCU.
- The signals from the RCU may be in the electrical, hydraulic or pneumatic form.
- Manipulator system contains servos and feedback mechanism to enhance speed and accuracy of the motion.

## iii) Tooling or End effectors

- End effector is a device mounted at the end of the robot that perform a actual task.
- It is also called as gripper or robot tools.
- An end-effector can be machining tool, mechanical gripper, welding head, spray gun, etc.
- Selection of end effector depends on the type and accuracy of work, size of work envelope, power required, cycle time, cost, etc.
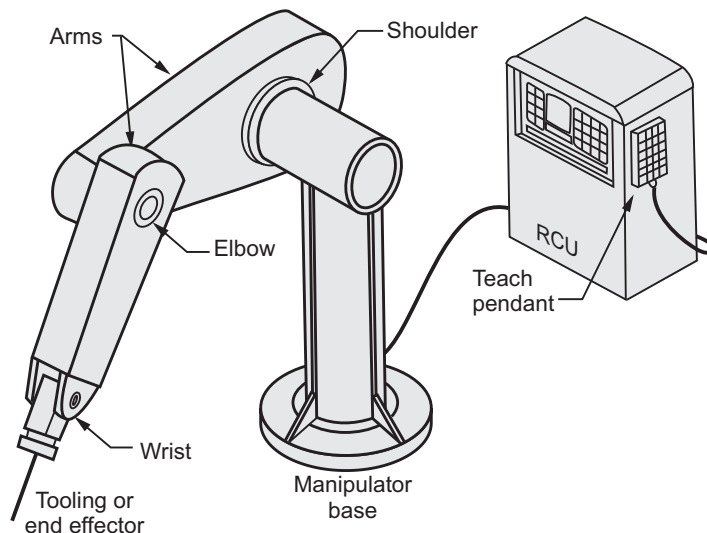


**Fig. 6.1 : Parts of the robots**

## 6.3 Classification of Robots

- The co-ordinates of the movements of the robot axes are controlled by RCU. These movements will form the different robot configurations.

- Hence different co-ordinate systems directly affect the shape of robot work envelope.

- Robots can be classified on the basis of different configurations as follows :

> (i)   Polar or spherical configuration
> (ii)  Cylindrical configuration
> (iii) Cartesian co-ordinate configuration

## i) Polar configuration

- Polar configuration forms a part spherical work envelope as shown in Fig. 6.2.
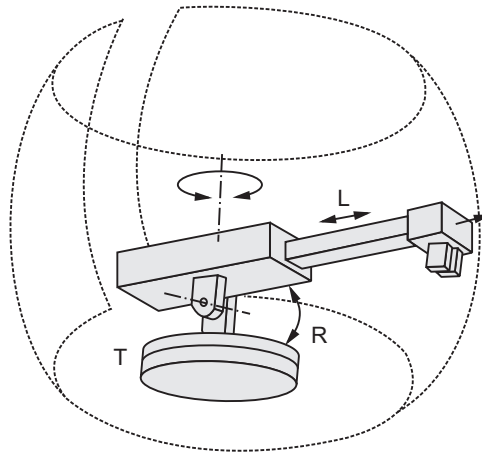


**Fig. 6.2 : Polar configuration**

- A robot with polar configuration has one linear and two rotary axes.

- Linear movement is provided to the robot arm which can retract or extend about its axis.

- Rotational movement is achieved by tilting of this arm above and below the horizontal plane.

- At the same time, the arm can swivelled about the base.

- Hence the arrangement of joints in this configuration is in the TRL (Twisting - Rotational - Linear) configuration.

- These robots required complex control for achieving straight line motion.

- Polar configuration used in spot welding, heavy load applications, etc.

## ii) Cylindrical configuration

- Cylindrical configuration forms cylindrical shaped work envelope as shown in Fig. 6.3.
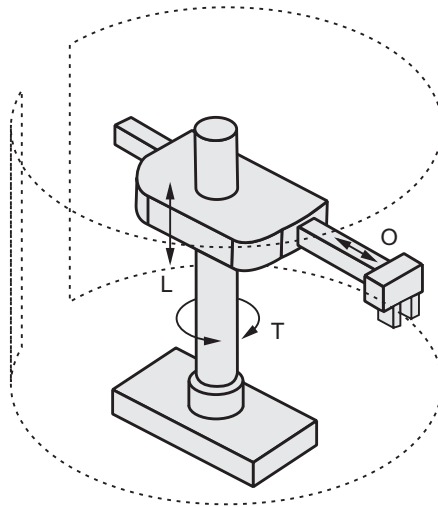
**Fig. 6.3 : Cylindrical configuration**

- A robot with this configuration has one rotory and two linear axes.

- The rotory motion is given to the robot arm and carriage slide mounted on the base.

- Both the linear motions are provided such as robot arm will move upward and downward in vertical plane as well as extend and retract in horizontal plane.

- Hence this arrangement forms TLO (Twisting - Linear - Orthogonal) configuration.

### iii) Cartesian configuration

- Cartesian configuration forms a rectangular work envelope as shown in Fig. 6.4.
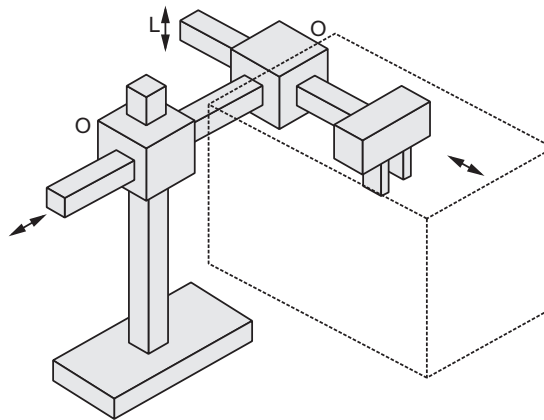


**Fig. 6.4 : Cartesian configuration**

- A robot with cartesian configuration has three linear axes.

- These linear movements are linear and parallel to the X, Y and Z plane.

- Hence the arrangement of joints in this configuration is LOO (Linear - Orthogonal - Orthogonal).
- These robots have greater configuration accuracy and repeatability than other types.
- Rectangular cartesian configuration is suitable for heavier loads.

## 6.4 Advantages of Robots

- Robots can perform tasks faster than humans and with much more consistency and accuracy.
- Industrial robots have capacity to enhance the quality of product as the applications are performed with precision and high repeatability.
- Throughput speed increases with use of robots that directly affect the production rate.
- Robots can work at constant speed without pausing for breaks, sleep, etc.
- The workplace safety is increased and workers does not need to perform dangerous applications in hazardous settings.
- Financial savings due to less material waste, reduced production time and improved worker safety.
- Reduced labour results in saving due to less labour cost and wages.
- Mechanical nature and computerised control makes robot technology more efficient and speedy which leads to higher production rate.
- A robot can work 24 / 7 with only limited occasional downtime for scheduled maintenance.

## 6.5 Disadvantages / Limitations of Robots

- High initial investment cost.
- Incorporting robots without planning does not assure results in achieving goals.
- Skilled employees are required to interact with robotic equipment.
- Unemployment of the workers.
- It needs continuous power supply.
- Robots are not suitable for decision making tasks.

## 6.6 Applications of Robots

Following are the areas of applications where robot technology is significantly used :
- **Heavy works :** Heavy parts or tools that can not be handled by human, can be easily handled with robots.

- **Hazardous work conditions :** The areas where work conditions are unhealthy, unsafe and uncomfortable for humans such as foundry practices, welding practices, etc. robots reduce the risk of any mishap.

- **Repetitive operations :** For repetitive and time consuming operations robots are well suited than human operator.

- **Material handling :** In manufacturing industries robots having gripper are used for moving parts from one position to another.

- **Assembly and inspection :** This is the highly repetitive and boring operation, hence the robots with small size and capacity are used.

- **High production applications :** As the use of robots reduces non productive time, higher production can be achieved.

## 6.7 Introduction to Automation

- Automation can be defined as the use of various control systems that involves automatic handling between machines.

- It creates and implement the technology to monitor and control the production, delivery and service of component.

- Automation involves many technologies including robotics, electro-optics, communication, process measurement and control, sensor, wireless applications, system integration, etc.

- The automation can be done in various ways including mechanical, hydraulic, pneumatic, electrical or with assistance of computers and robots.

**Advantages of automation**

- Increased productivity, quality and robustness of product or process.

- Highly improved consistency of output.

- Reduced operation and material or work handling time.

- Reduced human labour costs and expenses.

- Replaces human task involving hard and tedious work.

- Replaces human tasks in hazardous environment such as fire, space, nuclear plants, underwater, etc.

- Automation provides higher level jobs in the development, maintenance and running of the automated process.

**Disadvantages of automation**

- High initial cost.

- The development and research cost of an automation is higher and unpredictable.

- Automation causes unemployment by replacing the human labour.

- An automated system may have security threats.

## 6.8 Types of Automation

- Thereare following three types of an automation based on the design flexibilities :

  (i)   Fixed automation
  (ii)  Programmable automation
  (iii) Flexible automation

### i) Fixed automation

- For a particular component, when the sequence of manufacturing operations is fixed by the equipment configuration, the fixed automation system is used.
- The automation and integration of various fixed sequence of operation results in reduced setup and production time.
- Fixed automation system is limited to a specific component. It cannot accomodate different product configurations.
- This system is used where there is continuous high demand of component at high volume.
- For example, packaged drinking water plant and other packaging plants.

### ii) Programmable automation

- When the changes in the sequence of the manufacturing operation is possible for different product configurations, the programmable automation system is used.
- The changes in the sequence is done by varying the control instructions of the system.
- Flexibility of a system can be improved by developing and incorporating new programs.
- Programmable automation is suitable for batch production of low to medium volume.
- Each batch of production required a different setting of system regarding programme instructions, tool change, etc.

### iii) Flexible automation

- When the variety of products are manufactured continuously by accomodating various combinations and schedules of products, flexible automation is used.
- In the flexible automation, there is no loss of time during change-over from one product to another. The product design variations can be easily accomodate.
- Flexible automation results in the reduced production time losses with higher product flexibility.
- Also, it allows continuous production without downtime between batches and production of various components on the same machine.

## 6.9 Necessity of NC Machine Tool

- When any machine tool is manually operated, the operator controls the relative movements of the workpiece and tool.

- The accuracy of these movements is controlled by reference to some form of measuring device fitted on the machine slide or lead screw.

- The operator has to perform functions like starting and stopping the machine, turning the coolant on and off, etc.

- With manual control accuracy of final workpiece, quality and time required to manufacture depends on the skill, concentration and experience of the operator.

- When many batches of identical parts are required, it is preferable to use jigs, fixtures and templates.

- Automatic machine tools are also used in order to minimize errors and variable quality of manual operation.

- So, to avoid human errors, minimize production cost and due to many other reasons, NC i.e. **Numerical Control** machines comes into the picture.

## 6.10 Numerical Control (NC) Machine Tool

- Numerical control is a programmable automation in which actions are controlled by means of coded numbers, letters and other symbols."

- The numerical data which is required for producing a part is maintained on **punched tape.**

- This data is arranged in the form of blocks of information.

- The block contains cutting speed, feed, dimensional information and contour form.

- For preparing this data, part programmer is required which should have the knowledge of tools, cutting fluids, use of machinability data and process engineering.

- Fig. 6.5 (a) shows the block diagram for the procedure of production through NC.
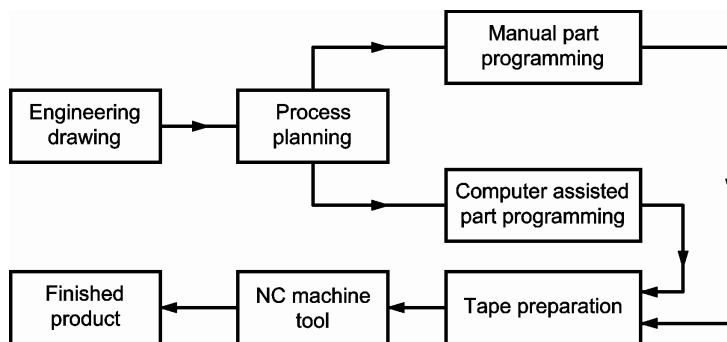


**Fig. 6.5 (a) : The procedure of production through numerical control**

- Fig. 6.5 (b) shows the block diagram for NC machine tool system.
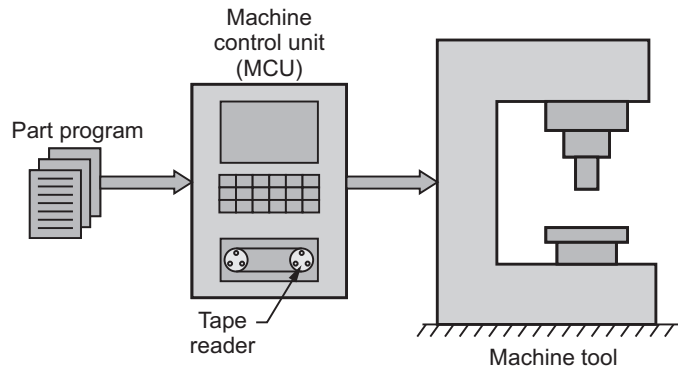


**Fig. 6.5 (b) : Elements of a NC system**

## 6.10.1 Basic Elements of NC System

A numerical control (NC) machine consists of following elements (Refer Fig. 6.5 (b)).

1. Machine Control Unit (MCU)
2. Machine tool and NC tooling
3. Part program and drawings.

### 1. Machine Control Unit (MCU)

- It is the heart of NC machine tool system and consists of many sub-units inside it.

- The first sub-unit is tape reader which receives the coded data from punched tape.

- The tape reader reads this data and passes data to the buffer storage through the decoding circuits.

- The buffer storage stores the received information, till it is required and transfers it to the required area.

- Almost all the operations like tool movements, tool change, speed and feed change and many others can be controlled by MCU.

### 2. Machine tool and NC tooling

- It is the manufacturing arm of NC machine tool system.

- It receives the raw material and performs different operations like turning, milling, drilling, grinding, etc.

- For performing these operations, it should receive the information from the MCU.

- As per the information, the desired shape and size is modified.

**3. Part program and drawings**

- NC machine operates as per coded information, which is Input Data for the machine.
- The feeding of this data may be manually or automatic.
- The manual feeding of input data includes operator and hence chances of error increases.
- Hence, data is fed by automatic means and for this purpose punched tape is mostly used.
- The other input media instead of punched tapes are :
  - o Punched cards
  - o Magnetic tapes
  - o Diskettes, etc.
- Now a days, to enter the program, instead of these media, magnetic cassettes, floppy discs, Compact Disc (CD) are used.

## 6.10.2 Advantages, Disadvantages and Applications of NC Machines

**Advantages**

- **High productivity :** Due to less set up and lead time, productivity is higher.
- **Less scrap :** As human errors are eliminated, accurate components are machined hence, scrap is reduced.
- **Reduced jigs and fixtures :** Work and tool positioning is done by NC tape, hence less requirement of jigs and fixtures.
- **High quality :** Due to higher accuracy of NC systems, the quality of products is easily controlled.
- **Flexibility in design :** In NC system complicated profiles can be easily produced at faster rate.
- **Utilization of manpower :** In NC system, there is greater utilization of manpower because, after setting a component, operator can perform other operations.
- Reduction in the inventory.
- Safety to the operator and machine tool.
- There is a greater flexibility in the manufacturing.
- Less floor space is required.
- As no jigs and fixtures are required, tooling cost is low.
- Skilled operator is not required.

**Disadvantages**

- **High initial cost :** Initial investment is high.

- **High maintenance cost :** Maintenance is costly and complicated.

- **Costy control system :** Control systems are also costly.

- **Skilled operator :** For part programming well trained and highly skilled operator is required.

- **Unemployment :** As only one operator is required, there is increase in unemployment.

**Applications**

- NC system is used where 100 % inspection is required.

- NC system is suitable for machining of parts where frequent changes in design occurs.

- Repetitive production of precise parts in small and medium size production can be done by NC system.

- When accuracy requirement is high, NC system is suitable.

- When high amount of material is to be removed, NC system is preferred.

- For complex machining operations also, NC system is required.

## 6.11 Computerized Numerical Control (CNC) Machine Tool

- Computerized Numerical Control (CNC) is a NC system which uses micro-computer as the machine control unit.

- The presence of a microprocessor, RAM, ROM, Input/Ouput (I/O) devices has raised the automation level in NC system.

- In CNC machines, various functions are controlled with the help of part programs which are generally entered through the keyboard.

### 6.11.1 Basic Elements of CNC System

A CNC system consists of following basic elements (Refer Fig. 6.6) :

| | |
|---|---|
| 1. Part program and drawings | 2. Input/Output devices |
| 3. Memory storage devices | 4. Micro-computer (MCU) |
| 5. CNC machine tool | 6. Feedback device |

**1. Part Program and Drawings :**

- The part program is written by observing the part drawing and the given cutting process parameters like feed, speed, depth of cut, etc.

## 2. Input/Output Devices :

- The written part program is entered into the micro-computer by using input devices like keyboard, CD, DVD, etc.
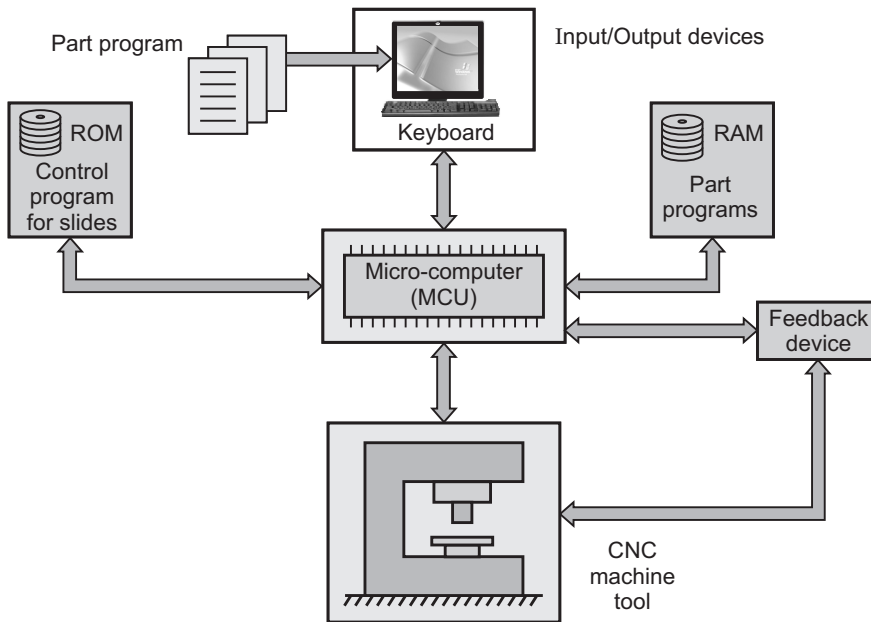


**Fig. 6.6 : Basic elements of CNC system**

## 3. Memory Storage Devices :

- The entered program is stored in computer memory which can be recalled whenever required.

- Also, the program can be easily edited and modified as per the requirement.

## 4. Micro-computer (MCU) :

- The entered part program is read by the micro-computer which is the machine control unit of CNC system.

- It controls all the movements of machine tool, actuation of all the drives, coolant supply, etc. of the machine tool.

## 5. CNC Machine Tool :

- It is the manufacturing arm of CNC machine tool system.

- It receives raw material and performs various operations which are needed.

- For performing these operations it should receive the information from the MCU.

- In CNC system, all the operations like spindle start and stop, tool positioning, tool changing, speed control, etc. are fully automatic.

**6. Feedback Device :**
- Feedback device receives feedback from the machine tool and gives it to the MCU.
- By using feedback device, the cause can be easily detected and rectified.

## 6.11.2 Advantages, Disadvantages and Applications of CNC System

**Advantages**

Advantages of CNC machines are similar to NC machine. Some additional advantages due to additional feature in CNC machine over conventional machines are as follows :
- **Program storage :** As computer is available, multiple programs can be stored in the machine.
- **Reliability of system :** As the data is directly entered with the help of computer, no need to use punched tape. It also improves reliability of the system.
- **Online part programming :** The part program can be done online with editing, if required.
- **Flexibility of system :** The system is too flexible, as new systems can be added at low costs.
- **Metric conversions :** Part program, which is written in inches, can be easily converted into millimeters i.e. metric conversion is easy.
- **Interpolations :** In NC system, there is interpolation for straight and circular path, but in CNC it is available for helical, parabolic and cubic curves also.
- **Expanded tool compensations :** For the purpose of tool offset and tool wear, tool compensation is provided.

**Disadvantages**

Disadvantages of CNC machines are similar to NC machines.
- **High initial cost :** Initial investment is high.
- **High maintenance cost :** Maintenance is costly and complicated.
- **Costly control system :** Control systems are also costly.
- **Skilled operator :** For part programming well trained and highly skilled operator is required.
- **Unemployment :** As only one operator is required, there is increase in unemployment.
- **Computer problem :** If there is any problem with computer, then the whole machine will get stop.
- **Costly software :** The software required for the operation of CNC machines is also costly.

**Applications**

- Applications of CNC system are similar to NC system.

## 6.12 Comparison of NC and CNC System

Table 6.1 gives the comparison between the NC and CNC system.

**Table 6.1 : Comparison of NC and CNC system**

| Sr.No. | Parameter | NC system | CNC system |
|---|---|---|---|
| 1. | Mode of entering the program | In this system part program is entered by using punch tape, magnetic tapes, punch cards, etc. | In this system, part program is entered by using keyboard, CD, DVD, floppy discs, etc. |
| 2. | Feedback device | No feedback device. | Feedback device is available. |
| 3. | Memory storage ability | Only one program can be stored at a time. | More than one program can be stored. |
| 4. | MCU | Tape reader acts as a MCU. | Micro-computer act as a MCU. |
| 5. | Program editing | The program is entered in the form punch tape, hence editing in program is difficult. | The program is entered through the keyboard, hence editing in program is simple. |
| 6. | Flexibility of system | Less flexible. | More flexible. |
| 7. | Productivity of system | Less | High |
| 8. | Initial cost | Moderate | High |

## Review Questions

1. *Explain essential parts of a robot with their significance.*
2. *Give classification of robots based on the different configurations.*
3. *With neat sketch show the various work envelops and configurations of the robot.*
4. *What are the advantages and limitations using robot technology in the engineering ?*
5. *Explain the field of applications of the robots.*
6. *Define automation and give its advantages and limitations.*
7. *Explain the various types of an automation.*

8. *Explain the necessity of NC machine tool.*

9. *What is NC machine ? Explain with block diagram.*

10. *What are the advantages, disadvantages and applications of NC system ?*

11. *What is CNC machine ? What are its basic elements ?*

12. *Explain CNC machine with block diagram.*

13. *What are the advantages and disadvantages of CNC machine tool ?*

14. *Compare NC and CNC machine tool system.*

## 6.13 Multiple Choice Questions with Answers

**Q.1** A configuration which forms spherical work envelope is known as _____ configuration.

    a) cylindrical                      b) cartesian

    c) polar                           d) none of these       **[Ans. : c]**

**Q.2** For manufacturing of specific component, _____ type of automation is used.

    a) programmable            b) fixed

    c) flexible                      d) none of these       **[Ans. : b]**

**Q.3** The first generation robots are known as _____ robots.

    a) clever                        b) dumb

    c) intelligent                 d) smart               **[Ans. : b]**

**Q.4** the robots, which can take important and strategic decisions are known as _____.

    a) smart robots            b) clever robots

    c) dumb robots            d) intelligent robots       **[Ans. : d]**

**Q.5** Clever robots are the _____ generation of robots.

    a) first                        b) second

    c) third                        d) fourth           **[Ans. : b]**

**Q.6** Intelligent robots are designed with the help of concept of _____ .

    a) natural intelligence       b) artificial intelligence

    c) both (a) and (b)          d) none of these       **[Ans. : b]**

**Q.7** RCU is _____ .

    a) Receiver Controller Unit       b) Robot Controller Unit

    c) Both (a) and (b)          d) none of these       **[Ans. : b]**

**Q.8** Twisting-Linear-Orthogonal (TLO) configuration can be formed with the help of _____ configuration.

a) cylindrical b) spherical

c) cartesian d) articulated **[Ans. : a]**

**Q.9** For the heavy load application _____ type of configuration is used.

a) polar b) cartesian

c) both (a) and (b) c) none of these **[Ans. : b]**

**Q.10** Robots with _____ configuration have high accuracy.

a) polar b) articulated

c) cylindrical d) cartesian **[Ans. : d]**

**Q.11** A robot with polar configuration has _____ axes.

a) one linear and two rotary b) one rotary and two linear

c) three linear d) none of these **[Ans. : a]**

**Q.12** Numerical control is a _____ automation.

a) fixed b) programmable

c) flexible d) none of these **[Ans. : b]**

**Q.13** MCU is _____ .

a) Main Control Unit b) Machine Control Unit

c) Mechanical Control Unit d) Miscellaneous Control Unit **[Ans. : b]**

**Q.14** In _____ system only one program can be stored at a time.

a) NC b) CNC

c) DNC d) both (a) and (b) **[Ans. : a]**

**Q.15** Flexibility of _____ system is more.

a) NC b) CNC

c) both (a) and (b) d) none of these **[Ans. : b]**

**Q.16** Micro-computer is used as a MCU in _____ system.

a) NC b) DNC

c) CNC d) both (a) and (b) **[Ans. : c]**

**Q.17** In case of _____ system punched tapes are used as an input for producing a part.

   a) NC                                b) DNC

   c) CNC                            d) none of these         **[Ans. : a]**

**Q.18** _____ is the heart of NC machine tool system.

   a) NC tooling                     b) Machine Control Unit

   c) Part program                 d) None of these         **[Ans. : b]**

*Robotics and Automation ends …*

## Module - IV

### Chapter - 7

# ENGINEERING MATERIALS

**Syllabus :** Types and applications of ferrous and nonferrous metals and alloys, **Composites :** Introduction: Definition, Classification and applications (aircraft and automobiles)

## 7.1 Introduction

- A **material** is that, out of which anything is made. It relates itself to matter.
- The knowledge of materials and their properties is of great significance for a design engineer.
- The machine elements should be made from such a material which has properties suitable for the operating conditions.

## 7.2 Classification of Engineering Materials

- The engineering materials are mainly classified as follows (Refer Fig. 7.1) :

> 1. Metals and their alloys.  2. Non-metals.
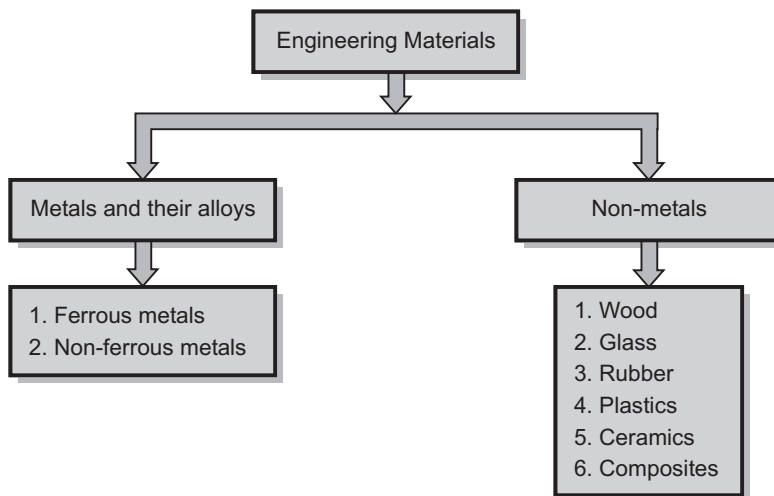


**Fig. 7.1 : Classification of engineering materials**

## 7.3 Ferrous Metals

- The ferrous metals are those which have the iron as their main element or constituent.
- Ferrous materials are the most important metals in the metallurgical and mechanical industries because of their extensive use.
- The commonly used ferrous metals are as follows :

> 1. Cast iron.  2. Alloy cast iron.
> 3. Steel (Main carbon steel).  4. Alloy steel.

## 7.3.1 Cast Iron

- Cast iron are the alloys of iron and carbon.
- Generally, commerical cast iron are complex in composition and their carbon content is in the range of 2.3 to 3.7 % with other elements like sulphur, manganese, phosphorus and silicon.
- Cast iron are formed by melting a metal and casting with or without machining to the desired final shape and size, hence called as **cast iron.**

### Characteristics of cast iron

- While manufacturing of cast iron, raw materials like pig iron, scrap limestone, coke etc. are used. All these elements are relatively cheap, hence the cast iron is the cheapest amongst all alloys.
- The melting point of cast iron is low i.e. 1140 to 1240 ºC.
- Due to high fluidity of melt, cast iron has excellent castability.
- By altering the chemical composition, cast iron can provide a wide range of metallic properties.

### Advantages of cast iron

- It is a low cost material.
- It can provide good damping capacity and high compressive strength.
- Cast iron has high resistance to wear and abrasion.
- It has high hardness.
- Corrosion resistance of cast iron is fairly good.
- It has excellent machinability.

### Limitations of cast iron

- It is brittle in nature.
- Its mechanical properties like toughness, stiffness, resilience, etc. are poor.
- Due to brittleness, it is poor against fatigue and impact loading.

### Applications of cast iron

Cast iron are used in the following machine elements :
- Machine beds, columns, hammers, road-rollers.
- Pipe fittings, valves, farm equipments, automotive parts.
- Camshafts, crank shafts, gears, ordnance parts.
- Motor covers, pump bodies, furnace parts.
- Engine frames, piston and cylinder, cylinder blocks and bearing blocks, etc.

**Types of cast iron**

Cast iron are classified as follows :

> 1. While cast iron  2. Gray cast iron
> 3. Malleable cast iron  4. Nodular cast iron.

## 7.3.2 Alloy Cast Iron

- Generally, cast iron has low impact resistance, corrosion resistance and temperature resistance. Hence, to increase these properties certain alloying elements are added in suitable amount.

- Usually, nickel, chromium, copper, silicon, vanadium, molybdenum etc. are used for this purpose.

**Properties of alloy cast iron**

- It has high strength.

- It has high oxidation resistance.

- It has high wear resistance and corrosion resistance.

**Applications of alloy cast iron**

Alloy cast iron are used in the manufacturing of following parts :

- Gears, automobile parts like pistons, piston rings, camshaft, crank shaft, cylinders.

- Brake drum, pulleys, grinding machinery parts, etc.

## 7.3.3 Plain Carbon Steel

- Steel is an alloy of iron and carbon with carbon content upto 1.6 % approximately.

- Carbon content increases the strength and hardness of steel.

- Plain carbon steel or carbon steel is defined as a steel which has its properties mainly due to its carbon content and does not contain more than 0.5 % of silicon and 1.5 % of manganese.

**Properties of plain carbon steel**

- They are ductile in nature.

- They have high fatigue and impact strength.

- Their mechanical properties like toughness, stiffness, resilience, etc. are high.

**Advantages of plain carbon steel**

- They have high tensile strength.

- They have high resilience and toughness.

- They can sustain fatigue and impact load.

**Limitations of plain carbon steel**
- The vibration damping property of steel is poor.
- They cannot be cast into complicated shapes.
- They have low wear resistance.
- Its cost is more than cast iron.

**Applications of plain carbon steel**

Plain carbon steel is used in the manufacturing of following parts :
- Stampings, fan blades, rivets, nuts, bolts, wires, structural steel, grill, shafts.
- Gears, valves, crank shaft, camshaft, axles, screws, springs.
- Cutting tools, milling cutters, blades, drill bits, musical instruments, agricultural applications, etc.

## 7.3.4 Alloy Steel
- To obtain the specific properties various alloying elements are added in steel.
- The specific properties define the applications of steel.
- The various alloying elements are as follows :

| i) | Carbon | ii) | Sulphur | iii) | Phosphorous |
|------|-----------|--------|-----------|--------|-------------|
| iv) | Silicon | v) | Manganese | vi) | Nickel |
| vii) | Chromium | viii) | Titanium | ix) | Tungsten |
| x) | Molybdenum | xi) | Vanadium | xii) | Cobalt, etc. |

**Properties of alloy steel**
- They are ductile in nature.
- They have high corrosion resistance.
- They have high strength.
- They are soft and having high toughness.

> **Note :** *Properties of alloy steel can be changed as per the amount of alloying elements.*

**Advantages of alloy steel**
- They have high tensile and fatigue strength.
- They have high wear resistance, corrosion resistance and creep resistance.
- They have high toughness and resilience.

**Limitations of alloy steel**
- Alloy steel cannot be cast into complicated shapes.
- Their vibration damping property is poor.
- They are costlier than steel and cast iron.

**Applications of alloy steel**

Alloy steels are used in the manufacturing of following parts :

- Aircraft engine parts, heat exchangers, wrist watches, sanitary fittings.
- Combustion chamber, furnace parts, gas burners, screws.
- Valves, pumps, surgical instruments, razor blades, turbine blades, missiles, structural components, etc.

# 7.4 Non-Ferrous Metals

- Non-ferrous metals are those which contain a metal other than iron as their main element or constituent.
- Non-ferrous metals find wide applications in various industrial sectors because of following advantages :
  - ○ Low density, hence light in weight.
  - ○ High electrical conductivity.
  - ○ Easy to fabricate.
  - ○ High corrosion resistance.
- The commonly used non-ferrous alloys are as follows :

  1. Copper and its alloys
     a) Brasses       b) Bronzes
  2. Aluminium and its alloys.
  3. Babbits.

## 7.4.1 Copper and its Alloys

- Copper is one of the most widely used non-ferrous metal.
- Various alloying elements are added to copper to improve and add some properties.
- Major alloying elements are zinc, silicon, aluminium, lead, manganese, nickel, phosphorous, tin, magnesium, etc.

**Properties of Copper**

- It has high ductility and malleability.
- It has high electrical and thermal conductivity.
- It is non-magnetic in nature.
- It can be easily alloyed with other metals.
- Its corrosion resistance is also high.

## Applications of Copper

Copper is used in the manufacturing of following parts :

- Electrical parts
- Heat exchangers
- Household utensils, etc.

## Types of Copper Alloys

Copper alloys are basically divided into two major groups :

1. Brasses (Alloy of copper and zinc).
2. Bronzes (Alloy of copper and tin).

## 1. Brasses

- Brasses are **alloys of copper and zinc** with small amount of other alloying elements.
- According to the percentage of copper and zinc, there are various types of brasses. For example, $\alpha$-brasses, $\alpha$-$\beta$ brasses.
- The properties of brasses can be changed by adding small amount of other alloying elements.

## Advantages of brasses

- It has high corrosion resistance.
- It has high ductility and malleability.
- Due to addition of zinc, it has high strength.
- It has high machinability.

## Limitations of brasses

- It has low thermal and electrical conductivity.
- Its cost is also high.

## Applications of brasses

Brasses are used in the manufacturing of following parts :

- Coins, needles, jewellery, condenser tubes.
- Cartridge cases, headlight reflectors, springs.
- Shafts, nuts, bolts, welding rods, machine parts, etc.

## 2. Bronzes

- Bronzes are alloys of copper and major alloying elements other than zinc or nickel.
- But, generally bronzes are **alloy of copper and tin.**
- Sometimes, it also alloyed with aluminium, beryllium, silicon, etc.

**Advantages of bronzes**

- It has high corrosion resistance.
- It is comparatively hard than brass.
- It can be rolled into sheets, rods or wires.
- It has high tensile strength.
- It has high ductility and malleability.

**Limitations of bronzes**

- The cost of bronzes is higher than the brasses.
- The strength of bronzes is lower than the ferrous metals.

**Applications of bronzes**

Bronzes are used in the manufacturing of following parts :

- Springs, gears, bearings, electrical appliances.
- Bolts, rivets, pressure vessels, bells, marine containers.
- Valve bodies, ordnance parts, gun barrels, pipe fittings, etc.

## 7.4.2 Aluminium and its Alloys

- Aluminium is another widely used non-ferrous metal.
- Aluminium can be easily alloyed with elements like silicon, copper, nickel, zinc, manganese, titanium, magnesium, etc.

**Advantages of aluminium alloys**

- It has high thermal and electrical conductivity.
- It has high corrosion resistance.
- It has high toughness.
- They are malleable and ductile.
- It can be easily cast and rolled.

**Applications of aluminium alloys**

Aluminium alloys are used in the manufacturing of following parts :

- Aluminium alloys are widely used in the aircraft industry.
- Motor housings, pump castings, pistons, cylinder heads.
- In food industry, food preparation equipments, refrigeration, storage containers, bakery equipments, etc.

## 7.4.3 Babbits

- Babbits or **white metals** are the alloys of lead and tin.

- Hence the babbits are divided into following two groups :

> 1. Lead-based babbits.
> 2. Tin-based babbits.

**Properties of babbits**

- Lead is a soft material which reduces load carrying capacity of babbits.
- Tin-based babbits have better corrosion and wear resistance.
- It has low coefficient of friction.

**Limitations of babbits**

- It has low compressive strength and fatigue strength.
- It is not suitable for high temperature conditions.

**Applications of babbits**

- Babbits are commonly used in the manufacturing of bearings used in I.C. engines, electric motors, lathe machine, milling machine, etc.

## 7.5 Introduction to Composites

- **Modern living** demands materials with specific properties based on severe surrounding conditions and end applications.
- Such specific applications include that of aerospace, aircrafts, high pressure vessels etc.
- Usually any single element / material are not able to cater to such specific material properties required.
- Hence a combination of two or more materials is used to take advantage of their individual properties.
- **Composite material** is defined as a material formed by the combination of two or more chemically dissimilar materials with distinct boundaries between them.
- Composite materials exhibit properties that are vastly different from those of the individual constituents and better suited for a particular application.
- With judicious choice of available materials, a totally different material having superior strength, rigidity or high temperature resistance can be formed.
- Microstructure of a composite material distinctly shows the individual constituents.
- The base material (soft phase) is called the matrix and the other material (hard phase) is called the additive or the reinforcing phase.

## 7.6 Classification of Composite Materials

- The classification of composite materials is summarized in Fig. 7.2.
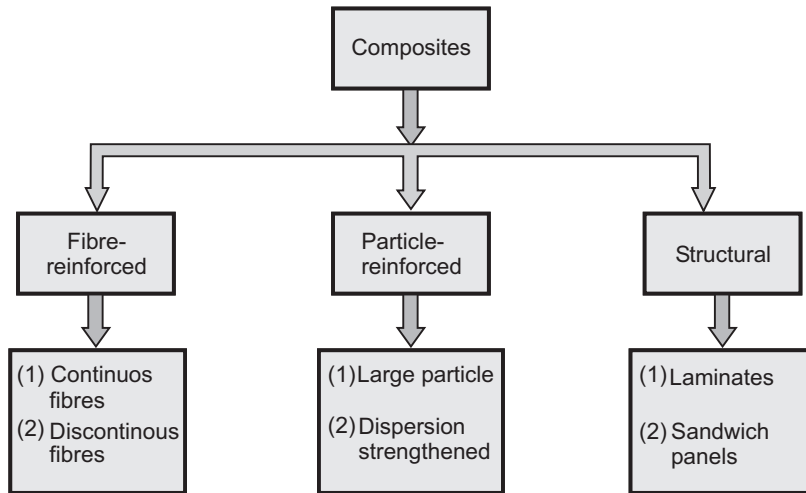


**Fig. 7.2 : Classification of composites**

### 7.6.1 Fiber-Reinforced Composites

- The composite material consists of high strength fibers dispersed in soft and ductile matrix.
- The combined material has better stiffness, strength and toughness.
- The function of fibers is to withstand the load, while matrix ensures uniform distribution of the applied load.
- The matrix also acts as a protective covering to the fibers against external environment, namely-corrosion, oxidation, electrical, etc.
- A number of factors influence the strength of fiber-reinforced composite, such as :
  i)   The distribution and orientation in between the fibers and matrix
  ii)  Percentage of fibers and matrix mix in the composite
  iii) Mechanical properties of the fibers and matrix
  iv)  Bonding at the fiber-matrix interface
- For effective strengthening of composite mix, the critical dimensions of fibers are defined.
- The critical length of fiber ($L_c$) is given by :

$$L_c = \frac{\sigma_f \times d}{\tau_c}$$

where,     $\sigma_f$  = Ultimate strength, d = Diameter of fiber,

$\tau_c$  = Shear strength

- Depending on the length of actual fibers, the fiber-reinforced composites are classified as : (Refer Fig. 7.3)

  i) Continuous fibers ($L > L_c$)  ii) Discontinuous fibers ($L < L_c$)



**(a) Continuous and aligned**    **(b) Discontinuous and aligned**    **(c) Discontinuous and randomly oriented**
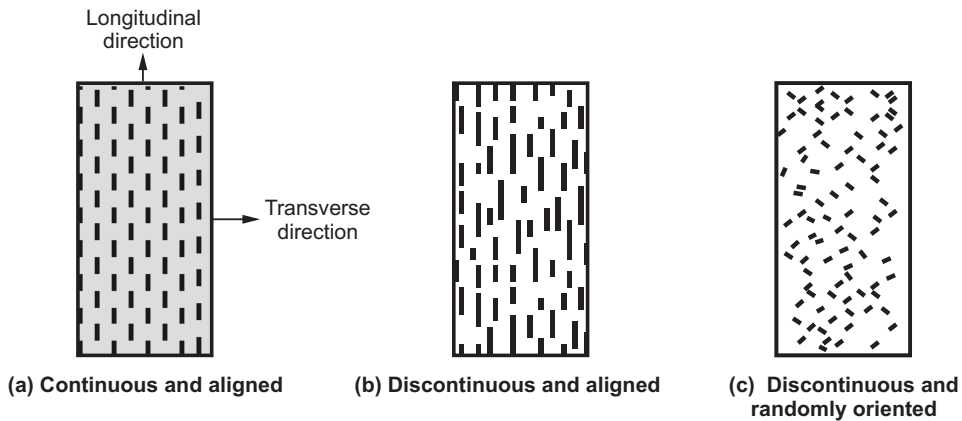
**Fig. 7.3 : Types of fiber-reinforced composites**

**Examples :**

- One of the popular example of fiber-reinforced composite is the FRP (Fiber-Reinforced Plastic).

- It consists of fibers of glass (mix of $SiO_2$, $Al_2O_3$, CaO, $B_2O_3$, MgO).

- The matrix is made of different types of plastics such as polysters, nylon, etc.

## 7.6.2 Particle-Reinforced Composites :

- In this type of composites, the strengthening is produced by particles of hard material.

- The matrix consists of soft phase.

- The function of particles is to impart strength and stiffness to the composite mix.

- Matrix ensures uniform distribution of applied load on the composite.

- Matrix also provides protective covering to the particles.

- The composites consist of fine particles of same overall dimensions (equiaxed) distributed uniformly across the matrix phase. Refer Fig. 7.4.



Particulate composite
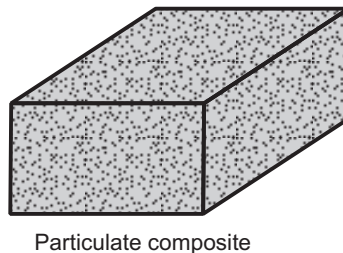
**Fig. 7.4 : Particle-reinforced composite**

Based on the strengthening mechanism, particle-reinforced composites can be classified as :

> 1. Large-particle composites
> 2. Dispersion strengthened particle reinforced composites

## i) Large-particle composites

- It consists of large particles of hard material in a soft matrix.
- The strengthening or reinforcement is induced by the virtue of size of particles.
- These hard particles restrict the movement of the matrix phase in the vicinity of the particle.

## Examples :

- A familiar example of particle-type reinforced composite is cement.
- Cement consists of cement matrix with sand and gravel as the particle strengtheners.
- For effective reinforcement, the sand and gravel size should be small and uniformly distributed across the cement matrix.

## ii) Dispersion strengthened particle reinforced composites

- It consists of atomic sized fine particles of hard material dispersed in a relative soft matrix material base.
- The presence of hard and fine particles restricts dislocations within the base material.
- The dispersed (strengthening) particles are chosen as unreactive to the base material.
- Such composites have high strength at elevated temperatures.

## Examples :

- Nickel alloys are used at high temperatures.
- To improve the high temperature strength of nickel alloys, thoria powder ($ThO_2$) in the proportion of 3 vol % is finely dispersed.
- The resultant composite is called thoria-dispersed nickel.

## 7.6.3 Structural Composites

- Structural composites are made up of two or more homogeneous materials.
- The properties of these composites depend on the properties of constituent materials and their geometrical design.
- Structural composites are classified as :

> (i)  Laminated composites      (ii)  Sandwich panel composites

## i) Laminated composites

- Laminated composites consist of two or more layers or sheets arranged in a stacking order. Refer Fig. 7.5.

- The sheets are stacked such that the high strength orientation of alternate sheets is same.

- The sheets are subsequently cemented using a bonding agent.

- The load on the composite is shared by all the layers or sheets in the composite.
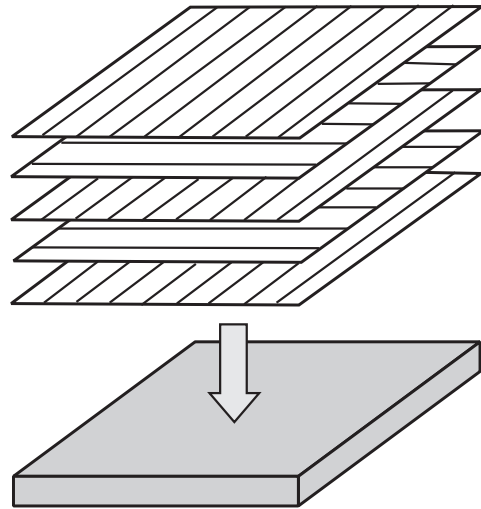


**Fig. 7.5 : Laminated composites**

**Examples :**

- Modern ski

## ii) Sandwich panel composites

- Sandwich panel composites consist of two high strength outer sheets withholding the core inside it. Refer Fig. 7.6.

- The core is usually a material of relatively low density, stiffness and strength.

- The outer sheets absorb most of the in-plane load applied on the composite material, while the core absorbs the shear load.
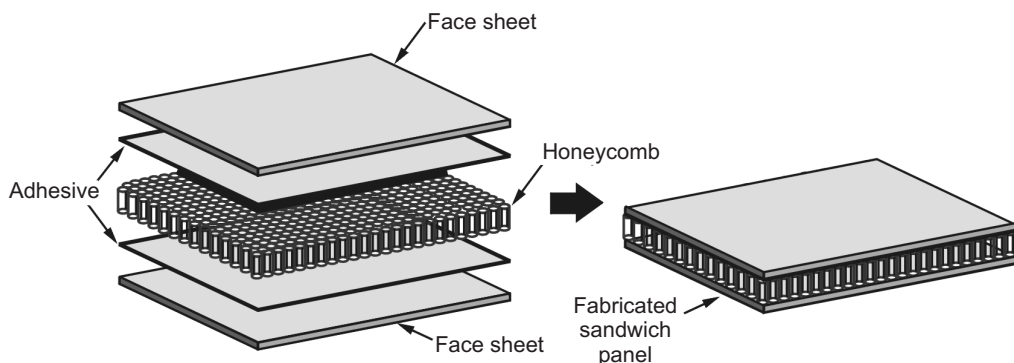


**Fig. 7.6 : Honeycomb core sandwich panel**

**Examples :**

- Plywood - It consists of high strength outer sheets with a soft wood phase in the core.

- Another example is copper clad stainless steel.

## 7.7 Composites on the Basis of Matrix

- On the basis of matrix composites are classified as follows :

> (i)   Polymer matrix composites (Fiber-Reinforced Plastic-FRP)
> (ii)  Metal Matrix Composites (MMC's)
> (iii) Ceramic matrix composites
> (iv)  Carbon-carbon composites

### 7.7.1 Polymer Matrix Composites

- It consists of fibers in a polymer resin matrix.
- It has good properties at room temperature and suitable for fabrication purpose, hence they are used in large quantities.
- The commonly used fibers are as follows :

> ○ Glass             ○ Aramid             ○ Carbon

**Glass fiber reinforced plastics (polymers)**
- These fibers are most widely used and they are least expensive of all the fibers.
- These composites have very high specific strength, but they are not rigid hence limited to service temperatures below 200 ºC.
- The most commonly used glass fiber is E-class and general polymer matrix materials are polyesters and vinyl esters.
- Polyesters are used for general structures where as epoxies are used in high strength applications.
- **Applications :** These composites are used in automotive and marine bodies, leaf springs, sporting goods, storage containers, industrial floorings, bathroom shower tubes, chairs, etc.

**Aramid fiber reinforced plastics (polymers)**
- Aramid fibers are used where light weight, high tensile and impact strength are desired.
- These fibers have good resistance to creep and fatigue.
- The main limitations of aramid fiber reinforced composites are
  - ○ Low compressive strength
  - ○ Moisture absorption
  - ○ Difficulty in machining
- **Kevlar 49** is the commonly used aramid fiber and general matrix materials are epoxies and polyesters.

- **Applications :** These fibers are used in bullet proof vests, pressure vessels, missile cases, automotive brake and clutch linings and gaskets, sports shoes, etc.

### Carbon fiber reinforced plastics (polymers)

- These fiber composites have lower-density, high strength and higher stiffness to weight ratio.

- An important property of this composite is its low coefficient of thermal expansion which gives better dimensional stability.

- Generally used matrix materials are epoxy, polyester and polyether ether ketone (PEEK).

- **Applications :** These fiber composites are used in sports and recreational equipments like golf stick and fishing rod, air craft and helicopter components (structures and satellites), motor cases, etc.

## 7.7.2 Metal Matrix Composites

- These composites provide high temperature resistance, non-flammability and high resistance to degradation by organic fluids as compared to polymer matrix composites.

- It contains continuous or discontinuous fibers or whiskers in a ductile metal matrix.

- The most commonly used matrices in ductile metals are aluminium, magnesium, copper, titanium, nickel and super alloys.

- The continuous fibers may be graphite, alumina, boron or silicon carbide.

- Characteristics of metal matrix composites are as follows :
  (i) High strength and stiffness.
  (ii) High coefficient of thermal expansion.
  (iii) High resistance to fatigue, abrasion and wear.

### Applications

i) Al reinforced with alumina fibers and used in automotive connecting rods and pistons.

ii) Al reinforced with silicon carbide (SiC) whiskers and used in aircraft wing panels.

iii) Cu reinforced with SiC fibers and used in propellers of ships.

iv) Ti reinforced with SiC fibers and used for turbine blades and discs.

## 7.7.3 Ceramic Matrix Composites

- Ceramic matrices like silicon carbide, silicon nitride and aluminium oxide are considered as structural material for high temperature applications.

- The main limitation of ceramic composites is their inherent brittleness and low fracture toughness.

- To improve fracture toughness of ceramics, the fibers of one ceramic are reinforced into another ceramic matrix.

**Applications**

(i) SiC fibers are reinforced with alumina and used as a cutting tool inserts for machining hard metal alloys.

(ii) Also they are used in high temperature applications like gas turbines and I.C. engines.

## 7.7.4 Carbon-Carbon Composites

- These composites are carbon fibers reinforced in carbon matrix.

- They are made by forming a carbon fiber fabric and impregnating the fabric by a polymer resin like phenolic.

- To convert the phenolic resin to carbon, the part is pyrolysed.

- The cycle of impregnation and pyrolysis is repeated for increasing the density and strength of the matrix.

- Carbon-carbon composites may operate at temperatures upto 3000 ºC.

- The characteristics of carbon-carbon composites are as follows :
  o High strength and stiffness.

  o High tensile strength.

  o High resistance to creep and fracture toughness.

  o High cost.

- **Applications :** Carbon-carbon composites are used in rocket motors, brake discs of racing cars and aircrafts, leading edges of aerospace vehicles, etc.

## 7.8 Hybrid Composites

- Hybrid composites are those composites which have a combination of two or more reinforced fibers.

- The most common hybrid composites are carbon-aramid reinforced epoxy (which combines strength and impact resistance) and glass-carbon reinforced epoxy (which gives a strong material at a reasonable price).

- Hybrid composites are usually used when a combination of properties of different types of fibers wants to be achieved or when longitudinal as well as lateral mechanical performances are required.

**Applications**

- The fishing rod is made of carbon-aramid reinforced plastic.

- Unidirectional carbon fibers give high stiffness in longitudinal direction, while lateral weaved aramid fibers allows for a high lateral strength.

- The canoe (used in boating) is made of an advanced sandwich of composite plastic : A carbon / kevlar reinforced epoxy on a core of PVC-foam.
- The bicycle frame is made of glass-carbon reinforced epoxy.

## 7.9 Advantages of Composites

- It is light in weight and it has very high specific strength.
- It has low coefficient of thermal expansion.
- It has high resistance to corrosion and chemicals like acids.
- It has high resistance to fatigue damage with good damping characteristics.
- It reduces further machining of parts.
- By using composites, tapered sections and compound contours can be easily made.
- The mixture of fiber and resin can be customised to meet stiffness, strength and manufacturing requirements.
- As compared to metals cost of composites is low.

## 7.10 Applications of Composites

### Applications in Aircraft Industry

- Composite materials have major role in weight reduction of aircrafts and spacecrafts.
- Composites used are carbon fibres, metal matrix composites etc. in wing assemblies, rotor blades of helicopter, propellers, seats and instruments enclosures, etc.

### Applications in Automobiles

- Applications of composites in auto industries has been limited to use of carbon composites.
- It is mainly used in race cars, high end performance vehicle and luxury vehicles.
- It provides structural integrity and crash worthiness and withstand forces of wind in high speed cars.

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## Review Questions

*1. What do you mean by material ?*

*2. Explain the classification of engineering materials.*

*3. Write short note on the following ferrous metals :*

*i) Cast iron    ii) Alloy steel    iii) Steel    iv) Alloy cast iron.*

---

4. *What is meant by non-ferrous metals ? What are their advantages ? Classify them.*

5. *What do you understand by composites ? Classify them.*

6. *Explain the various factors to be considered while selecting a material for a particular application.*

7. *Explain in brief various types of composites with examples.*

8. *What are the hybrid composites ? Give its advantages.*

9. *Give the applications of the composites in various fields.*

## 7.11 Multiple Choice Questions with Answers

**Q.1** Engineering materials are mainly classified as _____ .

    a) metals and their alloys      b) non-metals

    c) all of the above      **[Ans. : c]**

**Q.2** Ferrous metals are those which have _____ as main element.

    a) steel      b) iron

    c) copper      d) plastic      **[Ans. : b]**

**Q.3** _____ materials are the most important metals in metallurgical and mechanical industries.

    a) Ferrous      b) Non-ferrous

    c) None of the above      **[Ans. : a]**

**Q.4** The commonly used ferrous metals are _____ .

    a) cast iron      b) steel

    c) alloy cast iron and steel      d) all of the above      **[Ans. : d]**

**Q.5** _____ is formed by melting a metal and casting with or without machining to the desired final shape and size.

    a) Steel      b) Plastic

    c) Rubber      d) Cast iron      **[Ans. : d]**

**Q.6** The cost of cast iron is low because_____ .

    a) all the constituting elements are cheap

    b) manufacturing is cheap      c) its modification is cheap

    d) none of the above      **[Ans. : a]**

**Q.7** Cast iron has _____.

a) high hardness

b) high machinability

c) high resistance to wear

d) all of the above **[Ans. : d]**

**Q.8** Cast iron is used in _____ parts.

a) machine beds

b) hammers and valves

c) automobile parts

d) all of the above **[Ans. : d]**

**Q.9** _____ are used as alloying element for alloy cast iron.

a) Nickel and chromium

b) Copper and silicon

c) Vanadium and molybdenum

d) All of the above **[Ans. : d]**

**Q.10** Steel is an alloy of _____.

a) iron and steel

b) iron and copper

c) iron and carbon

d) iron and aluminium **[Ans. : c]**

**Q.11** _____ of cast iron is better than steel.

a) Vibration damping property

b) Toughness

c) Resilience

d) Stiffness **[Ans. : a]**

**Q.12** Carbon content increases _____ of steel.

a) strength

b) hardness

c) all of the above **[Ans. : c]**

**Q.13** _____ is used in the manufacturing of nuts, bolts, shafts, fan blades, cutting tools, etc.

a) Alloy steel

b) Plain carbon steel

c) Cast iron

d) All of the above **[Ans. : b]**

**Q.14** _____ are the applications of plain carbon steel.

a) Cutting tools and cutters

b) Nuts, bolts and screws

c) Fan blades, wires and springs

d) All of the above **[Ans. : d]**

**Q.15** _____ are the alloying elements for steel.

a) Carbon and sulphur

b) Silicon and manganese

c) Nickel and phosphorous

d) All of the above **[Ans. : d]**

**Q.16** Properties of alloy steel can be changed as per the _____.

    a) cost of alloying element        b) amount of alloying element

    c) all of the above                                  **[Ans. : b]**

**Q.17** Alloy steels are used in the manufacturing of _____.

    a) surgical instruments and missiles

    b) aircraft engine parts and heat exchangers

    c) razor and turbine blades        d) all of the above      **[Ans. : d]**

**Q.18** _____ is used for manufacturing of wrist watches, sanitary fittings, furnace parts, gas burners, etc.

    a) alloy steel                  b) plain carbon steel

    c) cast iron                   d) all of the above      **[Ans. : a]**

**Q.19** Non-ferrous metals are those which contain _____ as their main element.

    a) iron                      b) metal other than iron

    c) none of the above                                **[Ans. : b]**

**Q.20** Non-ferrous metals have _____.

    a) low density                 b) high electrical conductivity

    c) high corrosion resistance      d) all of the above      **[Ans. : d]**

**Q.21** Brasses and bronzes are types of _____.

    a) copper and its alloys        b) aluminium and its alloys

    c) all of the above                                    **[Ans. : a]**

**Q.22** _____ is the most widely used non-ferrous metal.

    a) Copper                    b) Aluminium

    c) All of the above                                **[Ans. : c]**

**Q.23** Various alloying elements are added to copper to _____.

    a) improve some properties     b) add some properties

    c) all of the above                                  **[Ans. : c]**

**Q.24** _____ are the major alloying elements for copper.

    a) Zinc and silicon           b) Aluminium and lead

    c) Manganese and nickel      d) All of the above      **[Ans. : d]**

**Q.25** Brasses are alloys of _____ .

    a) copper and tin                              b) copper and zinc

    c) copper and aluminium                d) copper and cast iron    **[Ans. : b]**

**Q.26** According to percentage of _____ the brasses may be $\alpha$ - brasses and $\alpha$ - $\beta$ brasses.

    a) copper and tin                              b) copper and zinc

    c) copper and aluminium                d) copper and cast iron    **[Ans. : b]**

**Q.27** _____ of brasses is low.

    a) Thermal conductivity                    b) Electrical conductivity

    c) All of the above                                 **[Ans. : c]**

**Q.28** _____ of brasses is high.

    a) Corrosion resistance and strength    b) Cost and machinability

    c) Ductility and malleability            d) All of the above       **[Ans. : d]**

**Q.29** _____ are used in the manufacturing of coils, needles, jewellery, etc.

    a) Brasses                                 b) Bronzes

    c) Steels                                   d) Cast irons        **[Ans. : a]**

**Q.30** Brasses are used in the manufacturing of _____.

    a) coins and needles                  b) cartridge cases and headlight reflectors

    c) welding rods and machine parts    d) all of the above       **[Ans. : d]**

**Q.31** Bronzes are alloys of _____.

    a) copper and tin                              b) copper and zinc

    c) copper and aluminium                d) copper and cast iron    **[Ans. : a]**

**Q.32** Bronzes are also alloyed with _____.

    a) aluminium                             b) silicon

    c) beryllium                              d) all of the above       **[Ans. : d]**

**Q.33** Bronzes are _____ than the brass.

    a)  softer                                 b) harder

    c) none of the above                            **[Ans. : b]**

**Q.34** Bronzes can be rolled into _____.

    a) sheets                                  b) rods

    c) wires                                  d) all of the above       **[Ans. : d]**

**Q.35** The cost of bronzes is _____ than the brasses.

    a) higher                     b) lower

    c) same                                              **[Ans. : a]**

**Q.36** Bronzes are used in the manufacturing of _____.

    a) gears and bearings           b) pressure vessels and marine containers

    c) ordnance parts and gun barrels     d) all of the above     **[Ans. : d]**

**Q.37** _____ are widely used in the aircraft industry.

    a) Copper and its alloys         b) Cast iron and its alloys

    c) Aluminium and its alloys      d) All of the above     **[Ans. : c]**

**Q.38** _____ are malleable and ductile.

    a) Copper and its alloys         b) Aluminium and its alloys

    c) All of the above                                **[Ans. : c]**

**Q.39** _____ of aluminium and its alloys is high.

    a) Thermal and electrical conductivity b) Corrosion resistance

    c) Toughness                     d) All of the above     **[Ans. : d]**

**Q.40** Aluminium alloys are used in the manufacturing of _____.

    a) motor and pump housing      b) food preparation equipments

    c) bakery equipments            d) all of the above     **[Ans. : d]**

*Engineering Materials ends …*

## Module - IV

# JOINING PROCESSES

**Syllabus : Soldering, Brazing and Welding :**

Definitions, Classification and method of soldering, Brazing and welding. Differences between soldering, Brazing and welding. Description of electric arc welding and oxy-acetylene welding.

## 8.1 Metal Joining Process

- Joining processes are used for joining metal parts and in general fabrication work.

- Such requirements generally occur when large/lengthy sections are required or when several pieces are to be joined together to fabricate a required structure.

- These processes are also applied when steam or water-tight joints are needed.

- Temporary or permanent type of fastening is also enabled by these processes.

- The commonly used joining processes are as follows :

  1. Welding          2. Soldering
  3. Brazing          4. Adhesive bonding

## 8.2 Soldering Process

- Soldering is a common process for joining steel, copper and other materials at low temperature.

- It is defined as a group of joining processes where coalescence is produced by heating to a suitable temperature and by using a filler metal having a liquidus not exceeding 427 ºC and below the solidus of base metals.

- The filler metal (solder) is generally distributed between the properly fitted surfaces of the joint by capillary action.

- Soldering is divided into two types i.e.

  ○ Soft solder          ○ Hard solder

- **Soft soldering** is used in sheet metal work for joining parts that are not exposed to the high temperature action and not subjected to excessive loads and forces.

- Soft soldering is also used for joining wires and small parts.

- A suitable flux is always used in soft soldering.

- Zinc chloride is a common flux used in this process.

- The function of flux is to prevent oxidation of the surfaces to be soldered or to dissolve oxides that settle on the metal surfaces while heating process.

- A blow torch or soldering iron constitutes the equipment for heating the base metals and melting the solder and the flux.

- **Hard soldering** uses solders which melt at higher temperatures and are stronger than those used in soft soldering.

- Silver soldering is a hard soldering method and in that silver alloyed with tin is used as solder.

- The temperatures of hard solders vary from 600 to 900 ºC.

- The fluxes are generally in the form of paste and applied to the joint before heating by using brush.

- In hard soldering, blow torch constitutes the equipment.

- Fig. 8.1 shows the commonly used soldering iron.



**Fig. 8.1 : Soldering iron**

- It consists of a copper bit tapered to form an edge at its end which is fastened to an iron rod in a wooden handle.

- Any source of heat is satisfactory for heating the bit.

- Generally, the bit is heated in gas or coke fire, cleaned, dipped in flux and then rubbed against the solder.

- All soldering techniques requires almost same procedure as discussed below (Refer Fig. 8.2) :
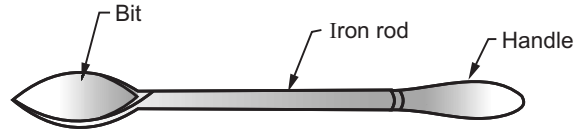
    o Clean the metal parts to be joined.

    o Fit the joints and heat the parts.

    o Apply the flux and filler materials.

    o Remove the heat and hold the assembly until the filler metal has completely solidified.

    o Clean the cooled parts, if required.
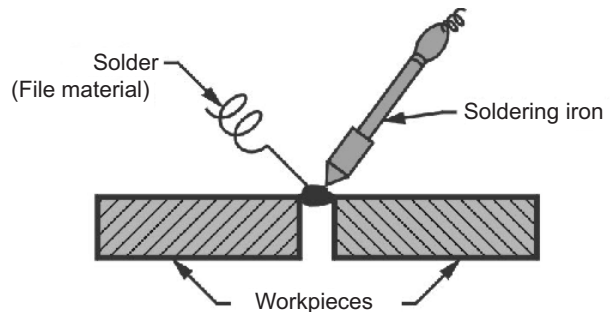


**Fig. 8.2 : Soldering process**

## 8.2.1 Advantages, Disadvantages and Applications of Soldering Process

**Advantages**

- By soldering process variety of dissimilar metals can be joined.

- It is a simple and low cost method.

- Workpieces of different thickness can also be joined.

- The joint formed in the process, do not require any machining.

- Soldering is a low temperature process, hence there is no change in the properties of metals.

**Disadvantages**

- Soldered joints do not have much strength, so the process should not be used for high load carrying members.

- Since soldering temperatures are low, a soldered joint has limited service at elevated temperatures.
- Corrosion resistance of soldered joint is less.
- Commonly used solder alloys are mixtures of tin and lead but, the used lead is toxic in nature.

**Applications**

Soldering process is commonly used for joining following components :
- Most frequent application of soldering is assembly of electronic components (chips, IC's, etc.) to printed circuit boards.
- Joints in sheet metal objects like food cans, roof flashing, iron, etc.
- Joints in the wires.
- Now-a-days jewellery components are also assembled and repaired by soldering process.

## 8.3 Brazing Process

- It is defined as a group of joining processes where coalescence is produced by heating to a suitable temperature and by using a filler metal having a liquidus above 470º C and below the solidus of the base metal.
- In brazing, metallic parts are joined by a non-ferrous filler metal or alloy.
- The filler metal is distributed between the closely fitted surfaces of the joint by capillary action.
- The filler metals used in the process are divided in two types :
  - Copper base alloys         - Silver base alloys
- Similar to soldering, the parts to be joined by brazing are carefully cleaned, the flux applied and the parts clamped in position for joining. Refer Fig. 8.3.



**(a) Before brazing**      **(b) Brazing**      **(c) After brazing**

**(a) Before brazing**      **(b) Beazing**      **(c) After brazing**
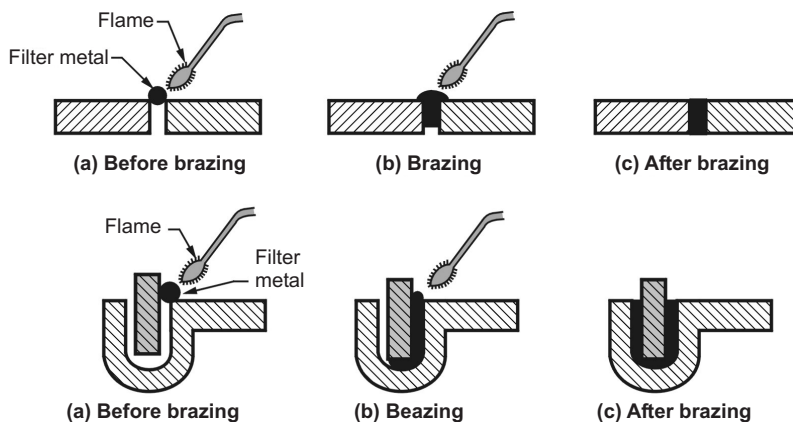
**Fig. 8.3 : Brazing of different components**

- **Borax** is commonly used flux in brazing process.

- They are then heated to a temperature above the melting point of the spelter (harder filler material) which is then allowed to flow by capillary action into the space between the parts and to slowly cool.

- There are various brazing methods such as :

  - Torch brazing
  - Immersion brazing
  - Resistance brazing
  - Furnace brazing

### Torch Brazing

- It is the most versatile method of brazing and finds wide application in industry.

- During brazing, the operator plays the torch flame (by using ordinary gas welding equipment) on the thoroughly cleaned parts.

- To prevent the oxidation of the parts during heating, flux is applied. The filler metal is then hand-fed to the joint area. Refer Fig. 8.4.
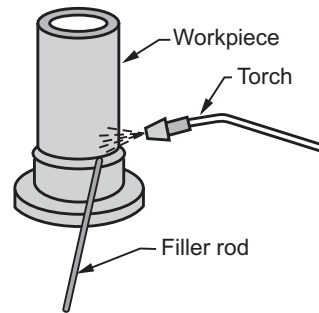


**Fig. 8.4 : Torch brazing**

### Furnace brazing

Furnace brazing is similar to ordinary brazing process; only the difference is that, for heating purpose instead of flame, furnace is used.

### Advantages

- By brazing process dissimilar metals and non-metals can be brazed.

- Due to uniform heating of parts, it produces less thermal distortion than the welding process.

- Complicated components can also be brazed at low cost.

- It is suitable for mass production.

- Machining of the brazed joint is not required.

- Brazing does not melt the base metal which allows much tighter control over the tolerances.

- Brazing produces a clean joint.

### Disadvantages

- Strength of the brazed joints is less as compared to welded joints.

- Brazed joints can be damaged under high service temperatures.

- Brazed joints requires a high degree of base metal cleanliness.

- The joint colour is different than that of base metal which creates an asthetic disadvantage.
- Filler metals used in the process are costly.

**Applications**

Brazing process is used in the joining of following components :
- Brazing can join :
  - Non-metals to metals       o  Porous metal components
  - Dissimilar metals
- Joining of electrical equipments, pipes, heat exchangers, etc.
- Joining of carbide tool tips, steam turbine blades, etc.

## 8.4 Welding Process

- It is a joining process used for various materials.
- The large varieties of materials that can be welded are metals and their alloys, although the term welding is also applied to the joining of other materials such as thermoplastics.
- Welding joins various metals with the help of a number of processes in which heat is supplied either electrically or by using a gas torch.
- For joining two or more pieces or metal together by one of the welding processes, the most essential requirement is **heat**.
- **Pressure** is also required, but not in all the processes.

### 8.4.1 Advantages, Disadvantages and Applications of Welding Process

**Advantages**
- A large number of metals or alloys, both similar and dissimilar can be joined by welding.
- Welding can be mechanized.
- A good weld is as strong as the base metal.
- Welding can join workpieces through spots, end to end and in a number of other configurations.
- General welding equipments are not very costly.
- Portable welding equipments are also available.

**Disadvantages**
- Welding gives out harmful radiations, fumes and spatter.
- Welding results in residual stresses and distortion of the workpieces.

- To hold and position the parts to be welded, generally jigs and fixtures are required.
- To produce a good welding job, a skilled welder is required.
- Heat generated due to welding produces metallurgical changes hence, the structure of welded joint is different than that of parent metal.
- Before welding, generally edge preparation of the workpieces is required.

**Applications**

Some of the important applications of welding process are as follows :
- Aircraft construction (Welding of engine parts, turbine frame, ducts, etc.)
- Rail-road equipments (Air receiver, engine, front and rear hoods, etc.)
- Pipings and pipelines (Open pipe joints, oil and gas pipelines, etc.).
- Pressure vessels (boilers) and tanks (Joining of nozzles, ends, tanks, etc.).
- Buildings and bridges (Colums base plates, erection of structures, etc.).
- Automobile parts (Trucks, buses, cars, cranes, bikes parts, etc.).
- Machine parts (Frames, beds, tools, dies, etc.).

## 8.4.2 Classification of Welding Process

- There are different ways of classifying welding and allied processes.
- Modern methods of welding may be classified under two broad categories i.e. plastic welding and fusion welding.
- In **plastic (pressure) welding**, the metal pieces to be joined are heated to a plastic state and then forced together by external pressure. In this method filler metal is not required.
  For example, forge welding, electric resistance welding, etc.
- In **fusion (non-pressure) welding**, the material at the joint is heated to molten state and allowed to solidify. In this method, filler material is required during the process.
  For example, arc welding, gas welding, etc.
- In general, welding and allied processes are classified as follows :

1. **Gas welding :**

   (a) Oxy-acetylene welding          (c) Air acetylene welding

   (b) Oxy-hydrocarbon welding        (d) Pressure gas welding

2. **Arc welding :**

   (a) Gas tungsten arc welding (TIG)  (e) Shielded metal arc welding

   (b) Gas metal arc welding (MIG)     (f) Submerged arc welding

(c) Electro-slag welding      (g) Plasma arc welding

(d) Stud arc welding

3. **Resistance welding :**

   (a) Spot welding      (d) Percussion welding

   (b) Seam welding      (e) Resistance butt welding

   (c) Projection welding

4. **Solid state welding :**

   (a) Friction welding      (c) Explosive welding

   (b) Ultrasonic welding      (d) Forge welding

5. **Thermo-chemical welding processes :**

   (a) Thermo welding      (b) Atomic hydrogen welding

6. **Radiant energy welding processes :**

   (a) Electron Beam Welding (EBW)      (b) Laser Beam Welding (LBW)

## 8.5 Gas Welding Process

- Gas welding is a fusion-welding or non-pressure welding method.
- It joins the metals, by using combustion heat of oxygen/air and fuel gas (acetylene, hydrogen, propane or butane) mixture.
- The flame thus produced causes melting and thus fuses together the edges of the parts to be welded, generally by adding a filler metal.
- Following are the types of gas welding :

  > a) Oxy-acetylene welding      b) Air-acetylene welding
  > c) Oxy-hydrogen welding      d) Pressure gas welding

### 8.5.1 Oxy-Acetylene Gas Welding    ☞ [ Dec. 2010, Dec. 2012, Dec. 2013 ]

### Principle of Operation :

- The oxy-acetylene welding system consists of two cylinders. One contains oxygen and other contains acetylene. For controlling the flow of gases corresponding valves are used. Refer Fig. 8.5 (b).
- When acetylene in correct proportion is mixed with oxygen in a welding torch and ignited, then the flame resulting at the tip of the torch is sufficiently hot to melt and join the parent metals.

- The oxy-acetylene flame reaches a temperature of about 3200 ºC and thus can melt all commercial metals and hence metal can flow together to form a complete bond.

- To build up the seam further for greater strength, a filler metal rod is added to the molten metal part. Refer Fig. 8.5(a).

- It does not require the components to be forced together under pressure during welding.



**(a) Actual welding**          **(b) Welding set-up**
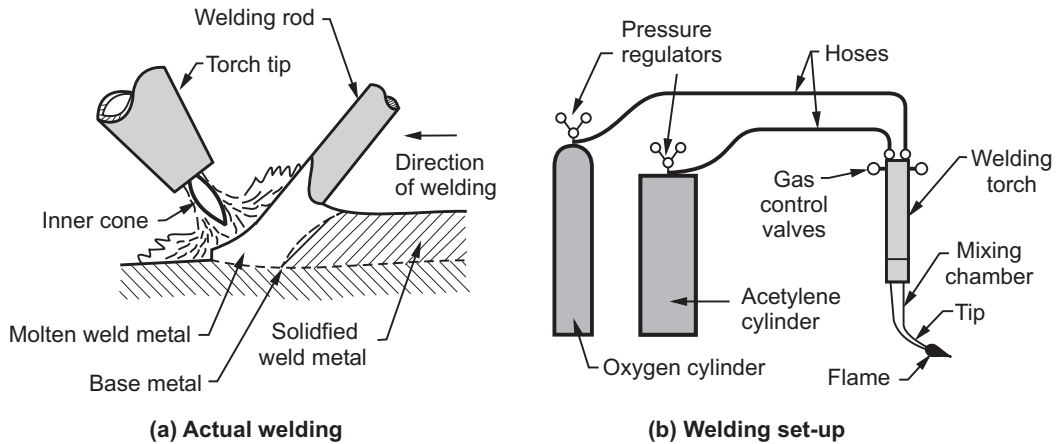
**Fig. 8.5 : Oxy-acetylene gas welding**

**Flame :**

- In oxy-acetylene welding, flame is of atmost importance.

- The correct type of flame is required for the production of satisfactory welds.

- The maximum temperature of the oxy-acetylene flame is 3100 ºC to 3300 ºC and the centre of the heat concentration is just at the extreme of the white cone.

- Combustion of gas mixture takes place in two stages :

**Stage 1 :**  Oxygen and acetylene in equal proportions by volume burn in the inner white cone. The oxygen combines with carbon of the acetylene and forms carbon monoxide, while the hydrogen is liberated.

$$2C_2H_2 + 2O_2 \rightarrow 4CO + 2H_2$$
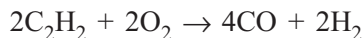
**Stage 2 :**  In this, the carbon monoxide uses the oxygen supplied from the air surrounding the flame and as a result of burning forms carbon-dioxide. The hydrogen also burns with oxygen and forms water vapour ($H_2O$).

$$4CO + 2H_2 + 3O_2 \rightarrow 4CO_2 + 2H_2O$$
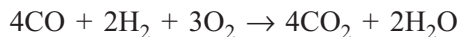
In order to operate the welding with maximum efficiency, the flame must be of proper size, shape and condition. The generated flames are classified into following three types

(Refer Fig. 8.6) :

a) Neutral flame (Acetylene and oxygen in equal proportion)
b) Oxidising flame (Excess of oxygen)
c) Reducing flame or carburising flame (Excess of acetylene)



**Neutral flame**

**Oxidising flame**
(Excess oxygen results high temperature upto 3480 ºC)

**Carburising flame**
(Excess acetylene result temperature 2000 ºC to 2800 ºC average)

**Fig. 8.6 : Oxy-acetylene gas flame**

**Neutral flame :**

- It is produced when equal volume of oxygen and acetylene are mixed in the welding torch and burnt at the tip of the torch.

- The temperature of the neutral flame is about 3260 ºC.

- The flame has a nicely defined inner cone which is light blue in colour and surrounded by an outer flame envelope.

- This flame is called as neutral flame because it does not cause any chemical change in the molten metal and hence will not oxidise or carburize the metal.

- A neutral flame is mostly used for the welding of :
  o Mild steel          o Aluminium          o Copper
  o Cast iron           o Stainless steel

**Oxidising flame :**

- After the development of neutral flame, if the oxygen supply is further increased then oxidising flame will be developed.

- It is recognised by the small white cone which is shorter, much bluer in colour and more pointed than neutral flame.

- This flame is hotter than neutral flame because of excess oxygen which causes the temperature to rise upto 3480 ºC.

- This excess oxygen causes the weld bead and surrounding area to have a dirty appearance hence, this flame has limited use in welding and not used in the welding of steel.

- An oxidising flame is used for :
  - Copper-base metals
  - Zinc-base metals
  - Ferrous metals such as manganese steel, cast iron, etc.

**Reducing flame (Carburising flame) :**

- If the amount of oxygen supplied to the neutral flame is reduced, then the generated flame will be a carburising flame or reducing flame i.e. more content of acetylene.

- It is recognised by acetylene feather which exists between the inner cone and the outer envelope.

- This outer flame envelope is longer than neutral flame and is usually much brighter in colour.

- A reducing flame has an approximate temperature of 2740 ºC.

- This flame is generally used for :
  - Welding of low alloy steel rods
  - Non-ferrous metals
  - High carbon steel

## 8.5.2 Advantages, Disadvantages and Applications of Gas Welding Processes

**Advantages**

- Operator has considerable control over the temperature of the metal in the weld zone.

- The rate of heating and cooling is relatively slow, which is advantageous in some cases.

- The equipment is versatile, low cost, self-sufficient and generally portable.

- The cost and maintenance of the welding equipment is low as compared to other welding processes.

- Gas welding can be applied to a wide variety of manufacturing and maintenance applications.

**Disadvantages**

- Refractory metals and reactive metals cannot be welded.

- Gas flame takes long time to heat the metal than arc welding.

- More safety problems are associated with the handling and storing of gases.

- Fluxes used in welding produces fumes that are irritating to the eyes, nose, throat and lungs.

- Heavy sections cannot be welded economically.

**Applications**

Gas welding is most widely used for the following purposes :

- Joining thin materials.
- Joining most ferrous and non-ferrous metals.
- In automobile and aircraft industries.
- In sheet metal fabricating plant.

## 8.6 Arc Welding Process

- Electric arc welding is a fusion welding process in which welding heat is obtained from an electric arc between an electrode and the workpiece.
- The electrode is first allowed to touch the workpiece to form an electric circuit and then separated continuously to flow through the gaseous medium.
- The temperature produced at the centre of the arc is 6000 ºC to 7000 ºC.
- In this, the base metal is melted by the temperature of the arc, forming a pool of molten metal which is forced out of the pool by blast from the arc.
- Electrode metal also gets melted and deposited at the weld.
- Either A. C. or D. C. supply is used for arc welding process.
- The electrodes used in the process are of two types i.e. bare electrodes and coated electrodes.
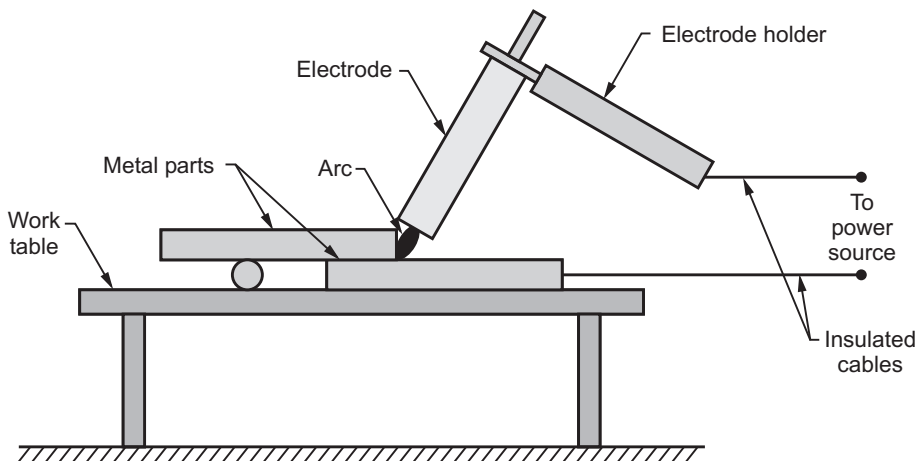


**Fig. 8.7 : Arc welding principle**

- Bare electrodes are cheaper but welds produced through these are of poor quality whereas, coated electrodes are used in modern welding machines as they carry a core of bare metallic wire produced with coating on the outer surface.

- The length of electrodes varies from 250 mm to 450 mm whereas, diameter varies from 1.6 mm to 9 mm.

**Arc Welding Equipments**

The most commonly used equipments for arc welding are as follows :

| | |
|---|---|
| a) A.C or D.C. machine | b) Wire brush |
| c) Cables and connectors | d) Earthing clamps |
| e) Chipping hammer | f) Wire brush |
| g) Helmet | h) Safety goggles |
| i) Cable lug | j) Hand gloves, apron, etc. |

## 8.6.1 Advantages, Disadvantages and Applications of Arc Welding Process

**Advantages**

- It is the most versatile process which can be applied for thin and thick setions.

- Welding of complicated shapes can also be done.

- Welding can be done in any position with high weld quality.

- Very neat appearance and smooth weld shapes can be obtained.

- Generally, edge preparation is not required.

- The equipments are portable and less expensive.

**Disadvantages**

- As the electrodes are coated, the chances of slag entrapment and their related defects are more.

- Welding control is difficult.

- The process needed filler material.

- It is a slow process.

**Applications**

Arc welding is commonly used in the manufacturing of following parts :

- Air receiver, boilers, pressure vessels fabrication.

- Automobile, chemical and aircraft industry.

- Ship buiding and bridge construction.

## 8.7 Comparison between Soldering, Brazing and Welding

☞ **[ June 2010, Dec. 2010, June 2011, June 2012, June 2013 ]**

| Sr. No. | Parameter | Soldering | Brazing | Welding |
|---|---|---|---|---|
| 1. | Principle | The filler metal is usually distributed between the properly fitted surfaces of the joint by capillary action. | The filler alloy is fed to one or more points in the assembly and it is drawn into the rest of the joint by capillary action. | The filler alloy is deposited directly at the point where it is desired. |
| 2. | Temperature | Filler metal has melting point below 427 °C. | Filler metal has melting point above 427 °C. | Filler metal has melting point above 427 °C. |
| 3. | Strength of joint | Weak | Strong | Moderate |
| 4. | Application | Used for carbon, low alloy steels, cast iron, stainless steel, Cu and alloys, Al and alloys, etc. | Used for cast iron, steels, Cu and alloys, Al and alloys, Mg and alloys, etc. | Used for cast iron, steels, malleable iron, Cu, Ni and alloys, etc. |
| 5. | Corrosion resistance | Less | More | Moderate |
| 6. | Joint profile | Small gap between the joints. | Smooth joint. | Joint shows the ripples. |

## Review Questions

1. *What are the various welding methods ? Describe them in brief.*

2. *What are the advantages, disadvantages and applications of welding process.*

3. *What do you understand by gas welding ? Explain in brief the equipment required for oxy-acetylene welding.*

4. *What are the different types of flames generated in gas welding ?*

5. *Explain electric arc welding principle.*

6. *What is mean by soldering ?*

7. *What is mean by soldering ?*

8. *Compare soldering, brazing and welding.*

## 8.8 Multiple Choice Questions with Answers

**Q.1** _____ are the commonly used joining processes.

a) Welding            b) Soldering and brazing

c) Adhesive bonding        d) All of the above      **[Ans. : d]**

**Q.2** For joining two or more pieces of metal together by any welding process the most essential requirement is _____.

a) pressure            b) heat

c) force              d) none of the above      **[Ans. : b]**

**Q.3** A large number of metals or alloys, both similar and dissimilar can be joined by _____.

a) brazing            b) soldering

c) welding            d) adhesive bonding      **[Ans. : c]**

**Q.4** Welding produces _____.

a) harmful radiations       b) fumes

c) spatter            d) all of the above      **[Ans. : d]**

**Q.5** Welding results in _____.

a) residual stresses         b) distortion of the workpieces

c) metallurgical changes in the workpiece    d) all of the above      **[Ans. : d]**

**Q.6** _____ are the important applications of welding process.

a) Crankshaft           b) Piston and cylinder

c) Leaf springs and crane hooks    d) None of the above      **[Ans. : d]**

**Q.7** _____ are the important applications of welding process.

a) Aircraft constructions      b) Rail-road equipments

c) Pipelines and pipings       d) All of the above      **[Ans. : d]**

**Q.8** Welding process is widely used in _____.

a) pressure vessels and tanks     b) buildings and bridges

c) automobile parts         d) all of the above      **[Ans. : d]**

**Q.9** _____ is a fusion welding process in which welding heat is obtained from an electric arc between an electrode and workpiece.

a) Resistance welding       b) Arc welding

c) Gas welding           d) None of the above      **[Ans. : b]**

**Q.10** The temperature produced at the centre of arc is _____.

    a) 6000 to 7000 ºC               b) 5000 to 10000 ºC

    c) 6000 to 10000 ºC             d) 1000 to 10000 ºC     **[Ans. : a]**

**Q.11** In arc welding process the base metal is melted by the temperature of _____.

    a) electrode                    b) source

    c) arc                         d) none of the above     **[Ans. : c]**

**Q.12** _____ is the most versatile welding process which can be applied for thin and thick sections.

    a) Arc welding process          b) Resistance welding process

    c) Gas welding process          d) None of the above     **[Ans. : a]**

**Q.13** In arc welding process _____.

    a) filler material is required       b) complicated shapes can be welded

    c) equipments are portable and less expensive

    d) all of the above     **[Ans. : d]**

**Q.14** Arc welding process is commonly used in the manufacturing of _____.

    a) air receiver, boilers, pressure vessel fabrication

    b) automobile, chemical and aircraft industry

    c) ship building and bridge construction

    d) all of the above     **[Ans. : d]**

**Q.15** _____ is a process in which two or more metal items are joined together by melting and flowing a filler metal into the joint.

    a) Welding                     b) Brazing

    c) Soldering                  d) All of the above     **[Ans. : c]**

**Q.16** The filler metal used in the soldering process is called as _____ .

    a) solder                      b) soldering iron

    c) torch                       d) none of the above     **[Ans. : a]**

**Q.17** In _____ process the base metals are not melted during the joining.

    a) soldering                   b) welding

    c) casting                    d) none of the above     **[Ans. : a]**

**Q.18** In soldering process the solder melts and flows in the gap by _____.

    a) fluidity                            b) capillary action

    c) none of the above                             **[Ans. : b]**

**Q.19** After soldering when the metal cools, the resulting joints are _____.

    a) not strong as base metal           b) having adequate strength

    c) having good electrical conductivity d) all of the above     **[Ans. : d]**

**Q.20** Hand soldering is performed with _____.

    a) soldering iron                      b) soldering gun

    c) soldering torch                    d) all of the above     **[Ans. : d]**

**Q.21** Soldering process is _____ .

    a) low cost method                   b) simple method

    c) low temperature method           d) all of the above     **[Ans. : d]**

**Q.22** In soldering method _____.

    a) workpieces of different thickness can be joined

    b) machining is not required

    c) dissimilar metals can be joined    d) all of the above     **[Ans. : d]**

**Q.23** Soldered joint has _____.

    a) low load carrying capacity        b) less corrosion resistance

    c) limited applications at high temperatures

    d) all of the above                        **[Ans. : d]**

**Q.24** _____ type of solder is toxic in nature.

    a) Tin                                b) Lead

    c) None of the above                            **[Ans. : b]**

**Q.25** For assembly of electronic components to the printed circuit boards _____ method is commonly used.

    a) soldering                       b) welding

    c) adhesive bonding                d) all of the above     **[Ans. : a]**

**Q.26** _____ are the application areas of soldering process.

    a) Joints in food cans, irons, etc.    b) Joints in the wires

    c) Joints in jewellery components    d) All of the above     **[Ans. : d]**

**Q.27** In _____ process metallic parts are joined by a non-ferrous filler metal.

a) brazing                                   b) soldering

c) welding                                   d) none of the above          **[Ans. : a]**

**Q.28** In brazing process the temperature used to melt the filler metal is above _____ .

a) 500 ºC                                    b) 450 ºC

c) 400 ºC                                    d) 600 ºC                    **[Ans. : b]**

**Q.29** In _____ process the parts to be joined are carefully cleaned, the flux is applied and the parts are clamped in position for joining.

a) soldering                                 b) brazing

c) all of the above                                                       **[Ans. : c]**

**Q.30** The filler metals used in _____ process are copper based and silver based alloys.

a) brazing                                   b) soldering

c) welding                                   d) all of the above          **[Ans. : a]**

**Q.31** The various methods of brazing are _____.

a) torch brazing                             b) furnace brazing

c) silver brazing                            d) all of the above          **[Ans. : d]**

**Q.32** By brazing process _____.

a) dissimilar metals and non-metals can be brazed

b) compliated components can be brazed

c) clean joint can be produced        d) all of the above          **[Ans. : d]**

**Q.33** In brazing process _____.

a) strength of joint is less

b) joints can be damaged under high temperatures

c) joint colour is different than that of base metal

d) all of the above                                                       **[Ans. : d]**

**Q.34** Brazing can join _____.

a) non-metals to metals                      b) porous metal components

c) dissimiar metals                          d) all of the above          **[Ans. : d]**

**Q.35** Brazing is used in the joining of _____.

a) electrical equipments                     b) pipes and heat exchangers

c) tool tips and turbine blades              d) all of the above          **[Ans. : d]**

**Q.36** The temperature range in arc welding process is about_____.  ☞ **[ June 2010 ]**

    a) 2000 to 3000 ºC                    b) 3000 to 4000 ºC

    c) 4000 to 5000 ºC                    d) 5000 to 6000 ºC     **[Ans. : b]**

**Q.37** The filler material used in brazing is _____.  ☞ **[ June 2010 ]**

    a) electrode                            b) spelter

    c) solder                               d) flux     **[Ans. : d]**

**Q.38** The oxy-acetylene flame, which contains more amount of oxygen and less amount of acetylene is _____.  ☞ **[ Dec. 2010 ]**

    a) neutral flame                       b) reducing flame

    c) oxidizing flame                   d) none of these     **[Ans. : c]**

**Q.39** Joining of two metal pieces using an alloy by the application of heat is called _____.  ☞ **[ Dec. 2010 ]**

    a) soldering                          b) welding

    c) brazing                             d) buffering     **[Ans. : c]**

**Q.40** Spelter is used in _____.  ☞ **[ June 2011 ]**

    a) soldering                          b) brazing

    c) resistance welding                d) arc welding     **[Ans. : b]**

**Q.41** Graphite is used as _____.  ☞ **[ June 2011 ]**

    a) filler material                     b) flux

    c) spelter                           d) lubricant     **[Ans. : c]**

**Q.42** Spot welding is an example of _____ welding.  ☞ **[ June 2012 ]**

    a) gas                               b) resistance

    c) TIG                               d) arc     **[Ans. : b]**

**Q.43** Welding is a _____ process used for metals.  ☞ **[ Dec. 2012 ]**

    a) metallurgical joining            b) forged forming

    c) mechanical joining             d) adhesive bonding     **[Ans. : a]**

**Q.44** Gas welding is a _____ method of joining two metals.  ☞ **[ Dec. 2012 ]**

    a) fission                           b) fusion

    c) gas reaction                     d) oxidizing     **[Ans. : b]**

**Q.45** _____ is used as flux in welding.  ☞ **[ June 2013 ]**

    a) Sodium phosphate          b) Sodium carbonate

    c) Sodium silicate          d) Sodium chloride      **[Ans. : d]**

**Q.46** Fusion welding is an example for _____ welding.  ☞ **[ Dec. 2013 ]**

    a) Resistance          b) Arc

    c) Forge          d) Thermit pressure      **[Ans. : b]**

**Q.47** Copper base filler metal is used for _____.  ☞ **[ Dec. 2013 ]**

    a) soft soldering          b) hard soldering

    c) brazing          d) welding      **[Ans. : c]**

## 8.9 University Questions with Answers

### June 2010

**Q.1** Distinguish among welding, soldering and brazing. **(Refer section 8.7)** **[6]**

### Dec. 2010

**Q.2** With a neat sketch, explain the working principle of oxy-acetylene gas welding. **(Refer section 8.5.1)** **[6]**

**Q.3** List any 4 differences between soldering and brazing. **(Refer section 8.7)** **[4]**

### June 2011

**Q.4** What are the differences between soldering and brazing ? **(Refer section 8.7)** **[5]**

**Q.5** Distinguish among welding, soldering and brazing. **(Refer section 8.7)** **[6]**

### June 2012

**Q.6** Distinguish among welding, soldering and brazing. **(Refer section 8.7)** **[6]**

### Dec. 2012

**Q.7** With a neat sketch, explain the working principle of oxy-acetylene gas welding. **(Refer section 8.5.1)** **[8]**

### June 2013

**Q.8** Differentiate between welding and brazing. **(Refer section 8.7)** **[4]**

**Dec. 2013**

**Q.9** Explain the principle of arc welding with a figure. **(Refer section 8.6)** [6]

**Q.10** Name the three types of oxy-acetylene flame. Explain the application of each of them. **(Refer section 8.5.1)** [6]

*Joining Processes ends…*

# Module - V

## CHAPTER - 9

# REFRIGERATION AND AIR CONDITIONING

**Syllabus : Refrigerants :** Properties of refrigerants, List of commonly used refrigerants.

**Refrigeration - Definitions** - Refrigerating effect, Ton of refrigeration, Ice making capacity, COP, Relative COP, Unit of refrigeration. Principle and working of vapour compression refrigeration and vapour absorption refrigeration : Principles and applications of air conditioners, Room air conditioner.

## 9.1 Refrigeration

- **Refrigeration** is defined as the branch of science that deals with the process of reducing and maintaining the temperature of that space or material below the temperature of surroundings.

- The system maintained at lower temperature is called as **refrigerated system** and equipment used to produce this is called as **refrigerator.**

- The cooling effect produced by refrigerator is termed as **refrigerating effect** and the working substance used to produce this effect is known as **refrigerant.**

- The heat withdrawn from the refrigerated space is rejected to atmosphere which acts as a natural heat reservoir.

- The heat transfer from the system to surrounding is reduced by providing insulating materials.

**Applications of refrigeration**

Refrigeration can be used in the following areas :

- Formation of ice.

- Preservation of food stuffs, fruits, vegetables, etc. in the storage area or transportation.

- Preservation of medicines and blood.

- Cooling of liquids in chemical process plants.

- Preservation of photographic films, archelogical documents, etc.

- Providing comfortable environment under difficult working conditions.

- Liquification of gases like oxygen, nitrogen, hydrogen, etc.

- It is used for processing of textiles, processing work, photographic material, etc.

- Processing of farm crops.

- For pre-cooling and pasteurization of milk and in preparation of butter.

## 9.2 Methods of Refrigeration                    ☞ [ June 12 ]

- Refrigerating effect can be produced by using following methods :

  1. Ice refrigeration
  2. Steam jet refrigeration
  3. Refrigeration by air expansion
  4. Vapour absorption cycle
  5. Vapour compression cycle

- Out of all these methods, vapour compression cycle is commonly used for applications like refrigerator, deep-freezers and air-conditioners.

**Unit of refrigeration**

- The capacity of refrigeration system is given in **Tons of Refrigeration (T.R).**

- A ton of refrigeration is defined as the quantity of heat required to be removed, to form one ton of ice at 0 ºC in 24 hours when initial condition of water is 0 ºC because same cooling effect will be obtained by melting the same ice.

- S.I. unit of 1 ton of refrigeration is,

$$1 \text{ TR } = 12660 \text{ kJ/hr} = 211 \text{ kJ/min}$$

or $\qquad 1 \text{ TR } = 3.517 \text{ kJ/sec} = 3.517 \text{ kW}$

∴ $\qquad \boxed{1 \text{ TR } = 3.517 \text{ kW}}$

- TR actually measures the rate of heat transfer.

**Coefficient of performance (COP)**

- COP of refrigerator is defined as the amount of heat extracted from refrigerator to work supplied.

Let, $\qquad Q_A$ = Amount of heat extracted in refrigerator

$\qquad W_{net}$ = Net work supplied to system

∴ $\qquad COP = \dfrac{Q_A}{W_{net}}$

# 9.3 Vapour Compression Refrigeration (VCR) System

☞ **[ Dec. 2010, June 2012, Dec. 2012, June 2013, Dec. 2013 ]**

- Vapour compression refrigeration system is most commonly used method of refrigeration for refrigerators, air-conditioners, etc.

- In this system, the liquid refrigerant boils in evaporator which at low pressure, by absorbing latent heat.

- The vapours formed are condensed in condenser which is at high pressure by rejecting latent heat.

- Thus, in this cycle heat is transferred in the form of sensible heat as well as latent heat which gives higher COP.

- Fig. 9.1 shows the simple vapour compression refrigeration system.

- In this system commonly used refrigerants are $NH_3$, R-11, R-12, R-22. In modern refrigerators Freon-22 and 134-a refrigerants are used.

- Simple vapour compression refrigeration system consists of four different processes :

| | |
|---|---|
| 1. Compression | 2. Condensation |
| 3. Expansion | 4. Evaporation (Vaporization) |
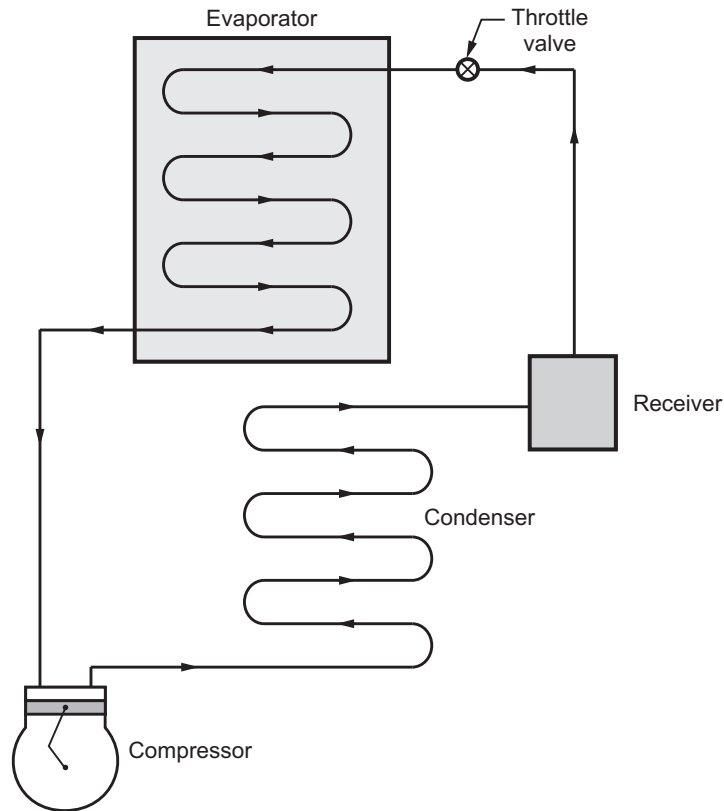
**Fig. 9.1 : Vapour compression refrigeration system**

**1. Compression :** During the suction stroke of compressor, low-pressure vapour in dry state is drawn from the evaporator. Here, the temperature and pressure of vapour increases until the vapour temperature is greater thatn the condenser temperature.

**2. Condensation :** During condensation, high pressure refrigerant vapour enters the condenser where the cooling medium absorbs the heat and converts the vapour into liquid.

**3. Expansion :** After condensation, the liquid refrigerant is stored in the receiver and from receiver it is passed to evaporator through expansion or throttle valve. This valve reduces the pressure by keeping the enthalpy constant (Throtting process).

**4. Evaporation (Vapourization) :** After expansion, low pressure liquid refrigerant enters in evaporator where considerable amount of heat is absorbed by it and converted into vapour. This low pressure vapour is sucked by the compressor and the cycle repeats.

## 9.4 Vapour Absorption Refrigeration (VAR) System

☞ **[ June 2010, June 2011, Dec. 2011, June 2013, Dec. 2013 ]**

- The vapour absorption system consist of absorbing the refrigerant ($NH_3$) after leaving the evaporator.
- The VAR system differs from VCR system only in the method of compression of refrigerant.
- The basic components of the vapour absorption refrigeration systems are as follows :
  - ○ Absorber
  - **o** Generator
  - ○ Condenser
  - ○ Receiver
  - ○ Expansion valve
  - ○ Evaporater
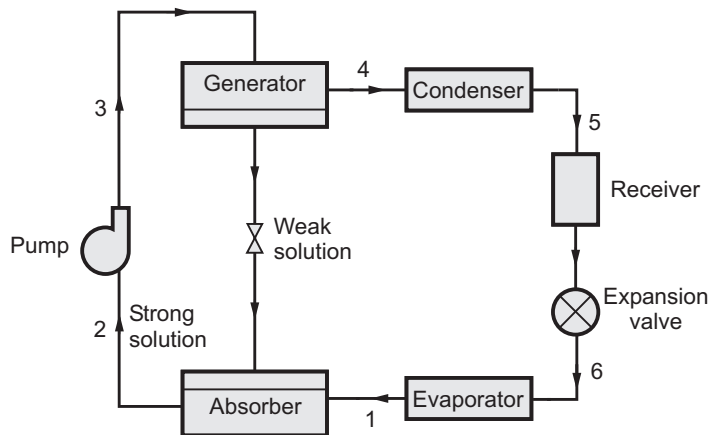


**Fig. 9.2 : Simple vapour absorption system**

- The ammonia vapour leaving the evaporator at point 1 is absorbed in the low temperature solution in the absorber. Here heat is rejected from the ammonia vapours.
- The strong solution of ammonia and water is pumped to generator raising its pressure.
- This solution is heated in the generator and hence ammonia vapours are seperated from water. The weak ammonia in water solution is returned to the absorber.
- The ammonia vapours from the generator are passed to the condenser where vapours reject heat to condening medium.
- The condensed ammonia liquid passes through the expansion valve in which the pressure and temperature is reduced.
- The low temperature, low pressure liquid ammonia passes through the evaporator and take out the heat from the refrigerated space and vaporises and the cycle continues.
- In this system, compression work is less than that of vapour compression system.
- The heat input is necessary to the generator in the form of steam or gas.

## 9.5 Refrigerants

- Refrigerant is the substance which carries heat from low temperature region and delivers to high temperature region.

- It removes heat in the form of either sensible heat or latent heat.

### 9.5.1 Desirable Properties of the Refrigerants    ☞ **[ June 2010, Dec. 2010 ]**

- The refrigerant should have low boiling and freezing point.

- The evaporator pressure should be near to atmospheric pressure and condenser pressure should not too high as it would require stronger equipment and hence higher cost.

- The condenser and evaporator should maintain positive pressures to avoid entry of air and moisture in the system.

- For higher COP critical temperature of the refrigerant should be very high and critical pressure should be low.

- Latent heat of vaporisation of a refrigerant should be as large as possible. Hence the amount refrigerant required as well as the initial cost of regrigerant reduces.

- Regrigerant should have high thermal conductivity.

- Refrigerant should not be toxic to produce health hazards.

- The refrigerant used should not be inflammable and explosive.

- Refrigerant should not be chemically reactive with material used for storage containers and piping. For example, ammonia reacts with the copper and its alloys in presence of water.

- Refrigerant should have high COP, low power consumption per tonne of refrigeration.

- Refrigerant should be easily available, low cost.

### 9.5.2 Commonly used Refrigerants

**Classification of refrigerants**

Refrigerants are broadly classified in two groups :

> 1. Primary refrigerants
> 2. Secondary refrigerants

### 1. Primary refrigerants

- These refrigerants directly take the part in refrigeration system.

- Primary refrigerants are of following types :

**i) Halocarbon compounds**

| | | |
|---|---|---|
| R-11 | - | Trichloro mono fluro methane ($CCl_3F$) |
| R-12 | - | Dichloro difluro methane ($CCl_2F_2$) |
| R-13 | - | Mono chloro trifluro methane ($CClF_3$) |
| R-21 | - | Dichloro mono fluro methane ($CHCl_2F$) |
| R-22 | - | Monochloro difluro methane ($CHClF_2$) |
| R-23 | - | Trifluro methane ($CHF_3$) |
| R-40 | - | Methyl chloride ($CH_3Cl$) |
| R-50 | - | Methane ($CH_4$) |
| R-100 | - | Ethyl chloride ($C_2H_5Cl$) |

The trade names of these refrigerants are Freon, Genetron, Isotron and Arctron. These refrigerants are used in domestic, commercial and industrial purpose.

**ii) Azeotropes :** These refrigerants are mixture of various refrigerants.

**iii) Hydrocarbons :** Methane, ethane, propane, etc. are the commonly used hydrocarbon refrigerants.

**iv) Inorganic compounds :** Refrigerants like ammonia, carbon di-oxide, sulphur di-oxide, air, etc. are various inorganic compounds.

**2. Secondary refrigerants**
- Secondary refrigerants are used where it is not desirable to carry heat from place which is to be cooled directly by refrigerant.
- Thus, heat carried by secondary refrigerant is given to primary refrigerant in evaporator and circulated again.
- The commonly used secondary refrigerants are *water* and *brines*.

## 9.5.3 Effect of Refrigerants on Environment

Many of the refrigerants which are in use for the past several decades are affecting the environment by following two ways.

> 1. Ozone layer depletion.
> 2. Global warming (Green house effect)

**1. Ozone Layer Depletion**

- It is thinning of ozone layer which surrounds the earth's stratosphere that is about 11 kms above the surface of the earth.

- The ozone layer absorbs the sun's ultraviolet rays (UV) substantially, thus acting a protective umbrella for the life on the earth from the harmful effects of high concentration of UV radiations.

- If this protective layer depletes, then ultraviolet rays will reach the earth surface and thus causing skin cancer, several infectious diseases, environmental problems, etc.

- The ozone layer is continuously being produced and destroyed in a natural cycle.

- But in this cycle, the overall amount of ozone remains stable.

- But the gases like chlorine, bromine react with it and reduce the ozone to oxygen and destroys it much faster than that of natural cycle leading to depletion of ozone in the stratosphere.

- Bromine is much more destructive than chlorine.

**2. Global Warming (Green House Effect)**

- Some of the heat absorbed by the earth from the sun is reflected back to the space.

- This does not allow the earth temperature to rise above an average level.

- A film of gases envelopes the earth's atmosphere.

- Some of these gases trap some of the reflected heat preventing it to reflect back to space, thereby increasing the earth's average temperature leading to **Global Warming**, which is also known as **Green House Effect**.

- Obviously higher concentration of the green house gases in the atmosphere will lead to a warmer earth and consequent harmful ecological changes.

## 9.6 Window Air Conditioner ☞ **[ June 2011, Dec. 2012, Dec. 2013 ]**

- Air conditioning is defined as the simultaneous control of temperature, humidity (moisture content in air), motion (circulation and air movement) and purity (air filtering and cleaning) of air within an enclosed space.

- Air conditioning is widely used in industries, offices, hospitals, commercial places, etc. for human comfort.

- Fig. 9.3 shows the arrangement of window air conditioner.

- In these type of air conditioners, evaporating and condensing units are incorporated in a common enclosure.

- Here evaporator is connected to compressor by suction pipe-line and compressor is connected to condenser by a delivery pipe-line.
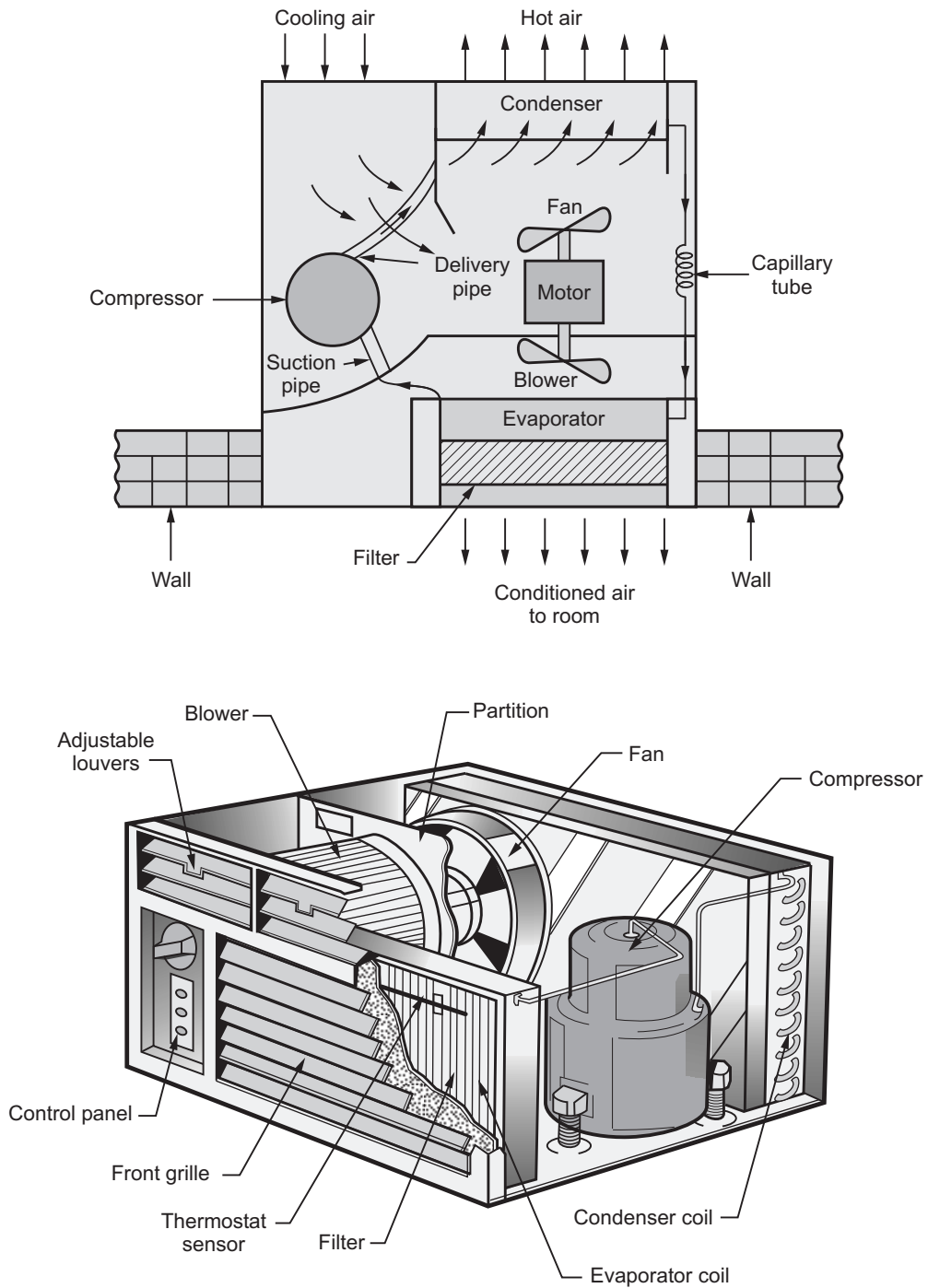
**Fig. 9.3 : Window air conditioner**

- During the operation low pressure air is withdrawn from the evaporator through the suction pipe-line to the hermetically sealed compressor. In this compressor, air is compressed to high pressure and delivered to condenser.

- By condensation process, heat is removed from the vapour refrigerant and liquid refrigerant is collected in the lower coils.

- This liquid refrigerant passes through the capillary tube and flows to the evaporator coils at low pressure.

- This liquid refrigerant inside the evaporator coil boils rapidly and picks up latent enthalpy from the luiqid surface.

- A blower is fitted in the cabinet behind evaporator coil which pumps air into upper compartment. The blower pulls room air through cooling coil and through the filter provided on the coil face. This air is then discharged back to the room through the upper compartment.

- The condenser cooling is done by using a fan which pulls air from sides and throws air over the condenser coil.

- Both fan and blower are operated by the same motor.

- The control panel of window air conditioner has three knobs :

  i) To control the speed of blower motor i.e. to give high cooling or low cooling.

  ii) It is of thermostat which is placed at the filter to sense temperature of room air being sucked by the blower.

  iii) It operates a flap in the insulated cabinet to allow ventilation of supplied air.

**Why smoking is prohibited in air conditioned areas?**

- In the window air conditioning system the air is circulated again and again after reducing its temperature.

- Because of smoking harmful gases are produced which are injurious to health of human beings. These gases are circulated in the room which may create problems to the respiratory system of human beings.

- Also, due to more smoking, the temperature of air inside the room will be increased which increases load on air conditioner or decreases the efficiency of air conditioner.

## 9.7 Split Air Conditioner

- The name of these air conditioners indicates that the conditioning system is splitted in two parts i.e. fan coil unit (fitted inside the room) and condensing unit (fitted outside the room).

- The function of each part of the system remains same.

- The two units are connected by suction and liquid line.

- Fig. 9.4 shows the simple arrangement of split air conditioner.
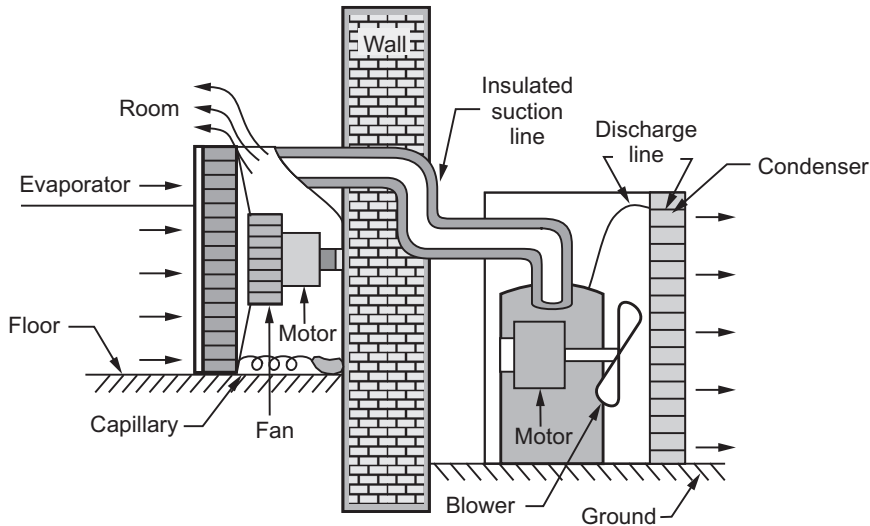


**Fig. 9.4 : Split air conditioner**

**Advantages**

- In window air conditioning system due to compressor more noise is generated but in split air conditioner compressor unit is away from the room which reduces disturbance in the room.
- The cooling coil can be located anywhere in the room wall.
- COP of these system is high.
- Less space is required.

**Limitations**

- It consumes more energy because there are two separate motors i.e. one in condensing unit and other in fan coil unit.
- For driving the compressor more power is required because of long refrigerant lines.
- These air conditioners has no ventilation provision.
- These systems are more costly.

## 9.7.1 Comparison between Window Air Conditioner and Refrigerator

| Sr. No. | Window air conditioner | Refrigerator |
|---------|------------------------|--------------|
| 1. | It maintains the temperature of room and controls the humidity. | It maintains the temperature of system below that of surrounding. |
| 2. | It is located at the inner and outer side of the room. | It is totally located inside the room. |

| 3. | Fan and blower are required. | Fan and blower are not required. |
|---|---|---|
| 4. | Its weight is comparatively less. | Its weight is more. |
| 5. | It is not a storage device. | It is a storage device. |

## 9.8 Mulitiple Choice Questions with Answers

**Q.1** 1 Ton of refrigeration = _____ .

    a) 3.517 kW                  b) 7.317 kW

    c) 7.315 kW                  d) 10 kW          **[Ans. : a]**

**Q.2** In vapour compression refrigeration system heat is transferred in the form of ___.

    a) sensible heat             b) latent heat

    c) sensible as well as latent heat      d) none of these        **[Ans. : c]**

**Q.3** Which of the following is not a part of vapour compression refrigeration system ?

    a) Compressor             b) Evaporator

    c) Condenser               d) Expander          **[Ans. : d]**

**Q.4** Which of the following is a part of vapour absorption system ?

    a) Condenser               b) Eraporator

    c) Generator               d) All of the above      **[Ans. : d]**

**Q.5** The refrigerant used for vapour absorption system is _____.

    a) R11                       b) R-50

    c) $NH_3$                     d) All of these          **[Ans. : c]**

**Q.6** Which of the following is a primary refrigerant ?

    a) Water                  b) Brines

    c) R11                     d) both (a) and (b)      **[Ans. : c]**

**Q.7** Refrigerant should have _____ boiling and freezing point.

    a) high                    b) low

    c) moderate               d) none of these

                                                     **[Ans. : b]**

**Q.8** Refrigerant should have _____ thermal conductivity.

    a) high                    b) low

    c) moderate               d) none of these        **[Ans. : a]**

**Q.9**    Coefficient of performance (COP) = _____.

a) $W_{net} \times Q_A$

b) $\dfrac{W_{net}}{Q_A}$

c) $\dfrac{Q_A}{W_{net}}$

d) None of these

[Ans. : c]

**Q.10**   In vapour compression refrigeration the expansion device used is _____.

a) throttle valve

b) capillary tube

c) both (a) and (b)

d) none of these          [Ans. : b]

**Q.11**   The condensor in window air conditioner is normally _____.

a) air cooled

b) water cooled

c) oil cooled

d) none of these          [Ans. : a]

**Q.12**   In window air conditioner _____ is used as expansion device.

a) compressor

b) throttle valve

c) capillary tube

d) cooler                 [Ans. : c]

**Q.13**   One ton of refrigeration is _____ kW.          ☞ **[ June 2010 ]**

a) 1.5

b) 2.5

c) 3.5

d) 4.5                    [Ans. : c]

**Q.14**   A vapour absorption system works solely on _____.          ☞ **[ June 2010 ]**

a) mechanical energy

b) both mechanical and thermal energy

c) thermal energy

d) none of these          [Ans. : c]

**Q.15**   Monochloro-diflaloro methane is a popular refregerant called _____.

☞ **[ June 2010 ]**

a) ammonia

b) water

c) freon 22

d) oxygen                 [Ans. : c]

**Q.16**   In a refrigerator, heat exchange takes place in _____.          ☞ **[ June 2010 ]**

a) compressor

b) throttle valve

c) condenser

d) none of these          [Ans. : c]

**Q.17**   Which of the following is not used as refrigerant ?          ☞ **[ Dec. 2010 ]**

a) Freon-22

b) Hydrogen

c) Ammonia

d) Sulphur dioxide        [Ans. : b]

**Q.18** In a refrigeration system, the ratio of heat absorbed in a system to the work supplied is called _____. ☞ **[ Dec. 2010 ]**

a) efficiency               b) effectiveness

c) coefficient of performance     d) none of these          **[Ans. : c]**

**Q.19** In a vapour absorption refrigerator, the absorber contains _____.

☞ **[ Dec. 2010 ]**

a) ammonia                b) cold water

c) carbon dioxide            d) methyl chloride

**[Ans. : b]**

**Q.20** Presence of moisture in a refrigeration cycle will show its effect at _____.

☞ **[ Dec. 2010 ]**

a) compressor suction          b) compressor discharge

c) expansion valve            d) condenser          **[Ans. : a]**

**Q.21** ____ converts vapour refrigerant into liquid refrigerant. ☞ **[ June 2011 ]**

a) Compressor              b) Evaporator

c) Condenser              d) Motor          **[Ans. : c]**

**Q.22** Throttle valve is used in refrigerator to _____. ☞ **[ June 2011 ]**

a) compress the refrigerant        b) expand the refrigerant

c) absorb the heat from refrigerant   d) condense the refrigerant     **[Ans. : b]**

**Q.23** Which of the following is not a desirable property of a refrigerant ?

☞ **[ June 2011 ]**

a) High latent heat of vapourization   b) High freezing point

c) Low viscosity            d) Low specific volume     **[Ans. : b]**

**Q.24** The purpose of air-conditioning is to _____. ☞ **[ June 2011 ]**

a) control temperature          b) control humidity

c) clean and purify air         d) all of the above       **[Ans. : d]**

**Q.25** An ideal refrigerant should have _____. ☞ **[ Dec. 2011 ]**

a) low specific heat          b) low viscosity

c) high thermal conductivity       d) all of these       **[Ans. : d]**

**Q.26** The principle of refrigeration is based on _____.  ☞ **[ Dec. 2011 ]**

a) law of conservation of energy

b) I$^{st}$ law of thermodynamics

c) II$^{nd}$ law of thermodynamics

d) zeroth law of thermodynamics  **[Ans. : c]**

**Q.27** The ratio of heat extracted from the refrigerator to the work done is called _____.

☞ **[ Dec. 2011 ]**

a) performance ratio  b) thermal efficiency

c) co-efficient of performance  d) performance index  **[Ans. : c]**

**Q.28** The most commonly used refrigerant in vapour absorption refrigeration system is

_____.  ☞ **[ Dec. 2011 ]**

a) Freon  b) $CO_2$  c) $SO_2$  d) $NH_3$  **[Ans. : d]**

**Q.29** An ideal refrigerant should have _____.  ☞ **[ June 2012 ]**

a) low freezing point  b) low boiling point

c) high latent heat of vapourization  d) all of these  **[Ans. : d]**

**Q.30** In vapour absorption refrigeration system _____ is/are used to pressurize the refrigerant.  ☞ **[ June 2012 ]**

a) a pump and generator  b) a compressor

c) both (a) and (b)  d) none of these  **[Ans. : a]**

**Q.31** Refrigeration is a process of heat extraction from _____.  ☞ **[ June 2012 ]**

a) a hot body and deliver to a cold body with the help of external work

b) a cold body and deliver to a hot body without the help of external work

c) a cold body and deliver to a hot body with the help of external work

d) a hot body and deliver to a cold body without the help of external work.

**[Ans. : b]**

**Q.32** Air conditioning is a process of _____.  ☞ **[ June 2012 ]**

a) control of temeprature  b) contorl of humidity

c) control of cleanliness and air motion  d) all of these  **[Ans. : d]**

**Q.33** _____ is the heart of the refrigerator. ☞ **[ Dec. 2012 ]**

    a) Compressor                       b) Condensor

    c) Expansion valve              d) Evaporator     **[Ans. : a]**

**Q.34** The ratio of heat absorbed in a system to work supplied is _____.

                                                                   ☞ **[ Dec. 2012 ]**

    a) refrigeration effect            b) COP

    c) ton of refrigeration           d) cooling effect     **[Ans. : b]**

**Q.35** In a refrigerator exchange of heat takes place in _____.   ☞ **[ Dec. 2012 ]**

    a) condenser     b) evaporator     c) compressor     d) both (a) and (b)

                                                                          **[Ans. : d]**

**Q.36** _____ is the refrigerant used in a vapour compression refrigerator.

                                                                   ☞ **[ Dec. 2012 ]**

    a) Ammonia       b) Air           c) Freon-22       d) Nitrogen

                                                                   **[Ans. : c]**

**Q.37** Brine is an example for _____.           ☞ **[ June 2013 ]**

    a) coolant       b) effluent       c) deodourant     d) refrigerant

                                                                          **[Ans. : d]**

**Q.38** The value of COP is greater than _____.   ☞ **[ June 2013 ]**

    a) infinity       b) ten          c) unity         d) hundred

                                                                         **[Ans. : c]**

**Q.39** A thermostat in A.C. is used to control _____.   ☞ **[ June 2013 ]**

    a) pressure       b) temperature     c) volume       d) efficiency

                                                                         **[Ans. : b]**

**Q.40** The viscosity of an ideal refrigerant should be _____.   ☞ **[ June 2013 ]**

    a) low          b) high         c) moderate     d) unity    **[Ans. : a]**

**Q.41** Good refrigerant should be _____.         ☞ **[ Dec. 2013 ]**

    a) high boiling point            b) flammable

    c) low thermal conductivity      d) nontoxic     **[Ans. : d]**

**Q.42** Unit of refrigeration is _____.                           ☞ **[ Dec. 2013 ]**

  a) COP of refrigeration              b) ton of refrigeration

  c) ampere of refrigeration           d) none of these          **[Ans. : b]**

**Q.43** Ammonia refrigerant is used in _____ refrigerator.        ☞ **[ Dec. 2013 ]**

  a) household                         b) absorption

  c) vapour compression                d) air conditioner          **[Ans. : b]**

**Q.44** Function of the throttle valve in a refrigerator is to _____.  ☞ **[ Dec. 2013 ]**

  a) reduce the pressure

  b) increase the pressure

  c) converts vapour refrigerant into liquid

  d) liquid refrigerant into vapour conversion.                    **[Ans. : c]**

## 9.9 University Questions with Answers

### June 2010

**Q.1** What are the desirable properties of refrigerant ? **(Refer section 9.5.1)**          **[6]**

**Q.2** With a neat sketch, explain the construction and working of a vapour absorption refrigeration system. **(Refer section 9.4)**          **[10]**

### Dec. 2010

**Q.3** What are the desirable properties of refrigerant ? **(Refer section 9.5.1)**          **[6]**

**Q.4** Explain with a neat sketch, working of a vapour compression refrigerator.
**(Refer section 9.3)**          **[10]**

### June 2011

**Q.5** With a neat sketch, explain working of room air conditioner.
**(Refer section 9.6)**          **[10]**

**Q.6** Explain vapour absorption refrigeration system with a neat sketch.
**(Refer section 9.4)**          **[6]**

### Dec. 2011

**Q.7** Explain vapour absorption refrigeration system. **(Refer section 9.4)**          **[8]**

**Q.8** Explain room air conditioner system. **(Refer section 9.6)**          **[8]**

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**June 2012**

**Q.9** Define : i) COP of refrigeration  ii) Ton of refrigeration. **(Refer section 9.2)**    [4]

**Q.10** Draw a neat sketch of vapour compressor refrigeration system. Indicate the state of the refrigerant at all salient points and direction of flow of refrigerant.
**(Refer section 9.3)**    [6]

**Q.11** Explain room air conditioner system. **(Refer section 9.6)**    [8]

**Dec. 2012**

**Q.12** Explain with a neat sketch, working of a vapour compression refrigerator.
**(Refer section 9.3)**    [8]

**Q.13** Explain room air conditioner system.  **(Refer section 9.6)**    [8]

**June 2013**

**Q.14** Mention the use of any four refrigerants.    [4]
**Ans. :**

(i) **Ammonia ($NH_3$) :** It is used in commercial ice making plants, large cold storage plants, etc.

(ii) **Carbon-dioxide ($CO_2$) :** It is used only in manufacturing of dry ice due to its high power requirements.

(iii) **R-11 (Trichloro monofluro methane) :** It is used upto 50 tonnes capacity refrigeration. Also in small office buildings and factories, R-11 used as a refrigerant.

(iv) **R-12 (Dichloro-difluro methane) :** It is used for domestic applications as well as suitable for high, medium, and low temperature applications. It is an excellent electric insulator hence used in sealed type compressors.

**Q.15** Explain vapour absorption refrigeration system.  **(Refer section 9.4)**    [6]

**Q.16** List the differences between compression and vapour absorption refrigeration.
 **(Refer sections 9.3 and 9.4)**    [6]

**Dec. 2013**

**Q.17** Explain vapour absorption refrigeration system.  **(Refer section 9.4)**    [8]

**Q.18** With a neat sketch of a room air-conditioner, explain its working principle.
 **(Refer section 9.6)**    [8]

*Refrigeration and Air Conditioning ends …*