A TEXT BOOK OF

Elements of Mechanical Engineering

As per Choice Based Credit System

of Visvesvaraya Technological University

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SUBHAS STORES

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A Text Book of

ELEMENTS OF MECHANICAL ENGINEERING

As per Choice Based Credit System

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Contents

1 Module	-Energy Resources and Steam	1
	Turbines	62
2 Module	-Internal Combustion Engines	74
	Machine Tools Operations	109
	Robotics	136
3 Module	-Automation	152
4 Module	-Engineering Materials and Composites	172
	Welding, brazing and Soldering	205
5 Module	-Refrigeration and Air-conditions	221
	New Syllabus	234
	Multiple choice questions	236
	Steam Tables	243

CHAPTER 1

ENERGY RESOURCES AND STEAM

1.1 Introduction

For generations, the human society has been using energy in various forms for carrying out all its activities. We use energy practically for everything we do, for example, to do work, to provide warmth, to move people and goods from one place to the other, to cook, to run household appliances and machines, etc. Most of the energy that we have been using now mainly comes from relatively cheaper sources such as coal, petroleum and natural gas found within the earth. Due to ever increasing rate of consumption of energy day by day, the rate of depletion of these sources has been very rapid resulting in their reserves reaching alarmingly low levels. This irreversible situation of today in the energy front has directed us to look at the alternate energy sources such as solar, wind, tidal, ocean, geothermal, biomass, etc.

1.2 Energy and its Forms

"Energy", a word derived from the Greek work "Energia", meaning capacity for doing work. Energy exists in various forms. The form that bodies in motion possess is called *kinetic energy*. The energy related to position is called *potential energy*. The energy contained in a chemical system by virtue of the motions of, and forces between the individual atoms and molecules of the system is called *internal energy*. The various other general forms of energy are, mechanical, thermal, chemical, electrical, radiant and atomic. All forms of energy are inter-convertible by appropriate processes.

1.3 Energy Resources

Energy either exists in the earth or comes from the outer space. The energy existing in the earth is known as *capital energy* and that comes from the outer space is called *celestial* or *income energy*. The capital energy sources are mainly, *fossil fuels, nuclear fuels* and *heat traps.* The celestial energy sources include, *electromagnetic, gravitational* and *particle energy* from stars, planets and moon, and as well as the potential energy of meteorites entering the earth's atmosphere. The useful celestial energy sources are the *electromagnetic energy* of the earth's sun, called *direct solar energy* and the *gravitational energy* of the earth's moon producing *tidal energy*. The other energy sources such as *wind, hydel, geothermal, biofuel,* etc. are derived from the direct solar energy.

1.4 Conventional and Nonconventional Energy resources

Conventional Energy resources

Presently most of our energy needs comes mainly from *fossil fuels* such as, coal, petroleum, natural gas, and *hydel resources* which are relatively cheaper. Although energy is also produced from nuclear fuels, it is not being used on a large scale due to its inherent hazardous nature and high cost of generation of power from nuclear source. Since the fossil fuels and hydel sources are in use over several decades, they are called *conventional energy resources.*

Nonconventional Energy resources

The ever increasing rapid use of the fossil fuels day by day has threatened exhausting of this source very soon. The hydel sources cannot become a major source of energy since it is not available everywhere and also depends on the unpredictable nature of the hydrological cycle. Moreover its cost of generation is also very high because of high initial investments and transmission problems.

Therefore time has come for searching altogether other sources of energy which are inexhaustible to gradually replace the conventional sources. Now, the other alternate energy sources that are tried for harnessing are, *solar energy, wind energy, tidal energy, ocean thermal energy, bio energy, fuel cells, solid wastes, hydrogen,* etc. These alternate inexhaustible sources of energy are called *nonconventional energy resources*

1.5 Renewable and Non-renewable Energy Resources

Both the conventional and nonconventional energy resources are reclassified depending on whether these sources on their continuous use will be exhausted or not, as *renewable* and *nonrenewable energy resources.* The ***renewable resource of energy*** is defined as the energy resources which are produced continuously in nature and are essentially inexhaustible at least in the time frame of human societies. These energy resources replenish themselves naturally in a relatively short time and therefore will always be available.

The examples of renewable energy resources are :

1. Direct Solar Energy	2. Wind Energy	3. Tidal Energy
4. Hydel Energy	5. Ocean Thermal Energy	6. Bio energy
7. Geothermal Energy	8. Peat	9. Fuel wood
10. Fuel cells	11. Solid Wastes	12. Hydrogen

Of the renewable energy resources listed above, geothermal energy, peat and fuel wood must be used at a rate less than their natural rate of renewal or they must be periodically be allowed time to build up again.

The *nonrenewable energy resources* are defined as the energy resources which have been accumulated over the ages and not quickly replenishable when they are exhausted

The examples of nonrenewable energy resources are :

1. Fossil Fuels
2. Nuclear Fuels
3. Heat Traps

1.6 Advantages and Disadvantages of Renewable energy Resources

Advantages

1. The renewable energy resources are non-exhaustible.
2. The renewable energy resources can be matched in scale to the need and also they can deliver the energy of the quality that is required for a specific task. A simplest example for this is a water heating device. For water heating, which is a low grade conversion, if we use electrical energy or high premium hydrocarbon fuels, which are high grade energy sources, there will be an improper match between the energy source and the task which reduces the thermodynamic efficiency. Suppose a solar water heater is used, not only it is cost effective, but there is a perfect match between the energy source and the task since the sun's rays directly heats up the water. The solar water heaters can also be built to suitable sizes which will supply the required quantity of water at the desired temperature.
3. Some of the renewable energy conversion systems often can be built on, or close to the site where the energy is required, which will minimise the transmission costs. For example, a windmill for driving a hydraulic pump may be built very close to the water source. A panel of photovoltaic cells used for domestic or street lighting is also another example.
4. The diversity of renewable energy resources and their technologies offer more flexibility while designing the conversion systems compared to the conventional energy systems.
5. The local or regional self sufficiency in the energy requirement can be achieved either fully or partially by harnessing the locally available renewable energy which otherwise would be left unutilized.
6. Except the biomass energy source, all other renewable energy resources offer pollution free environment and also help in maintaining the ecological balance.

Disadvantages

1. The intermittent nature of the availability of the energy from the renewable energy resources such as, solar, wind, tidal, etc. is a major setback in the continuous supply of energy.
2. Although the supply of energy from the sun is limitless, there is a definite limit to the rate at which the solar energy is received at the earth as it is dependent on the local atmospheric conditions, time of the day, part of the year and also on the latitude of the place.
3. Some of the renewable energy resources such as wind, tidal, etc. although available in large quantities, they are concentrated only in certain regions.
4. The state of the art in harnessing the renewable energy resources is not yet fully developed to meet the present day energy requirements.

5. Some of the renewable energy conversion systems such as solar cells, automatic tracking systems for solar concentrators, etc. require advanced technologies, hence costlier.
6. The application of renewable energy resources to transport sector has been found to be not viable as on today.

1.7 Comparison of Renewable and Non-renewable energy resources

The below table gives the comparison of renewable and non-renewable energy resources:

Sl. No.	Factor	Renewable energy resources	Non-renewable energy resources
1.	Exhaustibility / Inexhaustibility	Renewable energy resources are inexhaustible.	Non-renewable energy resources are exhaustible.
2.	Availability	Abundantly and freely available in the nature	Not abundantly available.
3.	Replenishment	Are replenished naturally over a useful period of time at the same rate at which they are consumed. For resources such as Solar energy, replenishment is automatic but during the day.	Cannot be replenished over desired period of time. Example: Fossil fuels
4.	Environment friendliness	Environment friendly except in case of biomass energy resource	Not environment friendly and can produce greenhouse gases that contribute to global warming. Example: Coal burnt produces carbon dioxide which is harmful to the environment
5.	Cost Factor	Cost of building systems to tap energy is high. The running cost is low.	Cost of production is low.But since the depletion rate is high, the demand is increasing and the supply is decreasing and this is eventually increasing the cost of usage. Example: petroleum fuel.
6.	Nature of availability	Intermittently available. Example: Solar energy is available in the day and not during the night.	Continuously available
7.	Regional Restriction and dependency factor	For Renewable energy resources such as Solar energy, there is no regional restriction and are available to almost all countries. This reduces dependency on certain countries.	Non-renewable energy resources such as petroleum is available in select countries (such as those in the Middle East) and hence the dependency is high.

1.8 Conventional Energy Resources and their Conversion

The formation of conventional energy resources and the conversion technologies of the fossil fuels are discussed briefly here.

1.8.1 Fossil Fuels

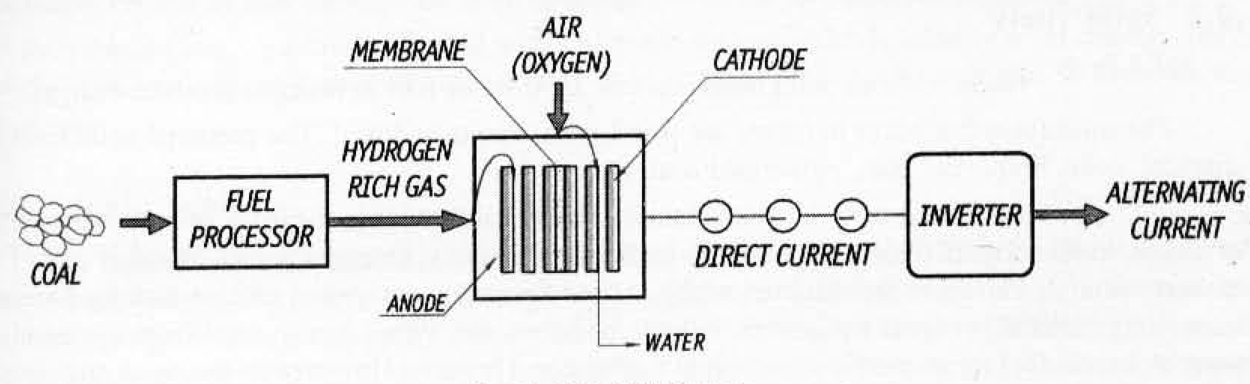
Fossil fuels are energy rich substances that have been formed from long-buried plants and micro-organisms. Fossil fuels include petroleum, coal and natural gas. Chemically fossil fuels consist largely of *hydrocarbons,* which are compounds of hydrogen and carbon. Hydrocarbons are formed from ancient living organisms that were buried under layers of sediment millions of years ago. As accumulating sediment layers exerted increasing heat and pressure, the remains of the organisms gradually transformed into hydrocarbons.

Petroleum Formation

Petroleum is formed chiefly from ancient microscopic plants and bacteria that lived in the ocean and saltwater seas. When these micro-organisms died and settled to the seafloor, they mixed with sand and the silt to form organic-rich mud. As layers of sediment accumulated over this organic ooze, the mud was gradually heated and slowly compressed into shale, chemically transforming into petroleum. The petroleum fills the tiny holes within nearby porous rocks. The liquid petroleum and gases which are less dense than water and lighter move upwards through the earth's crust. A portion of this petroleum eventually encounters an impermeable layer of rock which traps the petroleum, creating a reservoir of petroleum and natural gas.

Coal Formation

Coal is a solid fossil fuel formed from ancient plants — including trees, ferns, and mosses — that grew in swamps and bogs or along coastal shore lines. Generations of these plants died and were gradually buried under layers of sediment. As the sedimentary overburden increased, the organic material was subjected to increasing heat and pressure that cause the organic material to undergo a number of transitional states to form coal. The mounting pressure and temperature caused the original organic



Fossil Fuel Cell System
Fig. 1.1

material, which was rich in carbon, hydrogen and oxygen, to become increasingly carbon-rich and hydrogen-and - oxygen-poor. The successive stages of coal formation are *peat* (partially carbonized plant matter), *bituminous coal* (soft coal with higher carbon and low moisture), and *anthracite* (hard coal with highest carbon content and lowest moisture content).

1.9 Introduction to Fuels

Thermal or heat energy will be liberated when certain combustible substances are burnt. *A combustible substance containing carbon as the main combustible element, which on complete combustion liberates large quantity of heat that can be used for domestic, industrial and power production, is called a fuel.* A fuel contains combustible elements like carbon, hydrogen, compounds of hydrocarbon, sulphur, and incombustible elements like nitrogen and ash. Some fuels also contain traces of oxygen. Since the fuel contains mainly carbon and hydrogen as the combustible elements, it is known as *hydrocarbon fuel*. The heat energy liberated by the combustion of a fuel is converted into mechanical energy which can be used for generation of electrical energy in thermal power stations and for running automobiles, ships, locomotives, etc.

1.9.1 Classification of Fuels

Fuels are classified according to their:

i. Occurrence and preparation, and

ii. State of existence

In the first category, the fuels are classified as

(a) Natural or primary fuels and

(b) Artificial or secondary fuels

Natural fuels are found in nature. The example of natural fuels are wood, peat, lignite, coal, petroleum and natural gas.

Artificial fuels are prepared from natural fuels. The examples of the artificial fuels are charcoal, coke, kerosene, diesel, petrol, coal gas, producer gas, blast furnace gas, etc.

In the second category, the fuels are classified as (a) Solid fuels, (b) Liquid fuels and (c) Gaseous fuels.

1.9.2 Solid Fuels

Solid fuels refers to those solid materials that are used as fuel in order to produce energy.

The solid fuels that occur in nature are wood, peat, lignite and coal. The prepared solid fuels are charcoal, coke, briquetted coal, pulverised coal, etc.

Wood is a hard fibrous material that is found as a chief substance in the trunk or branches of a tree or shrub. Wood consists of 50% carbon, 6% hydrogen, 43% oxygen and 1% ash. Wood is one of the earliest materials known to the mankind which is used for various purposes such as making furniture, as building material, in sport equipment, in arts, medicine, etc. Wood is also used from thousands of years as a solid fuel for domestic uses such as cooking and heating. However its use as an engineering fuel is limited.

Peat is a partially carbonized decomposed material found in the boggy land. It has a very high water content and therefore has to be dried before use. It consists of 57% carbon, 6% hydrogen, 35% oxygen and 2% ash. Since the water proportion is very high, even when dry it burns very slowly and the calorific value of this fuel is low. In India, peat deposits occur in the Nilgiri hills and Palani hills of South India. It is mainly used as a domestic fuel.

Lignite or brown coal is also a partially carbonized decomposed vegetable material having more carbon content than peat but less carbon content than the other types of coal. Lignite can be amorphous, fibrous or woody in texture. Lignite (also called as brown coal) has moisture content of 66%, carbon content of 25 to 35% and ash content of 6 to 19%. In India lignite deposits occur in Assam, Kashmir, Rajasthan and Neyveli. It is used as domestic fuel, boiler fuel and in the manufacture of producer gas.

Coal is a highly carbonaceous matter that has been formed from the pre-historic vegetable deposits which have been decomposed and solidified under combined effect of great pressure and bacteria. It mainly consists of carbon, hydrogen, nitrogen and oxygen besides non-combustible inorganic matter.

Bituminous and Anthracite Coal: Coal is classified as bituminous and anthracite coal. *Bituminous coal* consists of 75 to 90% carbon and is used mainly in domestic and industrial sectors. In India, bituminous coal deposits are found in Bihar, West Bengal, Madhya Pradesh and Orissa. *Anthracite coal* is the highest class of coal containing 92 to 98% of carbon and is the most perfectly mineralized coal. It is used as a boiler fuel, for metallurgical purposes and domestic use. In India, anthracite coal is found in Kashmir and Eastern Himalayas.

Charcoal is a light black solid containing carbon and ash obtained by a process called *Slow Pyrolysis* where wood or other organic matter is heated in the absence of air or limited supply of air to a temperature of not less than 280 degrees Celsius. It is used for domestic and metallurgical purposes.

Coke is a solid fuel with few impurities and a high carbon content, commonly made from coal. Coke is prepared by strongly heating the bituminous coal in the absence of air. This process is known as *carbonization of coal*. During heating of coal, volatile matter escapes out leaving a dull black coherent mass called coke. When the carbonization of coal is carried between 500 to 700 degrees Celsius, the resulting coke is called *soft coke*. The coke produced by carbonization of coal between 900 to 1000 degrees Celsius is called *hard coke*. The hard coke is used as a blast furnace fuel for extracting pig iron from iron ores and also as a fuel in a cupola furnace for producing cast iron.

Briquetted Coal is produced from the finely ground coal by moulding under pressure with or without the binding material such as pitch, coal, tar, crude oil, clay, etc. It has the advantage of having practically no loss of fuel through the grate openings due to the formation of blocks.

Pulverised Coal is a low grade coal with a high ash content which is initially dried and then finely powdered in pulverising machines. It is widely used in cement industries and also in metallurgical processes.

1.9.3 Liquid Fuels

The liquid fuels are available in nature in the form of crude petroleum. They are discharged from natural reservoirs in the earth's crust through wells which are drilled in likely places until the oil is struck. Crude petroleum is refined by the process of distillation, number of oils of different grades such as petrol, kerosene or paraffin oil, diesel oil come off and leave finally a thick residue. The artificial liquid fuels obtained from coal are coal tar, benzol, etc.

Petroleum based liquid fuels includes Gasoline (petrol), Kerosene and Diesel oil

Petrol is known as gasoline. Gasoline is produced in oil refineries. It consists of mainly organic compounds which is obtained by the fractional distillation of petroleum, enhanced with various additives like antiknock compounds (aromatic hydrocarbons, ethers and alcohol) and corrosion inhibitors. It is the lightest and the most volatile liquid fuel mainly used in petrol engines. Its specific gravity ranges from 0.68 to 0.76.

Kerosene is known as paraffin oil. It is a combustible hydrocarbon liquid which is obtained from the fractional distillation of petroleum between 150 °C and 275 °C. It is heavier and less volatile fuel than petrol. Kerosene is immiscible in cold or hot water. However it is miscible in petroleum solvents. Kerosene is still used in rural parts of Asia as a fuel in lanterns for lighting up homes. But kerosene also finds its use in heating, cooking and also in commercial jets.

Diesel oil is obtained after petrol and kerosene are obtained during distillation. It is used in Diesel cycle engines. Its specific gravity is 0.86 to 0.95. It has a relatively low ignition temperature of 540°C. It is ignited by the heat of compression. The hydrocarbons in diesel oil contain between 13 and 25 carbon atoms.

Since petroleum is not easily available, it is worthwhile to mention certain ***non-petroleum based liquid fuels*** such as Alcohol and biodiesel.

Alcohol is an artificial liquid fuel that is produced by the fermentation of vegetable matters such as potatoes, beet, etc,. The energy content of alcohol is low. Most common alcohols are Methanol (Methyl alcohol), Ethanol (Ethyl Alcohol) and Butanol. Ethanol can be used as a fuel in combination with gasoline in the ratio of 9:1 (Gasoline:Ethanol) to help reduce the environmental effects of gasoline. Ethanol is used in industries and also finds its use in perfume and cosmetics. Alcohol is generally costlier than gasoline.

Biodiesel is explained later in section 1.10.2 of this chapter.

1.9.4 Gaseous Fuels

The gaseous fuels occur in nature as natural gas near the petroleum fields under the earth's surface. The artificial gases that are produced are coal gas, producer gas, water gas, mond gas, blast furnace gas, coke oven gas and sewer gas.

Natural gas is a fossil fuel found in or near the petroleum field under earth's surface. It consists of methane together with small amounts of other gases such as ethane, carbon dioxide and carbon monoxide. Natural gas is one of the safest and cleanest fuels available which emits less pollution than other fossil fuels. Upon burning, natural gas produces mostly carbon dioxide and water vapour. Natural gas is a non-renewable energy resource mostly used for cooking, heating, generation of electricity, as fuel for vehicles and as a chemical feedstock in plastics manufacture and organic chemicals.

Coal gas is a flammable gaseous fuel which is obtained by the carbonization (destructive distillation) of bituminous coal in the absence of air at 1300°C and it consists of mainly hydrogen, carbon monoxide, carbon dioxide and methane. To increase the yield of the coal gas, steam is added to react with hot coke. The by-products obtained are coke and coal tar. It is used in gas engines and also for lighting applications.

Producer gas is a mixture of flammable gases such as carbon monoxide & oxygen and non-flammable gases such as carbon dioxide and nitrogen which is obtained by the partial combustion of coal, or coke, in a medium air-steam blast. It has a lower heating value compared to other gaseous fuels. It is used in glass melting and power generation. It is also used as a fuel in large industrial furnaces. Producer gas containing hydrogen is a source material in the manufacture of synthetic ammonia.

Water gas is a synthesis gas which contains carbon monoxide and hydrogen and is obtained by passing steam over the incandescent coke. The endothermic reaction between steam and hydrocarbons produce the gas mixture. It is flammable and requires careful handling. It is used in furnaces and in welding.

Mond gas is produced by passing air and large amount of steam over waste coal at around 650°C. Mond gas consists of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. Mond gas can be produced very cheaply. It is used in gas engines, for heating applications and power generation.

Blast furnace gas is obtained as a by-product in the production of pig iron in the blast furnace. It has a low calorific value and contains nitrogen, carbon dioxide, carbon monoxide and some amount of oxygen. It is used in boilers, power plants, in steel works and gas engines. But this gas is toxic in nature.

Coke oven gas is obtained by the carbonization of bituminous coal in an oven at around 900 to 1000°C in the absence of air. It has a medium calorific value and it contains 50% hydrogen, 30% methane, 7% each of carbon monoxide and nitrogen, 3% each of carbon dioxide and higher hydrocarbons. Coke oven gas is toxic in nature and can explode. It is used for industrial heating. It is also used as a raw material for the synthesis of ammonia.

Sewer gas is a complex mixture of toxic and nontoxic gases which are produced and collected in sewage systems by the decomposition of organic household or industrial wastes. Methane is the principal constituent in Sewer gas. Though toxic in nature and causes harmful effects on health, the sewer gas can be used as a power source by piping it into a cleaning system and then used as a fuel to power a generator or combined heat and power (CHP) plant.

1.9.5 Properties of Fuels

The following are the important desirable properties in a fuel:

1. A fuel must release large amount of heat energy per unit mass when burnt. It must have a high calorific value.
2. A fuel must have moderate ignition temperature.
3. Combustion must be controllable.
4. A good fuel must not be toxic and must not be chemically explosive.
5. Must not corrode the storage containers.
6. It must not produce a harmful odour while burning (must not have a pungent irritating smell).
7. A fuel must have higher evaporation temperature at the point of use and hence must not be volatile in nature.
8. It must be easy to transport to desired points of use.
9. It must be convenient to store and safe to use and handle.
10. The production of heat must be environment friendly.
11. A fuel must have low moisture content since moisture content reduces the calorific value.
12. A fuel must be cost less and must be readily available to meet the demand quantity.
13. A fuel must have low contents of non-combustible matter because it is this non-combustible matter that forms ash deposits after burning.
14. Combustion of fuel must be non-spontaneous otherwise it leads to fire hazards.

1.9.6 Fuel Combustion

Fuel Combustion is an exothermic chemical reaction between the fuel and an oxidizer that produces energy in the form of heat and light.

FUEL + OXIDIZER ⟶ COMBUSTION PRODUCTS + HEAT ENERGY

The fuel and oxidizer which reacts together are called *reactants*. The combustion reaction produces various *products*.

Combustion requires two main reactants*Fuel* is the first reactant in combustion. The fuel is combustible and are Organic materials which contain carbon, hydrogen, sulphur, etc. The second reactant in combustion is an*oxidant* or an oxidizer. The universal oxidant which is required for combustion is Oxygen.

The combustion of organic materials results in a number of products such as carbon dioxide, water (usually released as water vapour) and energy in the form of heat and light.

The*ignition temperature* of a given fuel is the minimum temperature at which the fuel ignites, without the presence of an external spark or flame.

The various constituents of fuel that reacts with the oxidizer to produce products of combustion is usually represented by chemical equations. The equations suggest the quantity of oxidizer needed for complete combustion. Thus, it requires a nearly perfect mixture of fuel/air to enable complete combustion of fuel. This mixture is the Stoichiometric mixture which is defined below.

Stoichiometric Mixture or Air/Fuel ratio: The perfect fuel/air mixture in which both the fuel and the oxygen in the air are fully consumed is known as the*Stoichiometric mixture* or *Stoichiometric Air Fuel Ratio*. This mixture is normally specified as the ratio of the mass of air to the mass of a particular fuel.

1.9.7 Air/Fuel Ratio (A/F Ratio)

The measures of the amount of air and fuel used in the combustion process is defined in terms of a ratio called as the*Air/fuel ratio.*

Air/Fuel ratio = A/F Ratio = mass of air / mass of fuel

If the fuel is a liquid fuel or a solid fuel, then the mass factor is considered. If fuel is gaseous, volume of fuel is considered.

For complete combustion of fuel, the right amount of air is required. Any excess air will reduce the efficiency of a combustion system. If the supply of air for burning the fuel is in excess than required for complete combustion of the fuel, then such an Air/Fuel mixture is called as a *Lean or Weak mixture*. On the other hand, if the supply of air for burning the fuel is less than that required for complete combustion of the fuel, then such an Air/Fuel mixture is called as a *Rich mixture*.

The Stoichiometric Air/Fuel Ratio as defined above is the theoretical factor used to determine the excess air used in combustion. The difference of Actual A/F Ratio and the Stoichiometric A/F Ratio determines the excess air.

Thus, Percentage of excess air $= \dfrac{Actual\frac{A}{F}\ Ratio - Stoichiometric\frac{A}{F}\ Ratio}{Stoichiometric\frac{A}{F}\ Ratio} \times 100\%$

Mixture Strength: Mixture Strength determines how lean or rich is the A/F Mixture. It is defined as

$$Mixture\ Strength = \frac{Stoichiometric\frac{A}{F}\ Ratio}{Actual\frac{A}{F}\ Ratio} \times 100\%$$

The Stoichiometric Air fuel ratio for gasoline engines is 14.7:1. This means 14.7 parts of air to 1 part of fuel. Any mixture that has lesser air to fuel is a rich mixture. Any mixture that has more air compared to fuel is lean mixture.

1.9.8 Products of Combustion

The Combustion process yields many products. The usual products of combustion are

1. Carbon Dioxide (CO_2)
2. Carbon Monoxide (CO)
3. H_2O
4. Sulphur Dioxide (SO_2)
5. Nitrogen oxides (NO_x)
6. Lead
7. Particulate matter

Carbon dioxide is the principal combustion product because carbon accounts for 60 to 90% of the mass of the fuels that are burnt.

Carbon Monoxide is a colourless and odourless gas that is produced as a result of incomplete burning of carbon in the fuel. If the fuel is burnt completely, then the Carbon Monoxide is converted into Carbon dioxide.

As the combustion process involves heat, *water* is formed in the form of steam. But this condenses to water drops as it cools.

Sulphur dioxide gases are formed when fuel containing sulphur, like when coal and oil, is burned, and when gasoline is extracted from oil, or when metals are extracted from ore. SO_2 dissolves in water vapour forming acid and produces sulphates by interacting with other gases and particles in the air. Such sulphates are harmful to our environment.

Nitrogen Oxides are formed when fuel is burnt at high temperatures in the combustion process. Nitrogen dioxide (NO_2) and Nitric Oxide (NO) are the main components of Nitrogen oxides.

Lead and particulate matter (such as soot, dust, dirt, etc.) are also released during a combustion reaction.

1.9.9 Calorific Value of Fuels

The calorific value of a fuel is defined as total quantity of heat liberated by the complete combustion of unit quantity of fuel.

The calorific value of a solid or liquid fuel is defined as the quantity of heat liberated by the complete combustion of unit mass of a fuel. It is expressed in kJ/kg.

The calorific value of a gaseous fuel is defined as the quantity of heat liberated by the complete combustion of unit volume of a fuel at N T P conditions. It is expressed in kJ per cubic metre at N T P. conditions.

The calorific values are classified as

1. Higher or gross calorific value and
2. Lower or net calorific value.

Higher Calorific Value

It is abbreviated as H.C.V. All fuels containing hydrogen in the available form will combine with oxygen and form steam or water vapour during the process of combustion. If the products of combustion containing the water vapour are cooled back to the original temperature of the fuel, then all the water vapour formed earlier during combustion will be condensed evolving the absorbed latent heat, producing the maximum amount of heat per unit quantity of the fuel. This maximum heat value of the fuel is called *higher or gross calorific value. Thus the higher calorific value is defined as the total amount of heat produced when unit quantity of the fuel has been burnt completely and the products of combustion are cooled to the temperature of the supplied air and fuel, usually taken as $15^{o}C$.*

Lower Calorific Value

It is abbreviated as L.C.V. In the combustion furnaces the cooling of the products of combustion to the temperature at which the air and fuel is supplied, is not possible, and therefore the water vapour is not condensed, but escapes to the atmosphere carrying with it latent heat which it had absorbed during combustion. Hence the amount of heat carried by the products of combustion will be reduced by the amount equal to the latent heat absorbed by the water vapour. *Therefore, the lower calorific value is defined as the difference between the higher calorific value and the latent heat absorbed by the water vapour.* The amount of latent heat carried by the water vapour depends upon the partial pressure at which the evaporation takes place. It will be very difficult to decide precisely the exact partial pressure at which the evaporation takes place during combustion. The common practice is to assume that the evaporation is taking place at the saturation temperature of 15°C. The latent heat corresponding to this saturation temperature is 2466 kJ/kg. The lower calorific value of fuel is taken while working out the boiler and engine trials. The lower calorific value is given by:

$$LCV = HCV - \text{Heat carried by the water vapour formed per kg of fuel}$$

$$= HCV - m \times 2466 \text{ kJ/kg}$$

Where "m" is the mass of water vapour formed per kg of fuel burnt. Since 1 part by mass of hydrogen produces 9 parts by mass of water vapour, the mass of water vapour formed is 9H where H is the percentage of hydrogen by weight.

$$LCV = HCV - 9H \times 2466 \text{ kJ/kg}$$

Apparatus used to determine the Calorific Values

The calorific value of solid, liquid and gaseous fuels are determined using different types of calorimeters. *Bomb Calorimeter* is used to determine the calorific values of solid and liquid fuels. *Boy's Gas Calorimeter and Junker's Calorimeter* are used to determine the calorific values of only gaseous fuels. *Lewis Thompson Calorimeter* is used to determine the calorific value of coal.

1.9.10 Advantages and Disadvantages of Solid Fuels

Advantages:

1. Solid fuels can be stored conveniently without any risk of explosion.
2. They can be easily transported.
3. They have moderate ignition temperatures.
4. The cost of production is low.

Disadvantages:

1. The ash content of solid fuels is very high.
2. During combustion clinker will be formed.
3. Rate of combustion of solid fuels cannot be easily controlled.
4. Large quantity of heat will be wasted during combustion.
5. The cost of handling is high, since they require conveyors, hoppers, etc., for their handling.
6. They produce large quantity of smoke.
7. Their calorific value is low compared to the liquid fuels.
8. They require large quantity of excess air for complete combustion.

1.9.11 Advantages of Liquid Fuels over Solid Fuels

The following are some of the advantages of Liquid fuels:

1. The calorific value of liquid fuels per unit mass is higher than the solid fuels.
2. Improved rate of combustion compared to Solid Fuels
3. The flame and rate of combustion can be easily controlled by varying the quantity of the fuel supplied.

4. The ignition of the fuel is easy.
5. The combustion may be stopped instantaneously by cutting off the supply of fuel.
6. They burn without forming dust, clinker etc.
7. The quantity of excess air required for complete combustion is less.
8. They require less furnace space for combustion.
9. The loss of heat to Chimney is very low.
10. They can be easily stored in tanks and require less space. Hence the handling becomes easy.
11. The liquid fuels like petrol and diesel can be used in internal combustion engines directly.
12. The liquid fuels can be transported easily through pipes.
13. The liquid fuels burn without forming ash. In contrast, solid fuels leave large amounts of ash content that results in disposal problems.
14. Liquid fuels have lower ignition temperature than solid fuels.
15. Liquid fuels are generally lesser pollutants than solid fuels.
16. The content of moisture in solid fuels are higher and hence they burn with great difficulty. On the other hand, liquid fuels can be burnt quite easily and they also can quickly reach high temperatures than compared to the solid fuels. .

Disadvantages of liquid fuels:

1. The cost of liquid fuels is relatively high
2. The storage tanks must be specially designed.
3. There is a greater risk of fire hazards, particularly in case of highly inflammable and volatile liquid fuels.
4. The combustion chamber must be provided with specially designed burners.
5. Certain liquid fuels emit bad odour.

1.9.12 Advantages of Gaseous Fuels over Liquid Fuels

The following are some of the advantages of Gaseous fuels over Liquid Fuels:

1. The rate of combustion and the maximum temperature attained in the combustion chamber can be easily controlled by varying the quantity of supply of the gaseous fuel.
2. Gaseous fuels do not pollute and hence are environment friendly
3. Gaseous fuels undergo complete combustion with minimum air supply.
4. Combustion is controllable.

5. Gaseous fuels readily mixes with the air, which ensures complete combustion.
6. They burn without any soot or smoke formation and produce no ash. Since there is no ash, the heat loss in the exit gases is minimum.
7. They are free from solid and liquid impurities, hence do not affect the boiler plates.
8. They can be used directly in Internal Combustion Engines for direct power generation.
9. Gaseous fuels can be easily distributed to the points of use through pipelines.
10. The ignition of gaseous fuel is very simple.
11. They can be produced with the low grade coals.
12. They do not require any special type of burners for combustion.
13. Remote control of combustion is possible.
14. The gaseous fuel and the air may be preheated by the exhaust gases of combustion and thus economise the use of fuel by saving the heat.

Disadvantages of Gaseous Fuels:

1. They are readily inflammable and hence requires safety precautions to prevent fire hazards.
2. They require large storage tanks and hence require bigger storage facility.
3. Wherever pipelines are not available for transport, high pressure lower temperature containers that are well insulated are necessary.
4. They are more expensive than solid or liquid fuels.

1.10 Bio Fuels

1.10.1 Introduction to Bio Fuels

What are Bio fuels? *Biofuels* are liquid fuels which are derived from biomass or bio waste. Biofuels are produced from sugar crops (sugarcane, sugarbeet), starch crops (corn, potatoes), oilseed crops (soybean, sunflower, rapeseed), and animal fats.

1.10.2 Commonly used types of bio fuels

1. ***Solid biofuels*** are fuels existing from thousands of years and these are biomasses that are burnt directly for energy. Examples include wood, charcoal, dried manure, non-food energy crops, domestic refuse, sawdust and grass cuttings.

2. ***Biodiesel*** is a domestically produced, renewable fuel that is produced from vegetable oils, animal oils/fats, waste cooking oil, recycled grease, etc. It is a clean-burning replacement for petroleum diesel fuel and is also non-toxic and biodegradable. These oils are converted to Biodiesel by a process known as ***trans-esterification***. Biodiesel can be used either as a pure fuel or blended with petroleum in certain percentages. 100% biodiesel is called B100 whereas B20 is a mixture of 20% by volume of biodiesel and 80% by volume of petroleum diesel. Biodiesel can be used in compression-ignition (diesel) engines with little or no modifications.

Biodiesel is essentially free of sulphur and aromatics. Since biodiesel burns clean, it results in a significant reduction of the types of pollutants contributing to smog and global warming and emits up to 85% fewer cancer-causing agents. The biodiesel fuel should be stored in a clean, dry, dark environment and the storage tanks may be of aluminium, steel, fluorinated polyethylene, etc.

3. ***Bioethanol or ethanol*** is an alcohol produced by fermentation, majorly from carbohydrates produced in sugar or starch crops like sugarcane, corn or sweet sorghum (a type of grass). Cellulosic biomass, which are derived from non-food sources, like trees and grasses, is also currently being developed as a feedstock for ethanol production.

4. ***Gaseous biofuels*** are biofuels used in the gaseous form. Example if the *biogas*, which is essentially methane gas produced from biodegradable waste or energy crops. *Syngas* is another example of gaseous biofuel which is basically a mixture of carbon monoxide and hydrogen derived from partial combustion of biomass

1.10.3 Engineering applications of biofuels

Bio fuels find their use in various Engineering applications as given below:

1. *Biogas* is a cheap and sustainable fuel used in lighting, cooking or generating electricity. In India, biogas or gobar gas is produced mainly in rural parts at household level or at large-scale by *anaerobic digestion* of organic material, usually animal dung, human excreta and crop residue. Biogas is also use as a power source for tractors, pump-sets, etc.

2. Biodiesel finds its use automotive industry mainly in cars and trucks which now come with a flex-fuel option that permits them to run on ethanol/gasoline blends from 0% to 85% ethanol. It has been found that normal gasoline vehicles can operate on a 10 percent ethanol blend without any issues. Newer Diesel cars and trucks can run on biodiesel, but the older models may need replacement of their fuel lines and gaskets with modern synthetic materials, since biodiesel is a solvent.

3. Small engines, of the kind seen in lawn mowers and chainsaws, can utilize ethanol blends up to 10 percent without problems.

4. Biofuel finds its application in aviation industry and flights are already tested to run with a 20% blend of biofuels in its engine. Various airlines around the World have tested the use of biofuels and the studies and research are in progress on the effect of biofuels on the engine performance.

5. The Marine industry also uses biodiesel in suitable blend mixtures to be used in recreational boats, inland commercial ships, ocean-going commercial ships, research vessels and fleets.

6. Syngas, a gaseous biofuel can be used directly in combustion engines or gas turbines and also can be used to produce methanol and hydrogen or even be converted into diesel substitutes or gasoline.

1.10.4 Comparison of bio fuels with petroleum fuels

The Table below offers brief comparison of bio fuels and petroleum fuels

Sl. No.	Factor	Bio Fuels	Petroleum Fuels
1.	Calorific Value	The calorific value of biofuels vary from 30 to 37.27 MJ/kg. The variations in the calorific values are mainly due to variability of the feedstock (which is source of triglycerides)	The calorific value of petroleum fuels vary between 43 to 48 MJ/kg.
2.	Emissions	The Greenhouse gas emissions are less in biofuels. About 17.90 pounds of Carbon dioxide is emitted from the fossil fuel content when a gallon of B20 Biodiesel is burnt. About 20.13 pounds of Carbon dioxide are produced by burning one gallon of B100 (100% biodiesel). The use of B20 biodiesel reduces Carbon-di-oxide gas emissions by 15%. Recently it has been reported that biofuels derived from algae can cut emissions of Carbon dioxide by 68% compared to the Petroleum fuels.	Greenhouse gas emissions are more in petroleum fuels. Greenhouse gases trap the sun rays inside our atmosphere which causes global warming. It is about 19.64 pounds of carbon dioxide that is produced by burning a gallon of gasoline without ethanol. About 22.38 pounds of carbon dioxide are produced by burning a gallon of diesel fuel.

Sl. No.	Factor	Bio Fuels	Petroleum Fuels
3.	Biodegradability	Biodegradable	Not biodegradable
4.	Toxicity	Non-toxic	It is toxic and crude petroleum oil can be carcinogenic (cancer-causing) When oil or petroleum distillates are burnt, due to incomplete combustion, Carbon monoxide, methanol and soot are also released. These are toxic and causes serious health issues.
5.	Renewability	It is a Renewable fuel since biofuels are made from organic wastes which are available in plenty.	Non Renewable fuel are limited to oil fields of very few regions in the World.
6.	Safety	It is safe to produce biofuels	It is not safer. For instance to find oil reserves, dangerous drilling and mining activities prove to be unsafe.

1.11 Solar Power

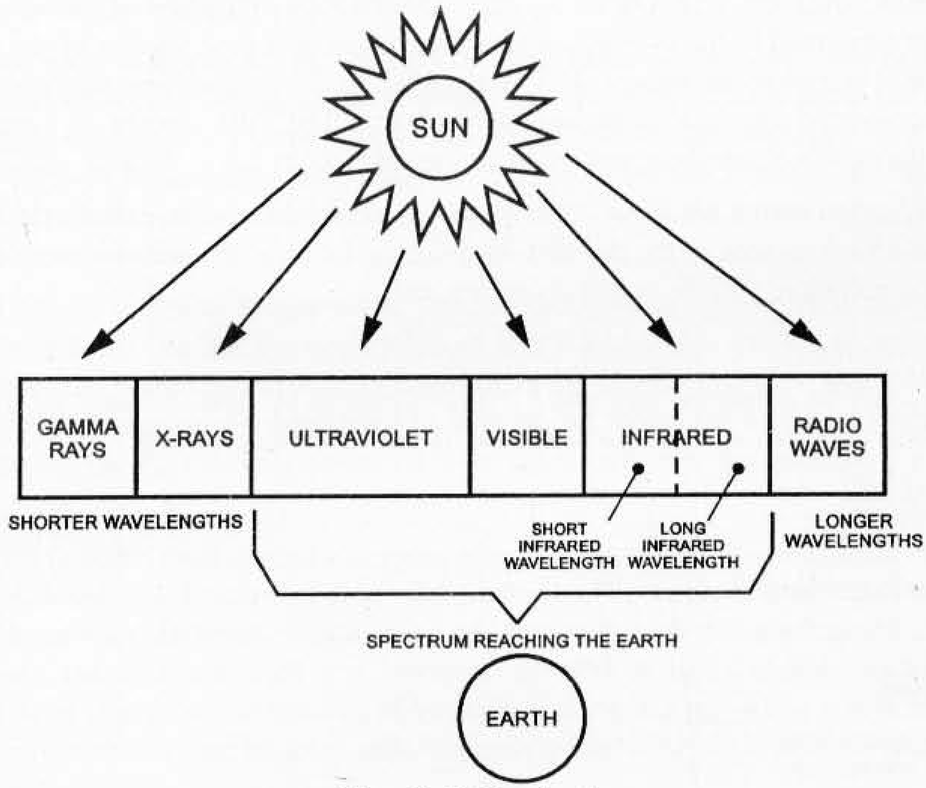
1.11.1 Solar Radiation

Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy. Solar radiation helps sustain life and effects climate changes. Solar radiation comes in many forms, such as visible light, radio waves, heat (infrared), x-rays, gamma rays and ultraviolet rays. Only the portion of the spectrum that includes Ultraviolet rays, Visible light, infrared rays reaches the earth's surface as shown in the *Fig. 1.2.*

Measurements for solar radiation are higher on clear, sunny day and usually low on cloudy days. In case of Sun being down, or when there are heavy clouds blocking the sun, solar radiation is measured at zero.

Energy from the Sun can be tapped and used for various applications like cooking, water heating, lighting, in power plants, and much more.

Solar Power is the power obtained by harnessing the energy given out by Sun's rays.



Solar Radiation Spectrum
Fig. 1.2

1.11.2 Solar Constant

It is the quantity of radiant solar energy received at the outer layer of the earth's atmosphere that has a mean value of 1370 watts per square meter. It is a measure of incoming solar irradiance or solar electromagnetic radiation per unit area incident on a plane that is perpendicular to the rays at a distance equal to mean distance between the earth and the sun (one AU or Astronomical Unit). It was the French physicist Claude Pouillet who first made the estimate of the Solar constant by using an instrument called *Pyrheliometer.*

Sun is the source of all life on the earth. All forms of energy available on the earth are derived from the sun. The sun is considered to be a sphere of intensely hot gaseous matter continuously generating heat by thermonuclear fusion reactions which convert hydrogen atoms to helium atoms. Fuelled by the thermonuclear fusion the radiant energy, called *solar energy* produced in the sun is transmitted to the earth through space in quanta of energy called *photons.* The sun radiates energy into space at a rate of nearly 4×10^{26} watt. This energy is in the form of electromagnetic radiation with a wide range of wavelengths from short wavelength X-rays to long wavelength radio waves. But 99% of the solar radiation lies in the narrow band of visible spectrum between the ultraviolet and infrared.

Less than one thousandth of a millionth of this phenomenal output is intercepted by the earth as it progresses around the sun some 145-153 million kilometre away or a little over 8 minutes at the speed of light. At the outer bounds of the earth's atmosphere the intensity of solar radiation averages to about 1.35 kW/m^2 over the year. On an average, about 30% is reflected or scattered back into space, and 23% is consumed in the evaporation and convection, and precipitation of the water in the hydrological cycle. The remaining energy, 47% is absorbed by the atmosphere, the land surface and the oceans, and converted into heat at ambient temperature. The total amount of energy captured over the year by the earth's atmosphere and the hydrological cycle is 3.8×10^{24}J.

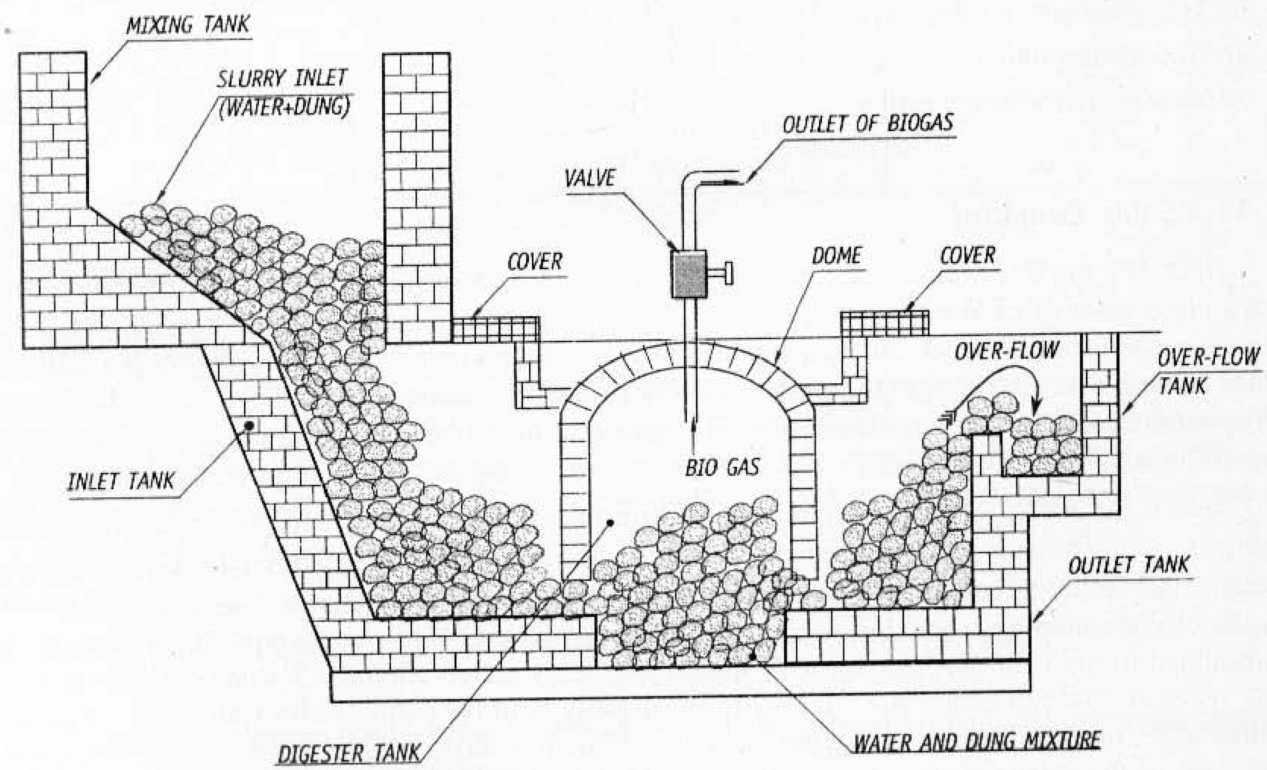
The intensity of incoming solar radiation at any point on the earth's surface depends on the multitude of factors such as time of the day and the year, the latitude, the season, the extent of cloud cover, atmospheric pollution, and the height above sea level.

Solar Energy Conversion

Solar energy can be converted into other forms of energy by three primary processes — the *heliochemical process*, the *helioelectrical process* and the *heliothermal process*.

Heliochemical Process

The *heliochemical process* is a photosynthesis process which is the source of all fossil fuels and the food on which we live today. The photosynthesis is a complex biochemical reaction in which the plants using the solar energy synthesise to produce energy rich molecules of starch



Bio-Gas Plant
Fig. 1.3

and cellulose, and oxygen from the inorganic materials like carbon dioxide and water. Thus, photosynthesis is a form of biological conversion of solar energy into chemical energy called *bioenergy* which will be stored in plants. The overall efficiency of this conversion process from solar energy to stored energy is very low.

Even the most efficient energy plants, like sugar cane, capture and store energy in new plant matter only 3 to 4% of the energy in the sunshine, and they only achieve these rates for a short time during the growing season. Photosynthetic conversion efficiencies averaged over the year ranges from 0.5 to 1.3% in temperature zones and 0.5 to 2.4% in the sun tropics. The bioenergy stored as chemical energy in the energy rich crops can be converted into the useful energy by combustion or converted into storable fuels.

Fig 1.3. shows a typical biogas plant. The mixture of dung and water is poured into a mixing chamber, where these two are thoroughly mixed into liquid slurry and led to an underground inlet chamber which then flows into the digester chamber. In the digester chamber, anaerobic digestion in the absence of oxygen and pyrolysis takes place to form biogas, which can be tapped from a pipe above the dome as shown in the *Fig1.3*. This biogas can then be utilized into various applications.

Helioelectrical Process

In the *helioelectrical process,* using the principle of photovoltaic effect, the solar energy is *directly* converted into electrical energy. Although the principle of photovoltaic effect was known for over a century, the first solar cell was produced in 1954 at Bell Laboratories in the U.S.A. Till recently, the most significant application of the solar cell was for providing power for space vehicles. Of late, even though the cost of solar cells is highly prohibitive, they are being used for terrestrial low power applications.

A wide variety of materials exhibit the photovoltaic effect. But semiconductors have the capability of generating electric power at a level sufficiently high enough for practical applications. Among the semiconductors, the most commonly used are silicon, germanium, cadmium sulphide, gallium arsenide, etc. The silicon is the one that is generally used because of its higher conversion efficiencies, longer life and low cost.

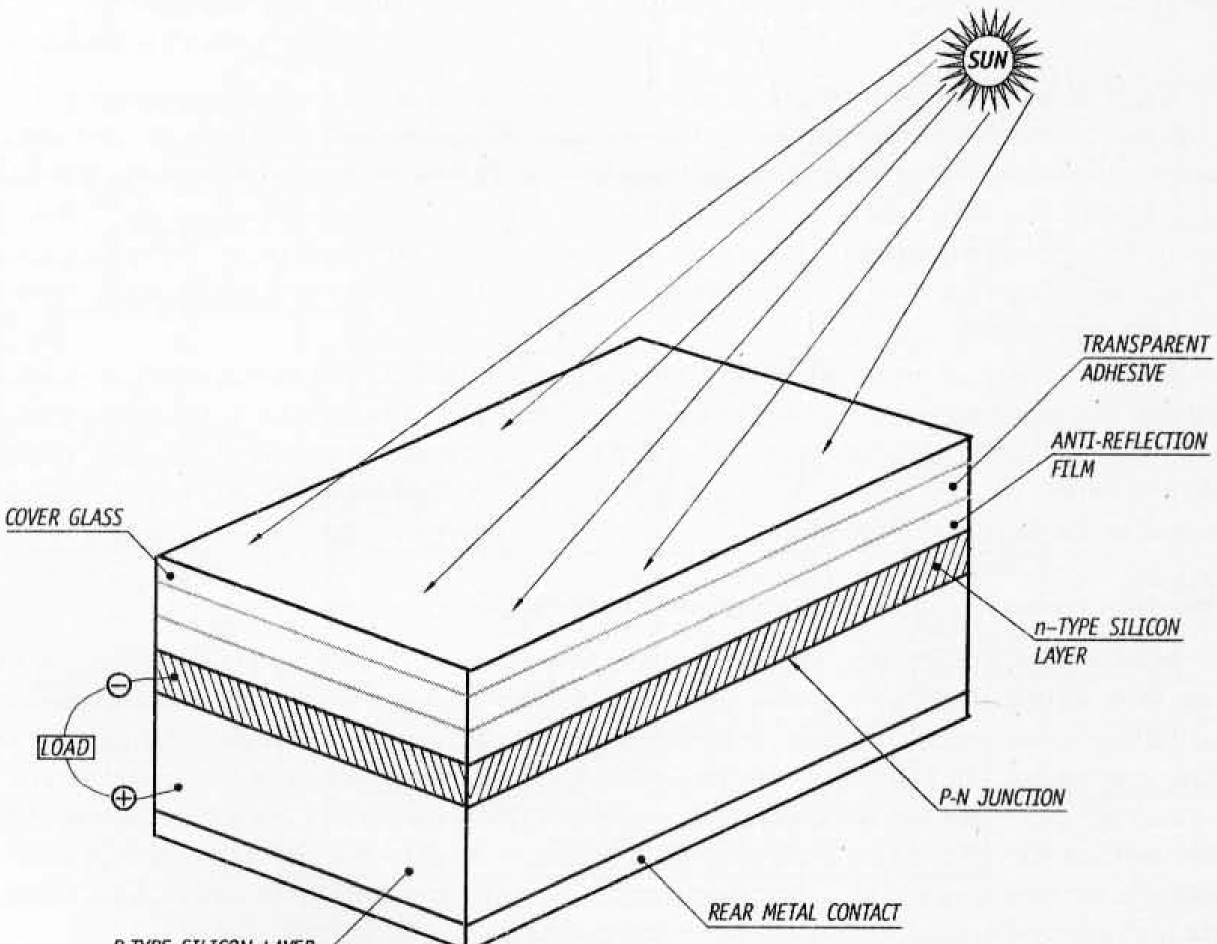
Principle of conversion of Solar Energy into Electrical Energy

In an ordinary copper wire, the copper atoms have electrons that are free to move from atom to atom. Such a flow of electrons makes up an electric current. In an ideal state, the semiconductor materials are insulators as they have no free electrons. But if very small amounts of impurities such as antimony, arsenic, or phosphorus are present in semiconductor materials, a few free electrons are produced that can move and form an electric current. When photons from the sun are absorbed by a semiconductor, they create free electrons with higher energies than the electrons which provide the bonding in the base crystal. Once these electrons are created, there must be an electric field to induce these high energy electrons to flow out of the semiconductor.

The actual conversion of solar energy directly into electrical energy in a semiconductor, for example a silicon cell, is as follows. *Fig. 1.4* shows a typical silicon cell (solar cell).The silicon is neither a good conductor nor a good insulator. It has an outer electron shell of four valence electrons.

In its crystalline state, a silicon atom forms covalent bonds with four neighboring atoms. Addition of traces of an element such as arsenic, or phosphorus, or antimony that contain one more electron than the silicon i.e., five valence electrons, renders the silicon conductive. Four of the five electrons complete covalent bonds with adjacent silicon atoms. The fifth, or the excess electron, at the room temperature, have sufficient energy to become a free electron which will be *negatively* charged. The conduction in silicon which is added with materials such as arsenic or phosphorous is effected by such negative free electrons. The silicon with added materials such as arsenic or phosphorus is called *n-type silicon.*

The addition of elements such as boron or gallium to silicon reduces the number of valence electrons in the atom to three, i.e., one less that in the silicon. This type of atom has insufficient valence electrons to complete four valence bonds. The incomplete bond results in a vacancy or *hole.* The hole acts as *positive* charge and makes the silicon conductive. The silicon with added materials such as boron is called *p-type silicon.*



Solar Cell

Fig. 1.4

A semiconductor device is made either from *p-type* or *n-type* base material into which one or more impurities of the positive polarity are introduced to form p-n-layers. The interface between the layers having opposite polarity is called *p-n junction.*

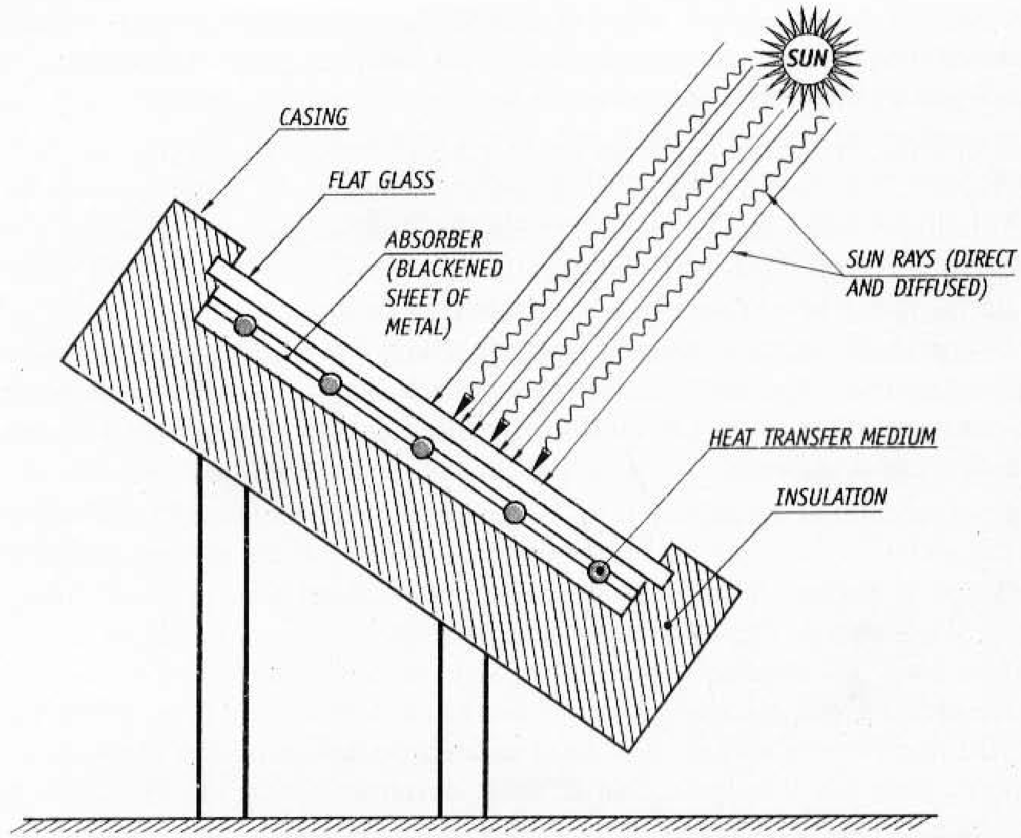
In a p-n junction, free electrons from n-side tend to diffuse into p-side where they readily recombine because of the very large hole concentration. Similarly all holes from the p-side of the junction tend to diffuse into n-side of the region and rapidly combine with numerous free electrons. Free electrons moving from n-side to p-side leave a *net positive charge* behind in the n-side of the junction, while migrating hole from p-side to n-side leave a *negative charge* on the p-side of the junction. This charge distribution near the junction gives rise to an electric field and hence a potential difference across the junction. This electric field originates mainly due to the chemical difference in the material on the two sides of the junction. This electric field built in the vicinity of the junction is permanent in nature.

When a p-n junction of a semiconductor is exposed to sunlight some of the solar photons are absorbed in the vicinity of p-n junction. The photons absorbed at the p-n junction will have high energy to dislodge an electron from the fixed position in the material and gives it enough energy to move freely in the material. The electron evicted from its customary bond can travel though the entire crystalline solid and capable of responding to electric field and other influences. The bond from which the electron was ejected is *short* of one electron creating a hole which is also mobile. Thus the ejected free electron and the hole form an *electron-hole pair.* The electrons and the holes being of opposite charge will be pushed in different directions by the electric field which already exists in the vicinity of the junction if they come into the region near the p-n junction. The permanent electric field which had built-in near the p-n junction pushes the hole into the p-region and the electron into the n-region. Thus p-region becomes *positively charged* and the n-region becomes *negatively charged*. If an external load is applied, this charge difference will drive a current through it. The current will flow so long as the sunlight keeps generating the electron-hole pairs.

Heliothermal Process

In the *heliothermal process,* the radiant solar energy falling on the surface placed on the earth in the form of the visible light is converted *directly* into thermal energy. The surfaces on which the solar rays fall are called *collectors*. Basically, two types of collectors are used. In one of the types, known as non-concentrating type, generally called *flat plate collector,* the incident solar rays are absorbed by the collectors surface itself. In the other type known as concentrating type, generally called as *focusing collector,* the solar rays fall on a large curved reflecting surface which reflects all the incident rays and focus them to form a highly concentrated narrow beam which will be absorbed later.

The amount of solar radiation incident on a surface is called *solar insolation*. The total solar insolation on a surface is composed of a direct component, called *beam component* and a *diffused component* as well as *short wavelength component* reflected from other terrestrial surfaces. The amount of direct radiation on a surface held normal to the sun's rays depends on the time of the year, time of the day, the latitude of the place, as well as the atmospheric conditions. The amount of direct solar energy can be calculated with reasonable precision while the amount of diffused radiations depends on the local meteorological conditions.

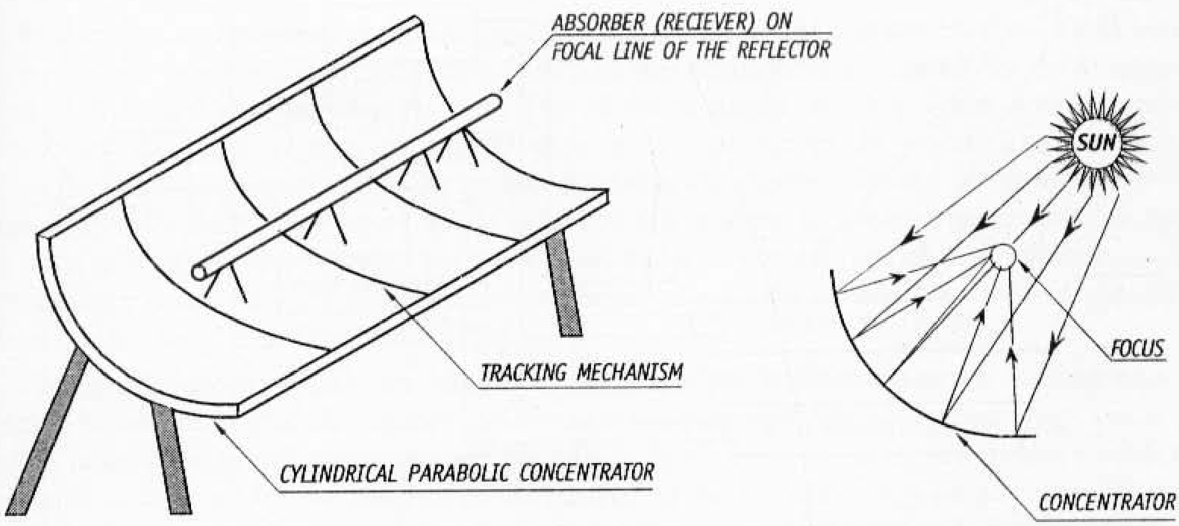


Flat - Plate Collector
Fig. 1.5

In the *flat plate collectors* as shown in *Fig. 1.5,* a blackened sheet of metal is used to absorb all the sunlight, direct, diffuse and terrestrially reflected. A sheet of metal coated in black has the property of absorbing the sunlight falling on it and convert it into heat. The heat generated in the sheet of metal is subsequently transferred to the other fluids like, air, water, etc. The heat energy will be continuously transferred to the fluid after the blackened surface attains a temperature at which the equilibrium state is established between the rate at which the solar energy is absorbed and the rate at which the heat energy is transferred to the fluid. When the conduction, convection and radiation losses during absorption, generation and transfer are prevented, this method of solar energy conversion will have very high conversion efficiencies, even as high as 100%.

In *flat plate collectors,* the conduction and convection losses can be minimised by placing the blackened sheet of metal in a closed thermally insulated box having its top covered by a transparent glass sheet so that the solar radiation can be allowed. The use of a glass cover serves as diathermanous medium permitting the short wavelength solar radiation to be transmitted through it, while blocking the long wavelength radiation from the surface of the blackened sheet. By coating the absorbing surface with selective coating substances having high absorptiveness in the short wavelength region and low emissivities in the long wavelength region the radiation losses from the absorbing surface may be reduced. Flat plate collectors are used for wide variety of low temperature applications such as cooking, water heating, drying of food grains and vegetables, seasoning of wood, desalination of water, etc.

In the *focusing collectors* as shown in *Fig. 1.6,* a mirror or a lens system is used to increase the intensity of solar radiation. Generally parabolic reflectors of either cylindrical shape or spherical shape are employed to focus the incident radiation. The focusing collectors intercept and concentrate only the direct rays of the sun, and hence they do not perform satisfactorily when the sky is cloudy or hazy. A very small quantity of the diffused radiation will fall upon the absorber, hence ignored. The focusing collectors require tracking systems to follow the path of the sun. The concentrated narrow focused beam is absorbed by a receiver placed at the focus of the reflector. The focusing collectors may be used for high temperature heating applications for industrial purposes.



Parabolic Focusing Collector
Fig. 1.6

1.11.3 Solar Pond

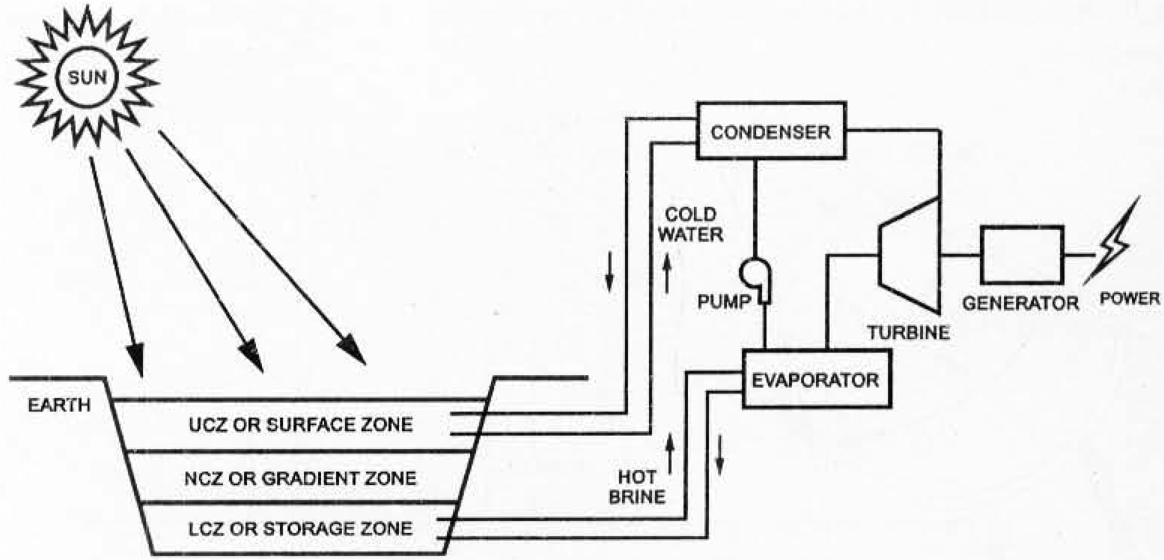
Even though Solar energy is abundantly available, it is intermittent when it comes to supply. Meaning that solar energy is not available during nights or clouding days. This necessitates storage of Solar energy to ensure continuous supply. This also involves high capital cost and one of the better ways would be to use a large water body or a pool to collect and store solar energy. This is called a *Solar Pond*.

So, a solar pond is a pool of saltwater that is used to collect and store solar energy. Here the convection is inhibited to permit accumulation of energy from solar radiation in the lower layers of the pond.

***Working Principle of Solar Pond*:**

The working principle of a solar pond is quite simple. It is an established fact that when water or air is heated they become lighter and rise upward. Likewise, in an ordinary pond, the radiation from the sun in the form of rays heat the water and the heated water within the pond rises and reaches the top. After reaching the top, it loses the heat into the atmosphere due to convection or evaporation. Due to loss of heat, the pond water remains at the atmospheric temperature. The solar pond on the other hand restricts this tendency by dissolving salt in the bottom layer of the pond making it too heavy to rise to the surface and cool. The salinity gradient prevents convection currents thereby preventing the heat to rise to the top layers. Thus the Solar Pond can store Solar Heat in its lower layers. A typical Solar Pond is as shown in *Fig. 1.7*.

There are three zones in a typical solar pond. The top zone is called as the *surface zone*, or UCZ (Upper Convective Zone) contains less salt content and is at atmospheric temperature. The bottom zone is called the *storage zone* or the LCZ (Lower Convective Zone), which is very hot and very salty and



Solar Pond
Fig. 1.7

has a temperature of 70°– 85° C. This is the zone which collects and stores solar energy in the form of heat. Between the UCZ and the LCZ zones is the *gradient zone* or NCZ (Non-Convective Zone). In this layer, as the depth increases, the salt content also increases, and thus creates a salinity or density gradient. The layers in the NCZ can neither fall nor rise. They cannot rise because the layer of water above the NCZ has less salt content and hence is lighter. On the other hand water from this layer cannot fall since the water layer below has a higher salt content and hence is heavier. Thus the NCZ acts as a transparent insulator which though allows sunlight to reach the LCZ but traps it there. This trapped heat (solar energy) in the LCZ is taken off from the pond in the form of hot brine to an evaporator which acts as a heat exchanger and this heat in the form of steam is fed to a turbine and the generator coupled to the turbine generates power. Cold water from the UCZ is fed to a condenser where the droplets formed is pumped to the heat exchanger. The cold water is again brought back to the UCZ and the loop continues.

It is better to construct a solar pond near places that have good supply of sea water for filling and flushing, where low cost salt is available, where there is high solar radiation and availability of land at low cost. Coastal areas in India are well suited for construction of Solar Pond.

In India, Solar Pond is available in *Bhuj* which is a city in the Kutch district of Gujarat. The Bhuj Solar Pond construction started at the Kutch dairy in 1987 and the area constructed is 6000 square metre. The project has been supplying processed heat from September 1993. The solar pond is 100 m long and 60 m wide and has a depth of 3.5 m. This project is a collaborative effort between Gujarat

Energy Development Agency, Gujarat Dairy Development Corporation Limited, and TERI (Tata Energy Research Institute) under the National Solar Pond programme of the Ministry of Non-Conventional Energy Sources. It has been the responsibility of the TERI to execute, operate, and maintain the Pond. At present, the Bhuj Pond is largest operating solar pond in the world.

1.12 Wind Energy

Wind energy is the energy contained in the force of the winds blowing across the earth's surface. When harnessed, wind energy can be converted into mechanical energy for performing work such as pumping water, grinding grain by wind mills and producing electrical energy by wind turbines.

Wind energy is defined as the kinetic energy associated with the movement of large masses of air over the earth's surface. The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above a warm area expands and becomes less dense. It is then forced upwards by a cool denser air which flows in from the surrounding areas causing a wind. The nature of terrain, the degree of cloud cover and the angle of the sun in the sky are all the factors which influence this process. In general, during the day the land mass tends to heat up more rapidly than the air over water. In coastal regions this manifests itself in a strong onshore wind. At night this process is reversed because the air cools down more rapidly over the land and the wind therefore blows offshore.

The main planetary winds are caused in much the same way. The earth receives maximum amount of solar radiation at the equator and minimum at the poles. The cool surface air sweeps down from the poles forcing the warm air over the tropics to rise. But the direction of these massive air movements is affected by the rotation of the earth and the net effect is a large counter-clockwise circulation of air around low pressure areas in the northern hemisphere and a clockwise circulation in the southern hemisphere. The strength and direction of these planetary winds change with season as the solar energy input varies.

Despite the wind's intermittent nature, wind flow patterns at any particular place remain remarkably constant year by year. Average wind speeds are greater in hilly and coastal areas than they are well inland.

Wind speeds increase with height. They have been traditionally measured at a standard height 10 m, where they are found to be 20-25% greater than close to the surface. At a height of 60 m, they may be 30-60% higher because of the reduction in drag effect of the earth surface.

Power in the Wind

Wind possesses kinetic energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of this energy and convert into useful work.

The kinetic energy of one cubic metre of air blowing at a velocity V is given by,

$$E = \frac{1}{2}\,\rho V^2 \quad J/m^3$$

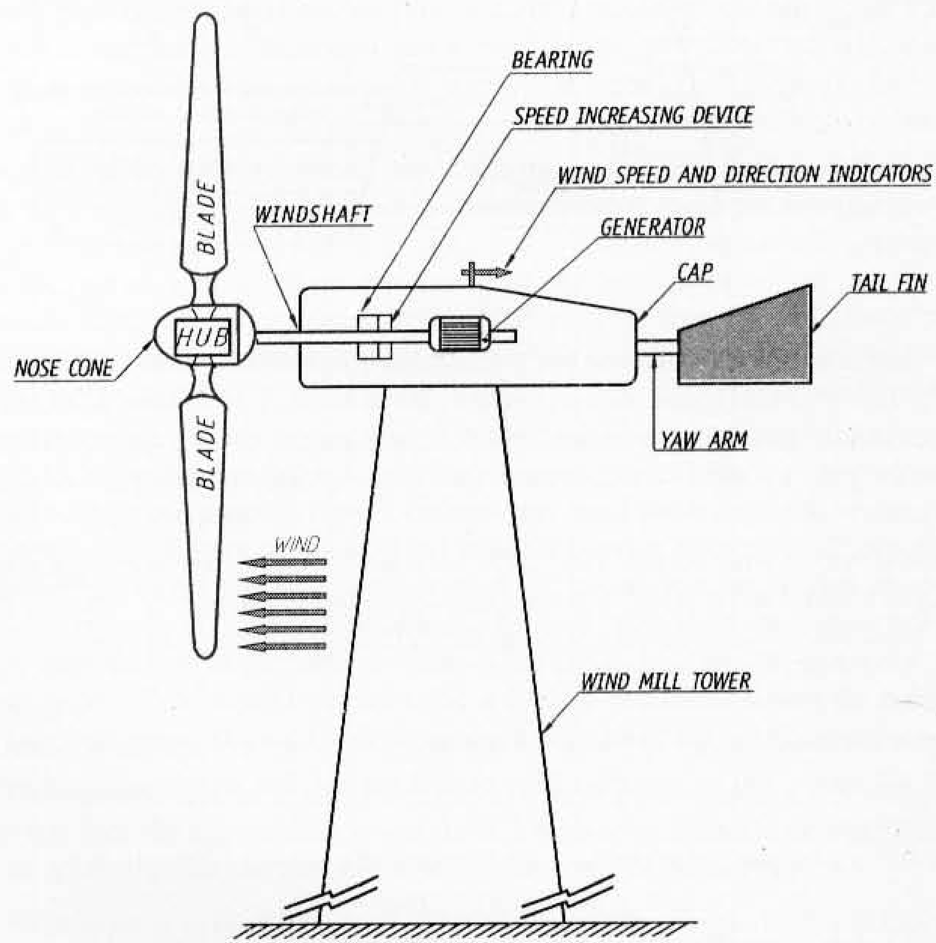
In one second, a volume element of air moves a distance of V m. The total volume crossing a plane, one square metre in area and oriented normal to the velocity vector in one second is therefore V m^3.

The rate at which the wind energy is transferred, i.e., wind power is given by,

$$P = EV$$
$$= \frac{1}{2} \rho V^3 \quad W/m^2$$

No device, however well designed can extract *all* the wind energy because the wind would have to be brought to halt and this would block the passage of incoming air through the rotor. The best that can be achieved is to partially decelerate the discharging air stream and thus leave the emerging air with a velocity component that is sufficient for it to move from the vicinity of the device. It has been found for maximum power output the *exit velocity is equal to one-third of the entrance velocity*. Therefore a so called 100% efficient device would only be able to convert up to a maximum of 60% of the available energy in the wind into mechanical energy.

The power available in the wind is proportional to the *third power of the velocity*. A 26% velocity increase results in doubling the power output, while a 26% decrease in velocity decreases the power output to about 40% of the initial value. But a 50% decrease in velocity reduces the power output to only 12.5% of the initial value. This indicates that the wind power drops are rapid with decrease in velocity.



Schematic Diagram of Wind Mill

Fig. 1.8

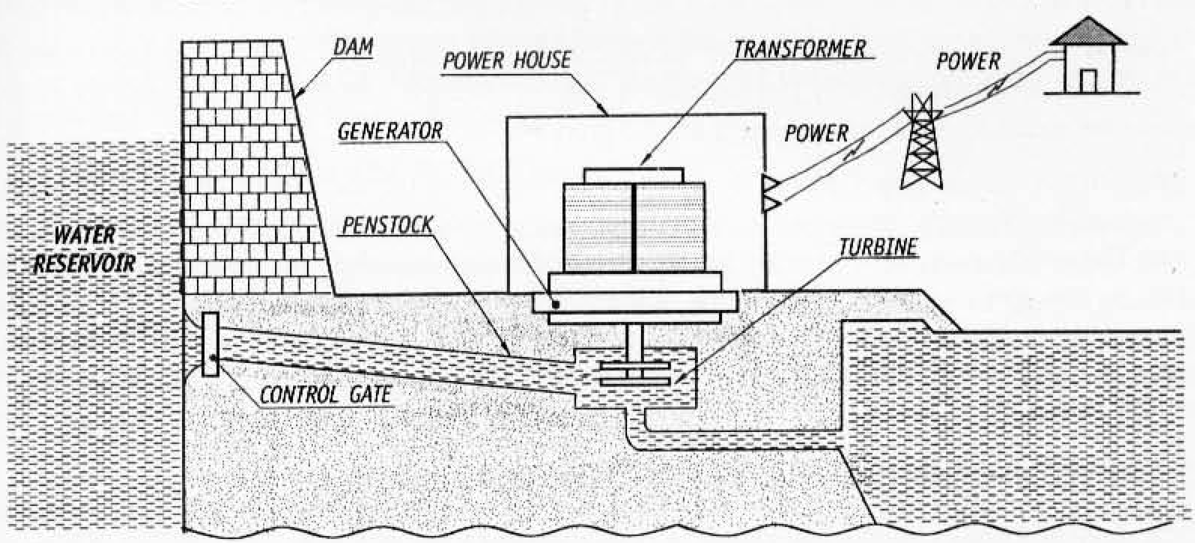
Wind Energy Conversion

A *windmill* is the oldest device built to convert the wind energy into mechanical energy used for grinding, milling and pumping applications. It consists of a rotor fitted with large sized blades. Now attempts are made to improve the performance of the wind turbines by applying sound engineering and aerodynamic principles. Although the wind energy converters are built for simple applications such as pumping water, etc. but the main focus of attention now lies in converting wind energy into electricity. A typical Windmill Schematic Diagram is shown in *Fig. 1.8.*

1.13 Hydro Power

Hydro energy is considered as an indirect source of solar energy. The water from the earth's surface gets evaporated by solar heat and is transported by winds. This in turn results in rainfall. This hydrological cycle is going on since ages. The rain water flowing as river can be stored to higher levels by building dams across the river and released in a controlled way to generate mechanical power. The potential energy of water stored at a height is converted into mechanical energy in water turbines. The mechanical energy produced by the water turbines is further converted into electrical energy by the electric generators which are coupled to the water turbines. A typical hydro-power station is as shown in *Fig. 1.9.*

The electrical energy generation by hydro-electric power plants is non-polluting and is a renewable source of energy. The several problems associated with the hydro energy are, construction of giant dams alters the ecology of both the upstream and downstream regions, dislocation of living activities, submerging of agricultural lands, etc.



Hydro-Power Station

Fig. 1.9

1.14 Nuclear Power

Nuclear energy is the chemical energy released during the splitting or fusing of atomic nuclei. The atom consists of a small, massive, positively charged core nucleus surrounded by electrons. The nucleus, containing most of the mass of the atom, is itself composed of *neutrons* and *protons* bound together by very strong nuclear forces, much greater than the electrical forces that bind the electrons to the nucleus. Protons carry a positive charge. Neutrons carry no electric charge. The binding energy of a nucleus is a measure of how tightly its protons and neutrons are held together by the nuclear forces.

A nuclear reaction involves changes in the structure of the nucleus. As a result of such changes, the nucleus gains or loses one or more neutrons or protons, and release useful amounts of energy. The nuclear energy, measured in *millions of electron volts* (MeV) is released by the *fusion* and *fission* nuclear reactions.

Fusion Process

In the fusion process, when light masses of nuclei such as deuterium and tritium—the two forms of hydrogen, are combined with the excess binding energy is released. When two nuclei of deuterium are forced together they momentarily form an unstable nucleus which immediately releases one neutron and become helium, or one proton and become tritium. The resulting nucleus has less mass than the two original nuclei — the lost mass gets converted into energy.

To ignite and sustain a fusion reaction, it would be necessary to heat the fuel to a temperature in excess of 100 million degree centigrade, which is the main disadvantage of this process.

A reactor based on deuterium-tritium fusion would release 80 percent of its energy in the very fast moving neutrons. These neutrons could heat a jacket of liquid lithium eventually producing usable electricity from a conventional steam powered generator. Neutrons would also cause fission in some lithium nuclei producing tritium fuel for the basic fusion reaction with deuterium.

Fission Process

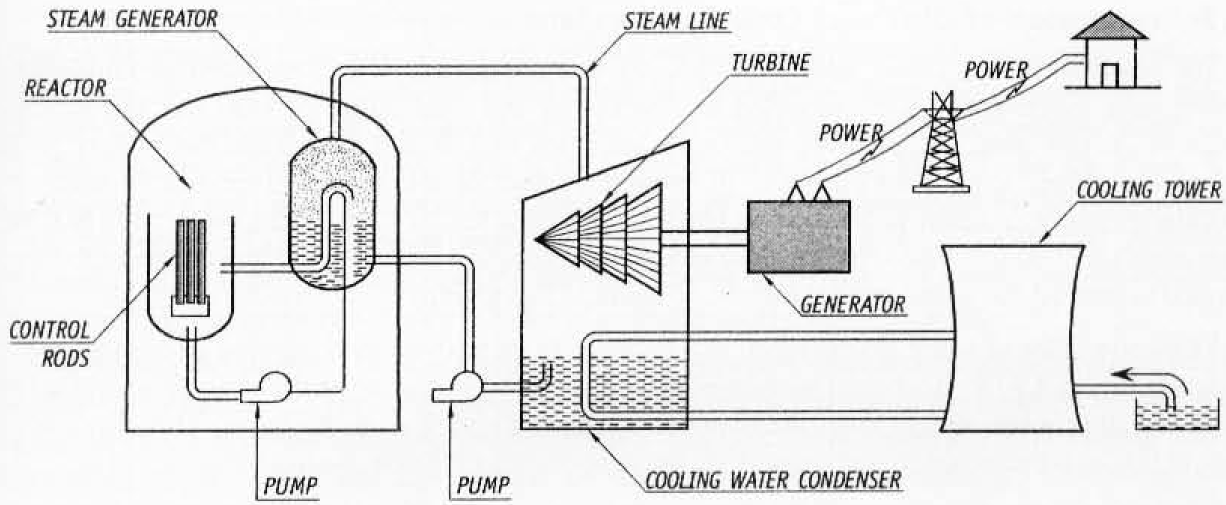
Nuclear fission involves splitting the nucleus of heavy atoms, like uranium or plutonium in a controlled nuclear chain reaction. During fission heat is released and this can be used to generate high pressure steam to drive turbo-generators and produce electricity.

Most of the nuclear power plants are based on the fission of the nucleus of Uranium–235 atoms. This nucleus is relatively unstable and can split into two or more fragments when struck by a neutron. The splitting or fission yields energy together with an emission of more neutrons. These neutrons in turn can go on to cause further splits in other nuclei producing more energy and more neutrons. This is known as a chain reaction. If there is a sufficient mass of U-235 in suitable geometry we can get a self sustaining chain reaction which can, therefore lead to continuous generation of energy.

1.15 Conversion of Nuclear Energy - Nuclear Power Plant

Fig 1.10 shows the schematic diagram of a Nuclear Power Plant. It essentially consists of a Nuclear Reactor (which is a device where nuclear chain reactions are initiated, controlled and also sustained at a steady rate), a steam generator, a cooling water condenser, a cooling tower, turbine and a generator. Control rods are housed inside the reactor vessel. These rods are used to control the splitting of uranium atoms.

The Reactor and Steam generator are housed inside a Containment Structure. The Nuclear reaction produces enormous amount of heat, which is transferred into a steam generator where steam is produced by reaction of heat with cooling water. This steam is led to the turbine using a Steam line and



Nuclear Energy Conversion
Fig. 1.10

the steam is utilized to drive the turbine and hence generate power using a generator. The advantage of this type of design is that the radioactive steam / water never get into contact with the turbine.

Till now we have discussed about the various renewable and non-renewable energy sources. As energy demands goes on increasing day-by-day, in the future there will be more and more onus on tapping energy from renewable energy sources because the non-renewable energy sources will slowly become depleted. Hence it is the duty of every one to start using the renewable energy sources to avoid an impending "Shortage of Energy Situation".

1.16 Steam formation and Properties

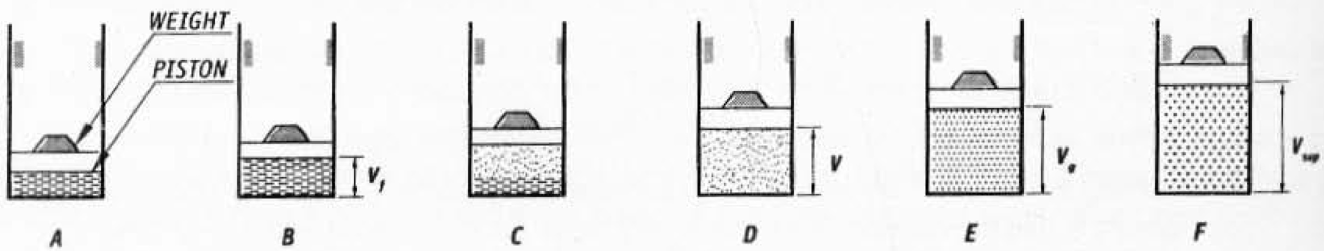
A *perfect gas* does not change its phase during a thermodynamic process. However, a *pure substance* which is a homogenous substance retains its chemical composition even though it undergoes a change in phase during a thermodynamic process. Water is one of the pure substances which can exist in the three different phases, viz., in the *solid phase* as *ice,* in the *liquid phase* as *water,* and in the *gaseous phase* as *steam.* Of course in all its three different phases, it retains the same chemical composition.

When the ice melts, it transforms from the solid phase to the liquid phase to form water. Similarly when the water is heated beyond the boiling point, it starts evaporating and transforms from the liquid phase to the gaseous phase to form steam which may be defined as the *vapour of water*. During this transformation, known as *vapourisation,* it remains as a *two phase mixture* of water and steam. After the vapourisation is complete it exists purely in the gaseous phase as steam. The different states of existence and the associated properties of steam required in its thermodynamic analysis are studied here. The important properties of steam are : *pressure, temperature, specific volume, enthalpy, internal energy* and *entropy*. These properties of the steam are determined by the steam generation experiment explained in *Art.1.17*.

1.17 Formation of Steam at Constant Pressure

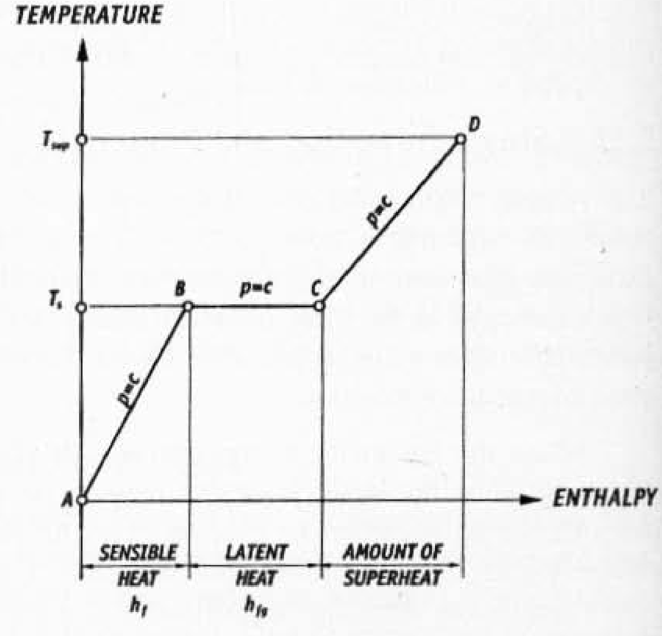
In practice, in the steam generators, known as boilers, water will be taken at atmospheric pressure and temperature, and converted into steam by the application of heat. As the steam is continuously generated, its pressure gradually increases and is supplied from the boilers to the engines or turbines at constant pressure. To know the values of the various properties of steam at a particular pressure, a steam generation experiment is conducted by heating the water from 0°C at a given constant pressure. Since the steam is generated at constant pressure, the amount of heat energy supplied to convert the water into steam will be equal to its *enthalpy*.

Consider 1 kg of water at 0°C taken in a cylinder fitted with a freely moving frictionless piston as shown in *Fig.1.11A*. A chosen weight is placed over the piston so that the total weight of the piston and the chosen weight exert the required constant pressure p on the water. This condition of water at 0°C is represented by the point A on the temperature-enthalpy graph as shown in *Fig.1.12*.



Formation of Steam
Fig.1.11

When this water is heated at constant pressure, its temperature rises till the boiling point is reached. When the boiling point of water is reached, there will be a slight increase in the volume of water as shown in *Fig.1.11B*. The temperature at which the water boils depends on the pressure acting on it. This temperature is called as ***saturation temperature***, and denoted as T_s. The *saturation temperature is defined as the temperature at which the water begins to boil at the stated pressure.* This condition of water at temperature T_s is represented by the point B on the graph. The heating of the water from 0°C to T_s°C at constant pressure is represented by the inclined line AB on the graph. The saturation temperature, i.e., the boiling temperature, of the water increases with the increase of pressure at which the water is heated.



Temperature-Enthalpy Diagram
Fig.1.12

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

Further addition of heat, initiates the evaporation of water while the temperature remains at the saturation temperature T_s because the water will be saturated with heat and any further addition of heat changes only the phase from the liquid phase to the gaseous phase. This evaporation will be continued at the same saturation temperature T_s until the whole of the water is completely converted into steam as shown in *Fig.1.11E*. This point is represented by the point C on the graph. This constant pressure and constant temperature heat addition process is represented by the horizontal line BC on the graph. *The amount of heat required to evaporate 1 kg of water at saturation temperature T_s to 1 kg of dry steam at the same saturation temperature at given constant pressure is called* ***latent heat of evaporation*** or ***enthalpy of evaporation*** and denoted as h_{fg}.

On heating the steam further at the same constant pressure, increases its temperature above the saturation temperature T_s. The temperature of the steam *above* the saturation temperature at a given pressure is called ***superheated temperature***. During this process of heating, the dry steam will be heated from its dry state, and this process of heating is called ***superheating***. The steam when superheated is called ***superheated steam***. This superheating is represented by the inclined line CD on the graph. *The amount of heat required to increase the temperature of dry steam from its saturation temperature to any desired higher temperature at the given constant pressure is called* ***amount of superheat*** *or* ***enthalpy of superheat****. The difference between the superheated temperature and the saturation temperature is defined as* ***degree of superheat****.*

Advantages of Superheated Steam :

1. At a given pressure, the superheated steam possess more heat energy compared to dry saturated steam or wet steam at the same pressure, hence its capacity to do the work will be higher.
2. When superheating is done by the exhausting combustion gases in a boiler, there will be a saving of the energy of combustion which improves the thermal efficiency of the boiler.
3. While expanding in a steam turbine it reduces and in extreme cases prevents the condensation, thus giving better economy.

Disadvantages of Superheated Steam :

1. The high superheated temperatures pose problems in the lubrication.
2. Higher depreciation and initial cost.

1.18 Different States of Steam

The steam as it is being generated can exist in *three* different states, viz., as *wet steam*, or *dry saturated steam*, or *superheated steam*.

Wet Steam

When the water is heated beyond the saturation state at constant pressure it starts evaporating. The steam evolving from the surface of the water entrains finely divided water molecules in it. This entrained water molecules suspended in the steam will be at the saturation temperature and will not yet have been absorbed the latent heat and evaporated into steam. Both the entrained water molecules and steam coexist to form a two phase mixture, called ***wet steam*** which will be in thermal equilibrium because both of them will be at the same saturation temperature.

Thus a *wet steam is defined as a two-phase mixture of entrained water molecules and steam in thermal equilibrium at the saturation temperature corresponding to a given pressure.*

Dryness Fraction of Steam

A wet steam can be of different *qualities*, i.e., having different proportions of water molecules and dry steam. Therefore it is necessary to state the quality of the wet steam. The quality of the wet steam is specified by the *dryness fraction* which indicates the amount of dry steam present in the given quantity of wet steam and is denoted as x. The dryness fraction of the wet steam will be *less than 1*.

The *dryness fraction of a steam is defined as the ratio of mass of the actual dry steam present in a known quantity of wet steam to the total mass of the wet steam.*

Let m_g = mass of dry steam present in the sample quantity of wet steam

m_f = mass of suspended water molecules in the sample quantity of wet steam

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

Dry Saturated Steam

Steam which is in contact with water from which it has been formed will be in thermal equilibrium with the water (i.e., the heat passing from steam into the water is balanced by the equal quantity of heat passing from the water into the steam) is said to be a ***saturated steam.*** *A saturated steam at the saturation temperature corresponding to a given pressure and having no water molecules entrained in it is defined as* ***dry saturated steam*** *or simply* ***dry steam.***

Since the dry saturated steam does not contain any water molecules in it, its *dryness fraction will be unity.*

Superheated Steam

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

A superheated steam is defined as the steam which is heated beyond its dry saturated state to temperatures higher than its saturated temperature at the given pressure.

1.19 Enthalpy of Steam

Enthalpy is defined as the sum of the internal energy and the product of the pressure and volume. It is denoted as h. The *enthalpy*, h is given by $h = u + (pv/J)$.

From the first law of Thermodynamics,

$$dQ = du + p.dv$$

$$= du + d(pv) - v.dp \qquad (\text{Because } d(pv) = v.dp + p.dv)$$

$$= d(u + pv) - v.dp$$

For a constant pressure process, dp = 0

Therefore, $dQ = d(u + pv)$

That is, $dQ = dh$

Therefore, for constant pressure steam generation process, the *amount of heat supplied to water to convert into steam is equal to the change in enthalpy.*

Enthalpy of Dry Saturated Steam

The *enthalpy of dry saturated steam is defined as the total amount of heat supplied at a given constant pressure to convert 1 kg of water into 1 kg of dry saturated steam at its saturation temperature. It is denoted as* h_g *and will be equal to sum of the sensible heat* h_f *and the latent heat of evaporation* h_{fg}.

$$h_g = h_f + h_{fg} \text{ kJ/kg}$$

Enthalpy of Wet Steam

Since a wet steam contains water molecules entrained in it, it will have absorbed only a fraction of the latent heat of evaporation proportional to the mass of the dry steam contained in the wet steam. Therefore the *enthalpy of wet steam is defined as the total amount of heat supplied at a constant pressure to convert 1 kg of water at 0°C to 1 kg of wet steam at the specified dryness fraction. It is denoted as* h *and will be equal to sum of the sensible heat and the product of the dryness fraction and the latent heat of evaporation.*

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

Enthalpy of Superheated Steam

To superheat the steam, the heat is supplied at a constant pressure to the dry saturated steam to increase its temperature beyond its saturation temperature. Therefore the *enthalpy of superheated steam is defined as the total amount of heat supplied at a given constant pressure to convert 1 kg of water at 0°C into 1 kg of superheated steam at the stated superheated temperature.* It is denoted as h_{sup} *and will be equal to sum of the enthalpy of dry saturated steam and the amount of superheat.* If T_{sup} is the superheated temperature, T_s is the saturated temperature and C_{ps} is the specific heat of superheated steam, then the amount of superheat will be equal to $C_{ps}\,(T_{sup} - T_s)$.

$$\therefore \quad h_{sup} = h_g + C_{ps}\,(T_{sup} - T_s) \text{ kJ/kg}$$

$$\text{or} \quad h_{sup} = h_f + h_{fg} + C_{ps}\,(T_{sup} - T_s) \text{ kJ/kg}$$

1.20 Specific Volume

The specific volume is the volume occupied by the unit mass of a substance. It is expressed in m^3/kg.

Specific Volume of Saturated Water

It is defined as the volume occupied by 1 kg of water at the saturation temperature at a given pressure, as shown in *Fig.1.11B* and is denoted by v_f.

Specific Volume of Dry Saturated Steam

It is defined as the volume occupied by 1 kg of dry saturated steam at a given pressure, as shown in Fig.1.11E and is denoted by v_g.

Specific Volume of Wet Steam

When the steam is wet, its specific volume will be equal to the sum of the volume occupied by the dried up portion of the steam in 1 kg of wet steam and the volume occupied by the entrained water molecules in the same 1 kg of wet steam. If x is the dryness fraction of the steam, and the mass of the water molecules will be equal to $(1 - x)$ kg.

Let v is the specific volume of wet steam.

$$v = xv_g + (1 - x)v_f \quad \text{m}^3/\text{kg}$$

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

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

Specific Volume of Superheated Steam

It is defined as the volume occupied by 1 kg of superheated steam at a given pressure and superheated temperature, as shown in *Fig.1.11F* and is denoted as v_{sup}.

The superheated steam behaves like a perfect gas, therefore its specific volume is determined approximately using Charles Law.

Let v_g = Specific volume of dry saturated steam at pressure p

T_s = Saturation temperature at pressure p

T_{sup} = Superheated temperature

v_{sup} = Specific volume of superheated steam at pressure p

From Charles Law,

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

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

1.21 External Work of Evaporation

When the heat is supplied at constant pressure to water at saturation temperature, it absorbs the latent heat of evaporation and evaporates into dry saturated steam. Due to the change from the liquid phase to the gaseous phase, there will be a large increase in volume of the dry saturated steam as shown in *Fig.1.11E.* Therefore the latent heat of vapourisation supplied during the evaporation not only changes the phase of the substance but also does an external work in moving the piston at constant pressure due to increase volume. The volume increases from v_f to v_g. The fraction of the latent heat of vapourisation which does an external work is called *external work of evaporation.*

External work of evaporation per kg of dry saturated steam $= p(v_g - v_f)$ kJ

At low pressures v_f is very small and hence can be neglected.

$\therefore$ External work of evaporation per kg of dry saturated steam $= pv_g$ kJ

External work of evaporation per kg of wet steam $= p\,xv_g$ kJ

External work of evaporation per kg of superheated steam $= p\,v_{sup}$ kJ

1.22 Internal Latent Heat

The latent heat of evaporation at a given pressure comprises of the energy required to do external work and the energy required to change the phase. The energy required to change the phase is called *true latent heat* or *internal latent heat*. The internal latent heat is obtained by *subtracting* the external work of evaporation from the latent heat of evaporation.

Internal latent heat of dry saturated steam $= (h_{fg} - pv_g)$ kJ/kg

1.23 Internal Energy of Steam

Since the latent heat of evaporation comprises of internal latent heat and the external work of evaporation, the enthalpy or the total heat energy of a dry saturated steam at a given pressure will be equal to the sum of the sensible heat, internal latent heat and the external work of evaporation. But the heat energy of external work of evaporation is not present in the steam as it has been spent in doing the external work. Therefore the actual energy stored in the steam comprises of only the sensible heat and the internal latent heat. This actual energy stored in the steam is called *internal energy.* It is obtained by subtracting the external work of evaporation from the enthalpy and is denoted by u.

The *internal energy of the steam is defined as the difference between the enthalpy of the steam and the external work of evaporation.*

Internal energy of dry steam : $u_g = h_g - pv_g$ kJ/kg

Internal energy of wet steam : $u = h_f + xh_{fg} - p\,xv_g$ kJ/kg

Internal energy of superheated steam : $u_{sup} = h_{sup} - pv_{sup}$ kJ/kg

1.24 Steam Tables

Generally the properties of steam which are likely to be used are pressure, saturation temperature, specific volume, enthalpy, etc. These properties have been determined experimentally at various pressures and tabulated in a table known as *Steam Table.*

The tabulations in the steam tables may be on the *Pressure* basis as shown in Table 1.1 or on the *Saturation Temperature* basis as shown in Table 1.2. For reference both the Steam Tables are given in Appendix part of this book.

TABLE 1.1

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Saturation Temperature °*C*	Specific Enthalpy kJ/kg			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_s	h_f	h_{fg}	h_g	v_f	v_g

TABLE 1.2

SATURATED WATER AND STEAM (TEMPERATURE) TABLE

Saturation Temperature °*C*	Absolute Pressure *bar*	Specific Enthalpy kJ/kg			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
T_s	p	h_f	h_{fg}	h_g	v_f	v_g

Problem 1.1

Find the enthalpy of 1 kg of steam at 12 bar when, (a) steam is dry saturated, (b) steam is 22% wet and (c) superheated to 250°C. Use the steam table. Assume the specific heat of the superheated steam as 2.25 kJ/kgK.

Solution :

From the steam tables at 12 bar, the following values are noted.

T_s = 188°C $\quad h_f$ = 798.43 kJ/kg $\quad h_{fg}$ = 1984.3 kJ/kg

(a) *Enthalpy of Dry saturated Steam :*

$$h_f = h_f + h_{fg}$$
$$= 798.43 + 1984.3 \text{ kJ/kg}$$
$$= 2782.73 \text{ kJ/kg}$$

(b) *Enthalpy of Wet Steam :*

When the steam is 22% wet, it will be 78% dry. Therefore the dryness fraction x = 0.78

$$h = h_f + x\,h_{fg}$$
$$= 798.43 + 0.78 \times 1984.3 \text{ kJ/kg}$$
$$= 2346.18 \text{ kJ/kg}$$

(c) *Enthalpy of Superheated Steam :*

$$h_{sup} = h_f + h_{fg} + C_{ps}\,(T_{sup} - T_{sat})$$
$$= 798.43 + 1984.3 + 2.25(250 - 188) \text{ kJ/kg}$$
$$= 2922.23 \text{ kJ/kg}$$

Problem 1.2

A steam at 10 bar and dryness 0.98 receives 140 kJ/kg at the same pressure. What is the final state of the steam ?

Solution :

From the steam tables, at 10 bar, the following values are noted.

T_s = 179.9°C $\quad h_f$ = 762.61 kJ/kg $\quad h_{fg}$ = 2013.6 kJ/kg

Enthalpy of wet steam at dryness fraction 0.98 is found out.

Enthalpy of Wet Steam :

$$h = h_f + x h_{fg}$$
$$= 762.61 + 0.98 \times 2013.6 \text{ kJ/kg}$$
$$= 2735.9 \text{ kJ/kg}$$

When 140 kJ of heat is added at the constant pressure its enthalpy will increase,

$$\therefore \quad \text{Enthalpy of heat addition} = 2735.9 + 140$$
$$= \mathbf{2875.9 \quad kJ/kg}$$

At 10 bar the enthalpy of dry saturated steam,

$$h_g = h_f + h_{fg}$$
$$= 762.61 + 2013.6 \text{ kJ/kg}$$
$$= \mathbf{2776.2 \quad kJ/kg}$$

Since the enthalpy of steam after heat addition is *greater* than the enthalpy of dry saturated steam at the same pressure, the steam is superheated. The superheated temperature of the steam is found as follows.

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_{sat}) \text{ kJ/kg}$$
$$2875.9 = 2776.2 + 2.25\,(T_{sup} - 179.9°C) \text{ kJ/kg}$$
$$\therefore \quad T_{sup} = \mathbf{224.2° \, C}$$

Problem 1.3

Find the specific volume and enthalpy of 1 kg of steam at 0.8 MPa : (a) when the dryness fraction is 0.9 and (b) when the steam is superheated to a temperature of 300°C. The specific heat of superheated steam is 2.25 kJ/kgK.

Solution :

From the steam tables at 0.8 MPa = 8 bar, the following values are noted.

$T_s = 170.4°C$	$h_f = 720.94$ kJ/kg
$v_s = 0.2403 \text{ m}^3/\text{kg}$	$h_{fg} = 2046.5$ kJ/kg
$v_f = 0.001115 \text{ m}^3/\text{kg}$	$h_g = 2767.5$ kJ/kg

(a) Specific Volume of Wet Steam :

$$v = x\,v_g \quad \text{m}^3/\text{kg}$$
$$= 0.9 \times 0.2403$$
$$= \mathbf{2.627 \quad m^3/kg}$$

(b) Specific Volume of the Superheated Steam :

$$v_{sup} = v_g \frac{T_{sup}}{T_s} \quad \text{m}^3/\text{kg}$$
$$= 0.2403 \, \frac{(300 + 273)}{(170.4 + 273)} \quad \text{m}^3/\text{kg}$$
$$= \mathbf{0.3105 \quad m^3/kg}$$

(c) Enthalpy of Wet Steam :

$$h = h_f + x h_{fg}$$
$$= 720.94 + 0.9 \times 2046.5$$
$$= \mathbf{2562.8 \quad kJ/kg}$$

(d) *Enthalpy of Superheated Steam :*

$$h_{sup} = h_g + C_{ps}\,(T_{sup} - T_s)$$
$$= 2767.5 + 2.25\,(300 - 170.4)$$
$$= \mathbf{3059.1\ kJ/kg}$$

Problem 1.4

The enthalpy of 1 kg of a steam at 70 bar is 2680 kJ. What is the condition of the steam ?

Solution :

At 70 bar, the following values are obtained from the steam tables.

$h_f = 1267.42$ kJ/kg $\quad h_{fg} = 1506$ kJ/kg $\quad h_g = 2773.5$ kJ/kg

Since the given enthalpy of the steam is less than the enthalpy of the dry saturated steam at the given pressure, the given steam must be a wet steam. Therefore its dryness fraction must be found.

$$h = h_f + x\,h_{fg} \quad \text{kJ/kg}$$
$$2680 = 1267.42 + x \times 1506 \quad \text{kJ/kg}$$
$$x = \mathbf{0.938}$$

Problem 1.5

6 kg of wet steam contains 0.56 kg of water particles in it. What is the dryness fraction of the steam ?

Solution :

Mass of the water particles = 0.56 kg

Mass of dry steam present = (6 – 0.56) kg

= 5.44 kg

Dryness fraction of Steam $= \dfrac{5.44}{6}$

$= \mathbf{0.906}$

Problem 1.6

5 kg of wet steam of dryness 0.8, passes from a boiler to a superheater at a constant pressure of 1MPa abs. In the superheater its temperature increases to 350°C. Determine the amount of heat supplied in the superheater. The specific heat of superheated steam C_{ps} = 2.25 kJ/kgK.

Solution :

$$p = 1 \text{ MPa abs} = 10 \text{ bar abs}$$

At p = 10 bar abs, the properties from the steam tables are :

T_s = 179.88°C $\quad h_f$ = 762.61 kJ/kg $\quad h_{fg}$ = 2013.6 kJ/kg

Problem 1.8

One kg of superheated steam at 1.5 MPa contains 3000 kJ of heat energy. Find the superheated temperature. If 500 kJ of heat energy is removed at the same pressure, what is the condition of the steam ? The specific heat of superheated steam C_{ps} = 2.25 kJ/kgK.

Solution :

$$p = 1.5 \text{ MPa} = 15 \text{ bar}$$

From the steam tables at pressure p = 15 bar,

$$T_s = 198.29°\text{C} \quad h_f = 844.6 \text{ kJ/kg} \quad h_{fg} = 1945.2 \text{ kJ/kg} \quad h_g = 2789.9 \text{ kJ/kg}$$

(a) Superheated temperature :

$$\text{Enthalpy of Superheat} = C_{ps}\,(T_{Sup} - T_s)$$

$$(3000 - 2789.9) = 2.25\,(T_{Sup} - 198.29)$$

$$\therefore \quad T_{Sup} = 291.66\ °\text{C}$$

(b) Condition of steam after 500 kJ of heat is removed :

When 500 kJ of heat is removed, the remaining heat is (3000 – 500) = 2500 kJ. This enthalpy is less than h_g = 2789.9 kJ/kg. Therefore the condition of the steam must be wet. The dryness fraction of the wet steam is determined as follows.

$$h = h_f + x\,h_{fg}$$

$$2500 = 844.6 + x \times 1945.2 \text{ kJ/kg}$$

$$\therefore \quad x = 0.85$$

Problem 1.9

A mixture of saturated water and saturated steam at a temperature of 250°C is contained in a closed vessel of 0.1 m³ capacity. If the mass of the saturated water is 2 kg, find the mass of the steam in the vessel. Also find the pressure, specific volume, dryness fraction and the enthalpy of the mixture.

Solution :

(a) Pressure of Steam :

Since the mixture in the vessel contains saturated water and saturated steam, it will be a *wet steam*. The pressure of the steam is found from the steam tables corresponding to T_s = 250°C is p = 39.77 bar

At p = 39.77 bar, the other properties are found from the steam tables :

$$v_f = 0.0012513 \text{ m}^3\text{/kg} \qquad h_f = 1085.8 \text{ kJ/kg}$$

$$v_g = 0.05004 \text{ m}^3\text{/kg} \qquad h_{fg} = 1714.6 \text{ kJ/kg}$$

(a) *Enthalpy of Wet Steam*

$$h = h_f + x\,h_{fg}$$
$$= 762.61 + 0.8 \times 2013.6 \quad kJ/kg$$
$$= \mathbf{2373.5 \quad kJ/kg}$$

(b) *Enthalpy of Superheated Steam*

$$h_{sup} = h_f + h_{fg} + C_{ps}\,(T_{sup} - T_s)$$
$$= 762.61 + 2013.6 + 2.25\,(350 - 179.88) \quad kJ/kg$$
$$= \mathbf{3159 \quad kJ/kg}$$

(c) *Amount of heat Supplied in the Superheater*

$$h_{sup} - h = (3159 - 2373.5) \quad kJ/kg$$
$$= \mathbf{785.5 \quad kJ/kg}$$

Total amount of heat

supplied in the Superheater $= 5 \times 785.5$ kJ/kg

$= \mathbf{3927.5 \ kJ}$

Problem 1.7

Two kg of dry saturated steam at 1 MPa is produced from the water at 40°C. Determine the quantity of heat supplied. The specific heat of water $C_{pw} = 4.18$ kJ/kg.

Solution :

$$p = 1 \text{ MPa} = 10 \text{ bar}$$

At 10 bar from steam tables

$$T_s = 179.88°\,C$$
$$h_{fg} = 2013.6 \quad kJ/kg$$

In *Fig. 1.13* it is seen that the dry saturated steam at 10 bar, represented at the point *C* is obtained from the water at a temperature T_w = 40°C, represented by the point *A*.

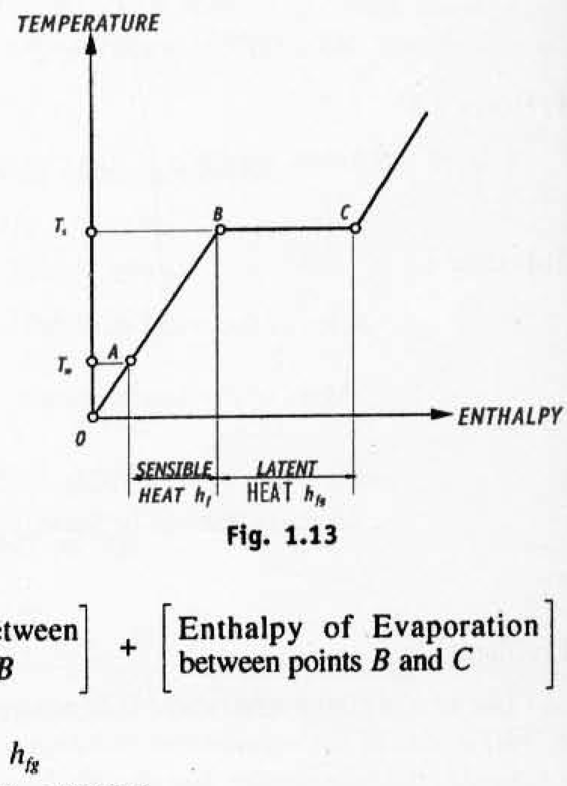


Fig. 1.13

$\therefore$ *Enthalpy (Heat) required* = [Sensible heat between the points *A* and *B*] + [Enthalpy of Evaporation between points *B* and *C*]

$$h_{sup} = C_{pw}\,(T_s - T_w) + h_{fg}$$
$$= 4.18\,(179.88 - 40) + 2013.6$$
$$= \mathbf{2598.3 \quad kJ/kg}$$

Total enthalpy required to produce 2 kg of dry saturated steam,

$$= 2 \times 2598.3$$
$$= \mathbf{5196.6 \quad kJ}$$

(b) Mass of the steam :

Since the vessel contains saturated water and steam,

$$\text{Volume of the vessel} = m_f v_f + m_g v_g$$

$$0.1 = 2 \times 0.0012513 + m_g \times 0.05004$$

$$\therefore \quad m_g = 1.95 \text{ kg}$$

$$\therefore \quad \text{Total mass of the mixture} = 1.95 + 2$$

$$= \mathbf{3.95 \text{ kg}}$$

(c) Dryness fraction of the steam :

$$x = \frac{m_g}{m_f + m_g}$$

$$= \frac{1.95}{3.95}$$

$$= \mathbf{0.493}$$

(d) Specific volume of the mixture :

$$v_s = \frac{0.1}{3.95}$$

$$= \mathbf{0.02531 \text{ m}^3/\text{kg}}$$

(d) Enthalpy of mixture :

$$h = h_f + x\, h_{fg}$$

$$= 1085.8 + 0.493 \times 1714.6$$

$$= 1931 \text{ kJ/kg}$$

$$\text{Total enthalpy} = 2 \times 1931$$

$$= \mathbf{3862 \text{ kJ}}$$

Problem 1.10

Determine the total heat content per unit mass (specific enthalpy) to water when it exists inthe following state using steam tables. Assume ambient pressure to the 100 kPa; (i) 10 bar absolute and 300°C, (ii) 100 kPa gauge and 150° C, (iii) Dry saturated steam at 100 kPa absolute, (iv) Steam at 12 bar and 95% quality, and (v) Saturated Water at 10°C.

Solution :

1 kPa $= 10^{-2}$ bar

(i) 10 bar absolute and 300°C

At 10 bar, the following properties are obtained from the steam tables.

$T_s = 179.9°C \quad h_f = 762.6\ kJ/kg \quad h_{fg} = 2013.6\ kJ/kg$

Since the given temperature of the steam is higher than T_s, the steam is superheated. The specific heat of superheated steam $C_{ps} = 2.25$ kJ/kgK.

$$\therefore \quad h_{sup} = h_f + h_{fg} + C_{ps}\,(T_{sup} - T_s)$$
$$= 762.6 + 2013.6 + 2.25\,(300 - 179.1) \text{ kJ/kg}$$
$$= \mathbf{3048.22 \text{ KJ/kg}}$$

(ii) 100 kPa gauge and 150°C

Absolute Pressure of Steam = Gauge Pressure + Ambient Pressure

= 100 kPa + 100 kPa

= 200 kPa

= **2 bar**

At 2 bar absolute pressure, the following properties are obtained from the steam tables.

$T_s = 120.2°C \quad h_f = 504.7\ kJ/kg \quad h_{fg} = 2201.6\ kJ/kg$

Since the given temperature of the steam is higher than T_s, the steam is superheated.

$$\therefore \quad h_{sup} = h_f + h_{fg} + C_{ps}\,(T_{sup} - T_s)$$
$$= 504.7 + 2201.6 + 2.25\,(150 - 120.2)$$
$$= \mathbf{2773.35 \text{ kJ/kg}}$$

(iii) Dry Saturated Steam at 100 kPa absolute

Pressure = 100 kPa abs

$= 100 \times 10^{-2}$ bar abs

= **1 bar abs**

At 0.1 bar, the enthalpy of dry saturated steam is obtained directly from the steam tables.

$$h_g = 2675.4 \quad KJ/kg$$

(iv) Steam at 12 bar and 95% quality

The given steam is a wet steam. At 12 bar, the following properties are obtained from the steam tables.

$$T_s = 188\ °C \quad h_f = 798.4\ kJ/kg \quad h_{fg} = 1984.3\ kJ/kg$$

The enthalpy of wet steam,

$$\therefore \quad h = h_f + x\ h_{fg}$$

$$= 798.4 + 0.95 \times 1984.3 \quad kJ/kg$$

$$= \mathbf{2683.48 \quad kJ/kg}$$

(v) Saturated Water at 100° C

The enthalpy of saturated water at 100°C is obtained directly from the steam tables based on temperature basis.

At $T_s = 100°C$, *the enthalpy of water is* $h_f = 419.1\ kJ/kg$

Problem 1.11

A spherical vessel 0.5 m diameter contains a mixture of saturated water and saturated steam at 300°C. The saturated water occupies one-fourth of its volume and the remaining saturated steam. Calculate their masses and the dryness fraction of the mixture. Also find the enthalpy of the mixture. How much of the heat is to be added to convert the mixture into dry saturated steam at the same pressure ?

Solution :

From the steam tables, the pressure at the saturation temperature of 300°C is $p = 85.927$ bar, and $v_f = 0.001404\ m^3/kg$, $v_g = 0.02165\ m^3/kg$.

$$\text{Volume of the spherical vessel} = \frac{4}{3}\pi r^3$$

$$= \frac{4}{3}\pi (0.25)^3$$

$$= \mathbf{0.06545\ m^3}$$

Volume of the Saturated water $= \frac{1}{4}\ 0.06545$

$= 0.01636\ m^3$

$\therefore$ Mass of Saturated Vapour $m_f = \dfrac{0.01636}{0.001404}$

$= 11.65$ kg

Volume of the Saturated Steam $= \frac{3}{4} \times 0.06545$

$= 0.049\ m^3$

$\therefore$ Mass of Saturated Vapour $m_g = \dfrac{0.049}{0.02165}$

$= 2.26$ kg

Dryness fraction of the mixture $= \dfrac{m_g}{m_f + m_g}$

$= \dfrac{2.26}{11.65 + 2.26}$

$= 0.162$

Enthalpy of the mixture :

At $T_s = 300°C$ from the steam tables, $h_f = 1345$ kJ/kg, $h_{fg} = 1406$ kJ/kg $h_g = 2751$ kJ/kg

$$h = h_f + x\ h_{fg}$$

$$= 1345 + 0.162 \times 1406$$

$$= 1572.77 \text{ kJ/kg}$$

Heat to be added to convert into dry saturated steam at same pressure :

Heat to be added $= h_g - h_g$

$= 2751 - 1572.77$

$= 1178.23$ kJ/kg

1.25 Boilers

Various types of fossil fuels are the sources from which the heat energy is derived to produce the steam which in turn run the steam engines and the steam turbines. Steam is produced in a closed vessel called *boiler*. In practice the steam is used mainly for two purposes : (i) Power generation, and (ii) Process heating. In power generation, the steam is used to run the steam turbines in thermal power plants. As a process steam, it is used in textile industry for sizing and bleaching. It is used in paper mills for bleaching of the paper. It is also used for processing in chemical industries, sugar factories, pharmaceutical industries, breweries, etc.

1.26 Definition of a Boiler

Boiler is defined as a closed metallic vessel in which the water is heated beyond the boiling state by the application of heat liberated by the combustion of fuels to convert it into steam.

1.27 Function of a Boiler

The function of a boiler is to supply the steam at the required constant pressure with its quality either dry, or as nearly as dry, or superheated. The steam can be supplied from the boiler at a constant pressure by maintaining the steam generation rate and the steam flow rate equal.

1.28 Classification of Boiler

Boilers are classified based on the principle of working as : *(i) Fire tube boilers* and *(ii) Water tube boilers.*

1. ***Fire Tube Boiler :***

In the fire tube boilers, the hot flue gases produced by the combustion of fuels are led through a tube or a nest of tubes around which the water circulates as shown in *Fig. 1.14*. The examples of this type of boilers are Cochran boiler, Cornish boiler, Lancashire boiler, Locomotive boiler and Scotch Marine boiler. Fire tube boilers are suitable for steady working pressures up to 20 bar.

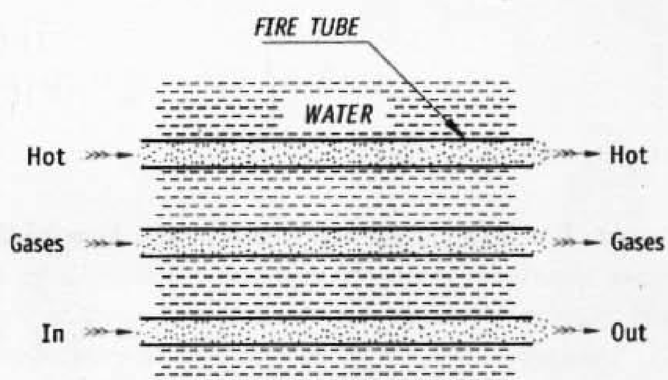


Fig. 1.14

2. ***Water Tube Boiler :***

In the water tube boilers, the water circulates inside the tubes while the hot gases produced by the combustion of the fuels pass around them externally as shown in *Fig. 1.15*. The examples of the water tube boilers are Babcock and Wilcox boiler, Stirling boiler, Yarrow boiler, etc. The water tube boilers are more suitable than the fire tube boilers for the generation of steam at very high pressures and also when the steam is to be raised quickly starting with cold water and fires out.

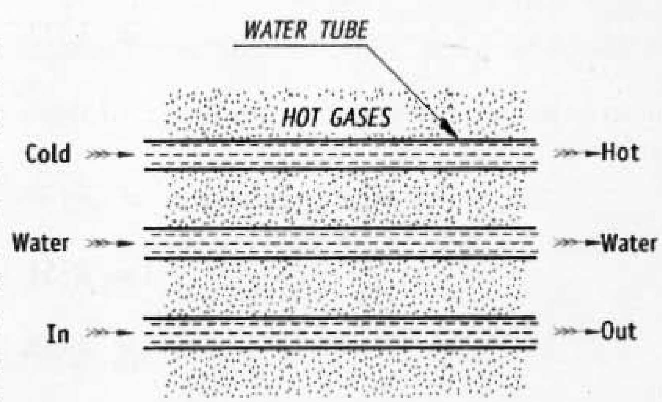
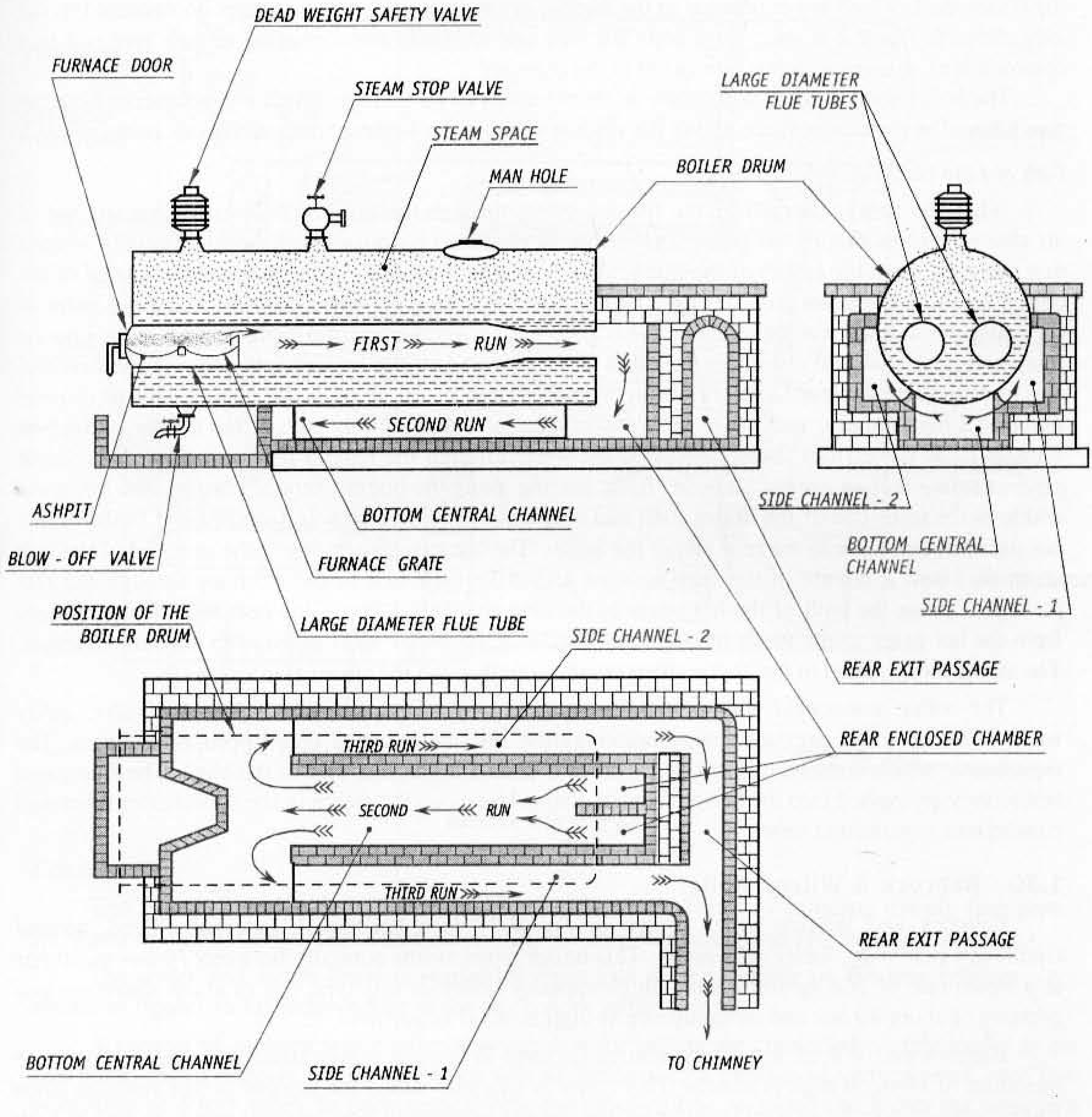


Fig. 1.15

1.29 Lancashire Boiler

Lancashire boiler is a horizontal, internally fired, natural circulation *fire tube boiler.* This boiler raises steam up to a pressure of *15 bar* and maximum evaporative capacity of *8500 kg of steam per hour.* This boiler is very widely used in sugar mills and chemical industries where the steam is required for processing work.



Lancashire Boiler
Fig. 1.16

Construction :

This boiler consists of a horizontal cylindrical shell placed on a brick work setting as shown in *Fig. 1.16. Two large flue tubes* of diameter about 0.4 times of that of the boiler shell are fitted inside the boiler shell and runs throughout its length. In each of these flue tubes two furnace grates are provided inside at their front end. The space underneath the grate is the ash pit. The brick work setting is designed so as to provide an *enclosed chamber* for each of the flue tubes at the rear end of the boiler shell, which are connected to the *bottom central channel* which in turn is connected to the *side channels 1 and 2* at their front end. The two side channels are connected at their rear end to a common *rear passage* which is connected to the chimney.

The boiler shell is filled with water to three-fourths of its volume which will submerge both the flue tubes. The remaining space above the surface of the water in the boiler shell is the *steam space.*

Path of Flue Gases :

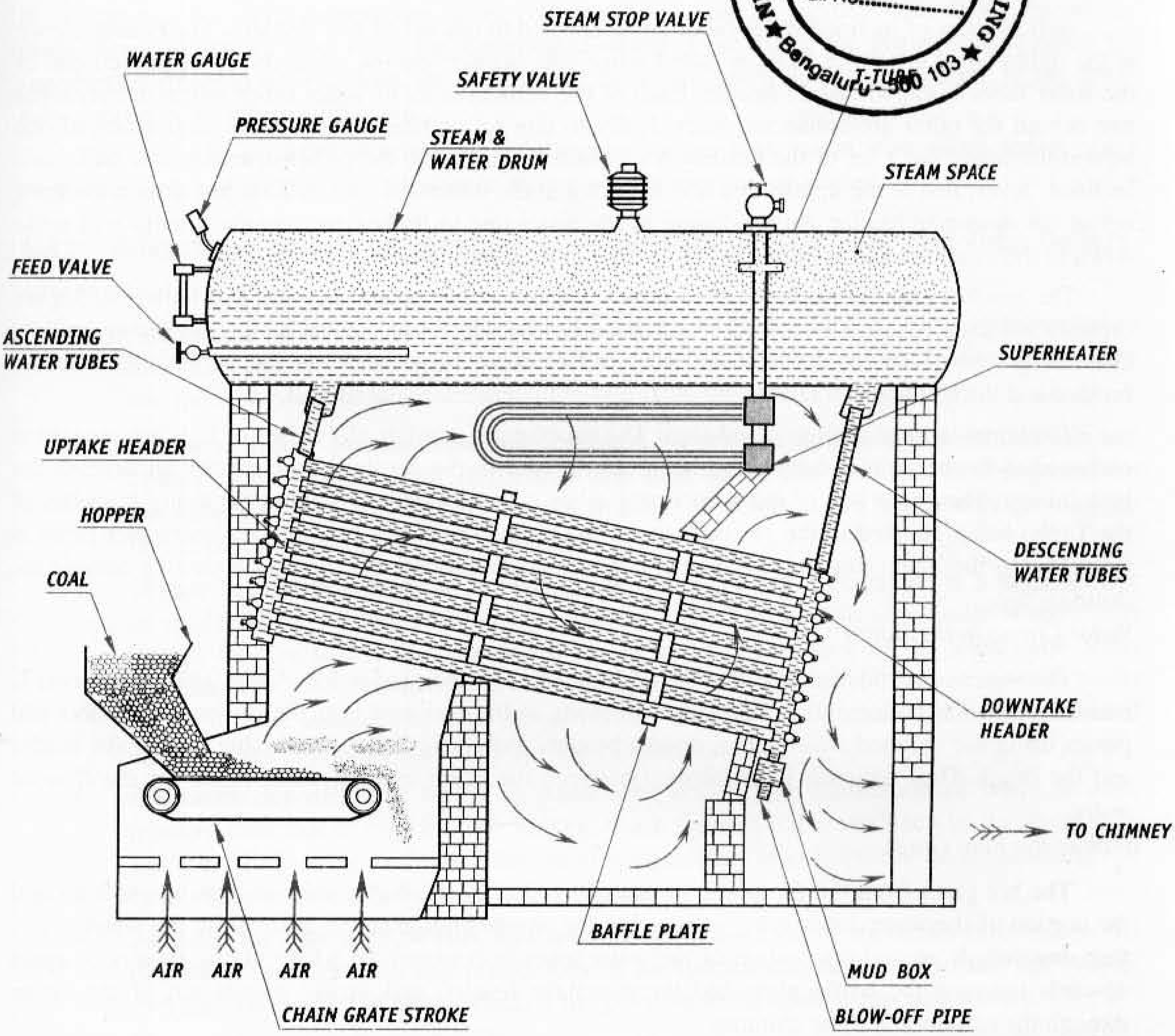
When the fuel is charged on the furnace grates through the *furnace door* sufficient amount of air also enters the area of the grate. The hot gases produced by burning of the fuel initially in their *first run* pass along the length of the flue tubes through them from the *front end to the rear end* of the boiler. As these hot gases pass through the flue tubes heat transfer takes place from the hot gases to the water through the walls of the flue tubes. The hot gases emerge from both the flue tubes into the respective rear enclosed chambers provided at the rear end of the boiler shell. Now in their *second run* from the rear enclosed chambers they pass downwards and *unite in the bottom central channel and travel from the rear end to the front end of the boiler.* During this path of the hot gases the heat transfer takes place from the hot gases to the water through the *bottom portion of the boiler shell exposed to the bottom central channel*. After passing along the bottom central channel, the hot gases divide at the front end of the boiler shell and enter into the side channels 1 and 2, and in their *third run pass through them to the rear end of the boiler.* The hot gases emerging at the rear end of the side channels 1 and 2 reunite in the *rear passage* and make their exit to the chimney through the rear passage. During the path of the hot gases in the side channels 1 and 2 the heat transfer takes place from the hot gases to the water through the *portion of the boiler shell exposed to the side channels.* The steam accumulated in the *steam space* is taken out through the *steam stop valve.*

The boiler is mounted with essential mountings and accessories like *steam stop valve, safety valve, blow off valve, pressure gauge, water gauge,* etc. as shown at their appropriate places. The *superheater* which consists of a set of U- tubes is placed at the rear end of the shell. The flue gases before they are passed into the bottom central channel heats up the steam in the superheater tubes and convert into superheated steam.

1.30 Babcock & Wilcox Boiler

Babcock and Wilcox boiler shown in *Fig. 1.17* is a horizontal, externally fired, natural circulation stationary, *water tube boiler.* This boiler raises steam normally between *10 bar* to *20 bar* at a steam rate of *200 kg per hour.* A high capacity boiler of this type can produce steam up to a pressure of about *40 bar* and steaming rate as high as *4000 kg per hour.*

Babcock and Wilcox water tube boilers are used in thermal power stations for generating large quantities of steam at high pressures. This boiler is specially suited for thermal power stations, since it is capable of coping up very quickly for the sudden increase in pressure and steaming rate at high peak loads.



Babcock & Wilcox Boiler
Fig. 1.17

Construction :

The Babcock and Wilcox water tube boiler shown in *Fig. 1.17* consists mainly four parts : *(i) water and steam drum, (ii) water tubes, (iii) chain grate stoker, and (iv) superheater tubes.*

The *water and steam drum is* suspended from *iron girders* resting on the iron columns, (not shown in figure) and is independent of the brick work setting.

A number of *inclined water tubes* at a very low inclination are connected at right angles to the end boxes called *headers.* The water tubes will be arranged in a number of vertical rows, each row consisting of 4 to 5 tubes. In each vertical row, the tubes will be arranged one below the other in a serpentine form. There will be a number of such vertical rows one behind the other. Each one such vertical rows of inclined water tubes are connected to one set of two headers. The header shown at the right end of the water tubes is called *down take header* and the other shown at the left end of the water tubes is called *uptake header.* Each of the vertical rows of water tubes which are arranged one behind the other are connected individually to one set of headers which are also arranged one behind the other. Each set of the headers are in turn connected to the boiler drum by one set of two inclined tubes, one at the uptake end and the other at the downtake end. A *mud box* is provided just below the downtake header. Any sediment in the water due to its heavier specific gravity will settle down in the mud box and is blown off from time to time through the *blow off pipe.*

The *moving grate* is provided at the front end below the uptake header. The boilers of higher capacity are usually provided with a chain grate stoker, which consists of a slowly moving endless chain of grate bar. The coal fed at the front end of the grate is burnt on the moving grate in the furnace and the residual ash falls at the other end of the grate into the ash pit.

The boiler is fitted with a *superheater.* The superheater consists of number of U-tubes secured at each end to the horizontal connecting boxes and placed in the combustion chamber underneath the boiler drum. The upper box of the superheater tubes is connected to a T-tube, the upper branches of the T-tube being situated in the steam space in the drum. The lower box of the superheater tubes is connected to the steam stop valve mounted over the drum through a vertical tube passing outside the drum.

Water Circuit in the Boiler :

The water is introduced into the boiler drum through the *feed valve.* A constant water level is maintained in the boiler drum. The water descends at the rear end into the downtake headers and passes up in the inclined water tubes, uptake headers and in the tubes connecting the uptake header and the drum. Thus a circuit is established between the drum and the water tubes for the flow of water.

Path of the Flue Gases :

The hot gases from the furnace grate are compelled by the *baffle plate* to pass upwards around the portion of the water tubes lying in-between the combustion chamber and below the water drum, then downwards around the portion of the water tubes in-between the baffle plates, then once again upwards between the baffle plate and the downtake header, and finally passes out of the boiler through the exit door and the chimney.

Circulation of the Water :

During this path of the hot gases, the hottest gases emerging directly from the grate come in contact with the hottest portions of the water tubes. The water in these portions of the water tubes gets evaporated. The water and the steam mixture from these portions of the water tubes ascends through the uptake headers and reach the boiler drum. Now due to this flow, a continuous rapid circulation of water is established between the boiler drum and the water tubes. The steam gets separated from the surface of the water in the boiler drum.

Superheating of the Steam

The steam from the steam space in the boiler drum is led into the branches of T-tube, and then passes into the upper connecting box of the superheater, then through its U-tubes. Since the superheater tubes are fitted in the combustion chamber and directly exposed to the hot gases, the steam passing in it will be superheated. The superheated steam from the superheater tubes are passed to the steam stop valve through the lower connecting box and the vertical tube fitted outside the drum. From the steam stop valve the superheated steam is passed to the prime mover. When the superheated steam is not required, the steam from the steam space directly passes out to the prime mover through the steam stop valve.

The boiler is mounted with the essential mountings such as steam stop valve, safety valve pressure gauge, and water level indicator as shown at their appropriate places.

1.31 Advantages and Disadvantages of Water Tube Boilers over Fire Tube Boilers

Advantages :

1. **Steam can be raised more quickly :** In water tube boilers, the ratio of water content to the steam capacity is comparatively less than the fire tube boiler. Hence water tube boilers can quickly generate steam at the required pressure than the fire tube boiler.

2. **Steam at higher pressures can be produced :** The water tube boilers do not contain any tubes inside the boiler drum. Hence the water tube boilers can withstand high pressures for the same wall thickness and the thermal stresses. Therefore water tube boilers can develop higher pressures than the fire tube boilers.

3. **Higher rate of evaporation :** In water tube boilers, water is contained in a large number of small diameter tubes, therefore the heating surface of a water tube boiler is more than that of the fire tube boiler. The relatively large heating surface of the water tube boiler increases the evaporation rate. The increased rate of evaporation of the water tube boiler makes it more suitable for large power plants, whereas the fire tube boilers are not suited for large power plants because of the low evaporation rate.

4. **Sediment deposition is less :** In water tube boilers, the circulation of water is more positive than that of the fire tube boilers, hence there is a less tendency of the deposits to settle on the heating surfaces. This positive circulation also helps the quick generation of steam than the fire tube boiler.

5. **Suitable for any type of fuel and method of firing :** Since the water tube boilers are externally fired, the size and proportions of the furnace can be altered to suit any type of fuel and the method of firing which is not possible in the case of fire tube boilers.

6. **More effective heat transfer :** The heat transfer in the water tube boilers is more effective than the fire tube boilers since the hot gases flow at right angles to the water tubes.

7. **Failure of water tubes will not affect the working of boiler :** Bursting of any of the water tubes does not pose any serious problems, whereas the bursting any of the flue tubes cause serious problems in fire tube boilers.

8. **Occupies less Space :** For a given power, water tube boiler occupies less space than that of the fire tube boilers.

9. **Easy maintenance :** All parts of the water tube boilers are easily accessible compared to the fire tube boilers, for cleaning, repairing and inspection and hence maintenance is easy.

10. **Easy transportation :** Water tube boilers can be easily dismantled, conveniently transported and erected quickly at the site than a fire tube boiler.

Disadvantages :

1. **Not suitable for ordinary water :** Water tube boilers require relatively pure feed water because impure feed water forms scale inside the water tubes, consequently there will be overheating and bursting of the water tubes.
2. **Not suitable for mobile application :** Water tube boilers are not suited for mobile purposes.
3. **High initial cost and hence not economical :** The initial cost of the water tube boiler is more than that of the fire tube boiler.

1.32 Difference between Water Tube and Fire Tube Boilers

1. Passage of Hot Gases :

In the water tube boilers, the hot gases pass around a large number of tubes through which the water circulates, whereas in a fire tube boiler the hot gases pass through the flue tubes.

2. Position of the Furnace :

In the water tube boilers, the furnace will be situated outside the boiler shell whereas in a fire tube boiler, the furnace will be within the boiler shell.

3. Water Circulation :

In water tube boilers, water will be in continuous circulation between the drum and the tubes, whereas in the fire tube boilers, the water circulation will be within the drum itself.

1.33 List of Boiler Mountings and Accessories

For the satisfactory functioning, efficient working, easy maintenance and the safety of the boilers, they have to be equipped with some type of *fittings* and *appliances.*

The first category, namely fittings, called *boiler mountings,* are required for the complete controlling of the steam generation, measurement of some of the important steam properties, and to provide safety to the boiler. They are fitted directly on the boilers. The essential boiler mountings as specified in the Indian Boiler Act are :

1. *Two water level indicators*
2. *Pressure gauge*
3. *Two safety valves*
4. *Steam stop valve*
5. *Blow off cock*
6. *Feed check valve*
7. *Fusible plug*

The second category, namely appliances, called *boiler accessories,* are required to improve the efficiency of steam power plant and to enable for the proper working of the boiler. The boiler accessories are *not* mounted directly on the boiler. The essential boiler accessories are :

1. *Economiser*
2. *Air preheater*
3. *Superheater*
4. *Feed pump*
5. *Steam separator*
6. *Steam trap*

1.34 Function of the Boiler Mountings and Accessories

1. Water Level Indicator :

The function of the water level indicator is to indicate the level of the water in the boiler drum and thereby guide the boiler attendant to maintain a constant level of water in the boiler. Every boiler will be fitted with two water level indicators. One of them will serve as stand by in case the other fails. The water level indicators will be fitted at the front end of the boiler so that they are clearly visible to the boiler operator.

2. Pressure Gauge :

The function of the pressure gauge is to indicate the pressure of the steam in the boiler in *bar* or *kN/m² or kPa guage.* The pressure gauge is normally mounted in the front end at the top of the boiler shell so as to be clearly visible to the operator. The pressure indicated by the pressure gauge will be above the atmospheric pressure. Therefore, *Absolute pressure = Gauge pressure + Atmospheric pressure.*

3. Safety Valves :

A boiler is designed to produce steam at a certain rated pressure, called *designed pressure,* however, the working pressures will be less than the *designed pressure.* When the boiler is in operation, either due to the sudden reduced rate of flow of steam out of the boiler, or sudden increased rate of steam generation which may be due to the low water levels or increased rate of combustion, there will accumulation of *excess steam* inside the boiler causing a sudden increase in pressure higher than the designed pressure and pose a danger to the safety of the boiler. At such an instant, the excess steam must be suddenly released from the boiler to reduce the pressure in it. A *safety valve* suddenly blows off all the excess steam from the boiler and shuts off automatically. Some safety valves blow off the steam with a loud noise so as to warn the boiler attendant to restore normalcy in the working of the boiler.

Boilers are often fitted with two safety valves with one of them set to function a little in advance of the other. The safety valves commonly used are ; *(i) Dead weight safety valve, (ii) Lever safety valve, (iii) Spring loaded safety valve, and (iv) High steam and low water safety valve.*

4. Steam Stop Valve :

A stop valve or Junction valve is used to regulate the flow of steam from the boiler. Although the terms "junction" and "stop" are often used indiscriminately, the valves mounted on the boilers, which change the direction of flow of steam by 90° are called *junction valves*, while the valves fitted in pipe lines which allow the steam in the same direction are called *stop valves.*

5. Feed Check Valve :

When the level of water in the boiler falls, it is brought back to the specified level by supplying the additional water called feed water. The pressure inside the boiler will be high therefore the pressure of the feed water has to be raised by a pump before it is fed into the boiler. The feed water at high pressure is fed into the boiler though the *feed check valve.* It has dual functions to perform. One of them is that it should regulate the rate of flow of feed water, and the other is that it should prevent the escape of the water from the boiler through the opened regulator valve in the event of instantaneous cease of working of the feed water pump, or when the pressure of the feed water in the pump falls due to the leakage on the delivery side of the pump. This valve is fitted in the feed water pipe line very close to the boiler.

6. Blowoff Valve or Cock :

The function of the blowoff valve is to remove periodically the sediments collected at the bottom of the boiler while in operation. It is also used to empty the water in the boiler when required for periodical cleaning and inspection.

7. Fusible Plug :

Fusible plug is a safety device used to extinguish the fire in the furnace of the boiler when the water level falls too much below the normal level. It is fitted over the crown of the furnace or the combustion chamber.

8. Economiser :

The combustion gases passing out from the boiler will have to be hotter than the water in the boiler, otherwise heat will be transferred from the water to the gases. Thus the gases coming out of the boiler contain large quantity of heat. Therefore maximum amount of heat from the gases should be recovered before it escapes to the chimney. The two accessories that recover heat from the exit gases are : *(i) economiser* and *(ii) air preheater.* In the economisers, the recovery of heat in the flue gases is done by heating the feed water. In the air preheaters, the recovery of heat is done by heating the air supplied for the combustion of the fuel in the furnace. The economisers are placed in the path of the exit gases. They improve the overall efficiency of the boiler by reducing the fuel consumption. The fuel consumption in the boiler is reduced because the feed water supplied to the boiler will be at higher temperatures.

9. Air Preheater :

The air preheater is an accessory which recovers the heat in the exit gases by heating the air supplied to the furnace of the boiler. Supplying of the preheated air into the furnace produces a high furnace temperature and accelerates the combustion of the fuel. Thus the thermal efficiency of the plant will be increased. An air preheater is installed between the economiser and the chimney.

10. Superheater :

Superheaters are used in boilers to increase the temperature of the steam above the saturation temperature. The dry saturated steam generated in the boiler is passed through a set of tubes placed in the path of the flue gases, in which it will be heated further by the hot gases to increase its temperature above the saturation temperature.

11. Steam Trap :

Steam trap is a device used to drain off the condensed water accumulating in the steam pipe lines while at the same time the high pressure steam does not escape out of it. It is connected to a small by-pass pipe which branches off from the main steam pipe line.

12. Steam Separator :

A steam separator, separates the water particles from the steam flowing in the pipe lines. It is installed very close to the steam turbine on the main supply pipe.

13. Feed Pump :

A feed pump is a boiler accessory required to force the feed water at higher pressure into the boilers. Commonly used pumps are *(i) reciprocating pump,* and *(ii) rotary pumps.*

EXERCISES 1

1. Define capital energy and income energy sources. Name the different energy resources of these two types.
2. Distinguish between conventional and Nonconventional energy sources.
3. Distinguish between renewable and non-renewable energy resources.
4. What are the advantages and disadvantages of renewable and non-renewable energy sources ?
5. What is a fuel ?
6. What are the various types of fuels ? Give examples for each.
7. Write a note on the following solid fuels:
   - a. wood
   - b. peat
   - c. lignite
   - d. coal
   - e. bituminous and anthracite coal
   - f. charcoal
   - g. coke
   - h. briquetted coal
   - i. pulverised coal
8. Write a note on the following liquid fuels:
   - a. Petrol
   - b. Kerosene
   - c. Diesel Oil
   - d. Alcohol
9. Write a note on the following gaseous fuels:
   - a. Natural gas
   - b. Coal gas
   - c. Producer gas
   - d. Water gas
   - e. Mond gas
   - f. Blast furnace gas
   - g. Coke oven gas
   - h. Sewer gas
10. List the important desirable properties in a fuel.
11. Define Fuel Combustion. Explain the reactants and products of Combustion.
12. What is air/fuel ratio?
13. Define Stoichiometric Air/Fuel Ratio and Mixture strength.
14. Define Calorific Value of a fuel.
15. Explain higher calorific value and lower calorific value.
16. What are the advantages and disadvantages of solid fuels?
17. What are the advantages of liquid fuels over solid fuels?
18. What are the disadvantages of liquid fuels?

19. What are the advantages of gaseous fuels over liquid fuels?
20. What are the disadvantages of gaseous fuels?
21. What are bio fuels?
22. Explain briefly the common types of bio fuels.
23. Explain some of the engineering applications of bio fuels
24. Name the three principal solar energy conversion processes.
25. Explain briefly the principle of conversion of solar energy directly into electrical energy in a solar cell.
26. Explain the difference between a flat plate collector and a focusing collector.
27. Write a short note on Wind energy and its conversions.
28. Briefly describe how planetary winds are set up ?
29. Explain fusion and fission processes.
30. Explain briefly with a neat diagram the working of a Hydro Power Plant.
31. Explain the fusion and fission processes.
32. Explain briefly with a neat diagram the working of a Nuclear Power Plant.

Properties of Steam

33. Define the following terms with respect to steam :

1. Saturation temperature	7. Amount of superheat
2. Latent heat of vapourisation	8. Enthalpy of wet steam
3. Quality of the steam	9. Enthalpy of dry saturated steam
4. Sensible heat	10. Enthalpy of superheated steam
5. Specific volume of the steam	11. Internal latent heat
6. Degree of superheat	12. Internal energy

34. Explain the terms with reference to the water vapour :

1. Dryness Fraction	5. Dry Saturated Steam
2. Wet Steam	6. Superheated Steam
3. Saturated Steam	7. Superheated Temperature

35. Draw the temperature-enthalpy diagram for a constant pressure heating process to represent on it the following.

(i) Sensible heat region (ii) Latent heat region
(iii) Superheated region (iv) Dryness fraction 0.75

36. Explain the different states of a steam. (VTU, March 2001)

37. What is the difference between sensible heat and latent heat ?

38. What is the difference between dry saturated steam and wet steam ?

39. What is the difference between dry saturated steam and superheated steam ?

40. What are the advantages and disadvantages of superheated Steam ?

41. Explain how the superheated steam can be differentiated from the dry saturated steam.

42. Explain briefly the formation of steam by graphical representation.

43. Explain the formation of steam at constant pressure with suitable sketches.

44. Show the enthalpy of a steam is equal to the total heat supplied in its generation.

45. Write an expression for the enthalpy of superheated steam and explain the terms used.

46. Differentiate between the latent heat of evaporation and internal latent heat.

47. The enthalpy of 1kg of steam of 8 bar pressure is 2373.5 kJ/kg. Find the condition of steam? (VTU, Apr/Sep 1999)

48. Explain the external work of evaporation.

49. What is the enthalpy of heat in 5 kg of steam under the following conditions ?

(i) 0.8 bar and 90% quality (ii) 20 bar and superheated to 300°C.

(12192.05 kJ, 14971.8 kJ)

50. The specific volume of steam at 10 bar is 0.2428 m³/kg. What is the condition of the steam ? **(292.95°C)**

51. Find the enthalpy required to produce 5 kg of dry saturated steam at 6 bar from water at 30°C. The specific heat of water of water C_{pw} = 4.18 kJ/kg. **(13117.75 kJ)**

52. 0.2 kg of steam with an initial dryness fraction of 0.7 is heated at constant pressure of 7 bar till its temperature rises to 250°C. Calculate the enthalpy required. Assume C_{ps} = 2.25 kJ/kgK. **(162.17 kJ)**

53. A steam initially will be at 9 bar and 0.98 dryness. Find the final quality and temperature of the steam after each of the following operations.

a) When the steam loses 50 kJ/kg at constant pressure. **(0.955)**

b) When the steam receives 100 kJ/kg at constant pressure. **(240°C)**

54. By actual measurement the enthalpy of a saturated steam at 190°C is 2500 kJ/kg. What is the quality of the steam ? **(0.856)**

55. Find the enthalpy of 5 kg of superheated steam at a pressure of 2 MPa and a temperature of 300°C. The specific heat of superheated steam is 2.25 kJ/kgK. **(14971.8 kJ)**

Boilers

56. What is a Boiler ? List the essential parts of a boiler. *(VTU, March 2001)*
57. What is the function of a boiler ?
58. With the help of a neat sketch the working of a Lancashire boiler and state its advantages . *(VTU, March 2001)*
59. Sketch and label all the parts of a Babcock and Wilcox boiler. Indicate the path of the flue gases and the water circulation.
60. Where are the superheaters located in the Lancashire and Babcock and Wilcox boilers ?
61. State any five differences between Water tube boiler and Fire tube boiler? *(VTU, March 2001)*
62. What are the advantages and disadvantages of water tube boilers over the fire tube boilers ? Explain.
63. In what circumstances are water tube boilers used in preference to the fire tube boilers ? Give reasons.
64. List the important boiler mounting and accessories.
65. Differentiate between boiler mountings and accessories.
66. What are boiler mountings ?
67. What are boiler accessories ?
68. Why two water gauges and two safety valves are fitted on a boiler ?
69. Name any five boiler mountings and mention their functions ? *(VTU, March 1999)*
70. Will the pressure indicated by a pressure gauge be greater or less than the atmospheric pressure ? If so, why ? How is the gauge pressure to be corrected to obtain the absolute pressure ?
71. Which are the valves that are essential for the working of a boiler ? Justify their necessity.
72. Is the feed pump, a boiler mounting or accessory ? Explain briefly.
73. What is the function of an economiser in improving the efficiency of the boiler plant ?
74. Differentiate between a stop valve and a safety valve.
75. Why safety valves are required in boilers ?
76. What is the function of a steam trap ? Where is it located ?
77. Name the valve through which the feed water enters the boilers when it is in operation.
78. Where is the separator fitted ? What is its function ?
79. What is the difference between an economiser and air preheater ?

80. What is the function of the following. Answer in one or two sentences :

1. Water Level Indicator
2. Pressure Gauge
3. Steam Stop Valve
4. Economiser
5. Air preheater
6. Superheater
7. Safety Valve
8. Steam Trap
9. Steam Separator

CHAPTER 2

TURBINES

2.1 Prime Movers

A prime mover is a self moving device which converts the available natural source of energy into mechanical energy of motion to drive the other machines. The various types of prime movers which convert heat energy produced by the combustion of fuels into mechanical energy are : Steam engines, Steam turbines, Gas turbines and Internal Combustion engines, Except steam engine which is obsolete the working principles of the other prime movers are discussed in this chapter *and the next.*

2.2 Steam Turbine

A steam turbine is defined as a prime mover in which the heat energy of the steam is transformed into mechanical energy directly in the form of rotary motion. The heat energy of the steam is first converted into kinetic (velocity) energy which in turn is transformed into mechanical energy of rotation.

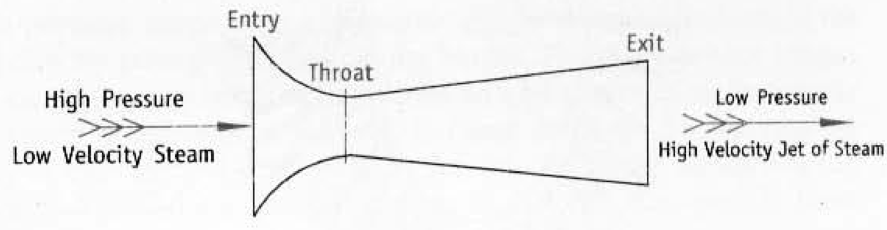
A steam turbine is mainly used as an ideal prime mover to drive the electric generators in thermal power plants to generate electric power. They are also used to proper the ships and to drive the uniform speed machines such as centrifugal gas compressors, textile and sugar industry machineries, etc.

2.3 Propelling Force in the Steam Turbine

The propelling force in a steam turbine depends mainly on the *dynamic action* of the steam. The steam is caused to fall in its pressure by expanding in a nozzle, *Fig. 2.1,* due to this fall in pressure, a certain amount of heat energy is converted into kinetic energy which sets the steam to flow with a greater velocity. The rapidly moving particles of the steam enter the rotating part of the turbine where it undergoes a *change in the direction of motion* which gives rise to *a change of momentum* and therefore a *force*. This constitutes the driving force of the turbine.

2.4 Expansion of Steam in the Nozzle

A high velocity jet of steam is produced by expanding a high pressure steam in a convergent-divergent nozzle shown in *Fig. 2.1.* The steam at high pressure and relatively low velocity enters the nozzle and as it passes between the entry and the throat, it expands to a low pressure. Due to this expansion in this portion of the nozzle the enthalpy of the steam is reduced. As there is no external work done and heat transfer in the nozzle, this *loss in the enthalpy of the steam must therefore be equal to the increase in the velocity (kinetic energy) of the steam.* Therefore a jet of steam at high velocity comes out of the throat section of the nozzle. The divergent portion of the nozzle beyond the throat is provided to complete any remaining expansion without the lateral spreading of the high velocity jet of steam.



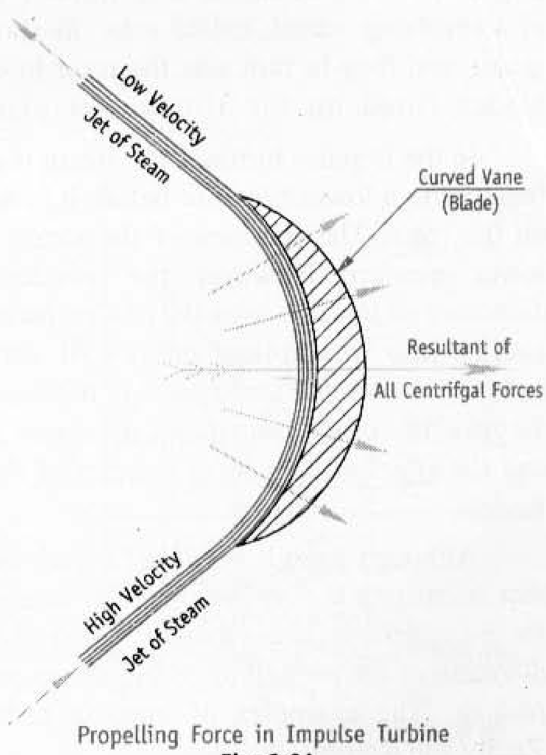
Expansion in Nozzle
Fig.2.1

2.5 Classification of Turbines

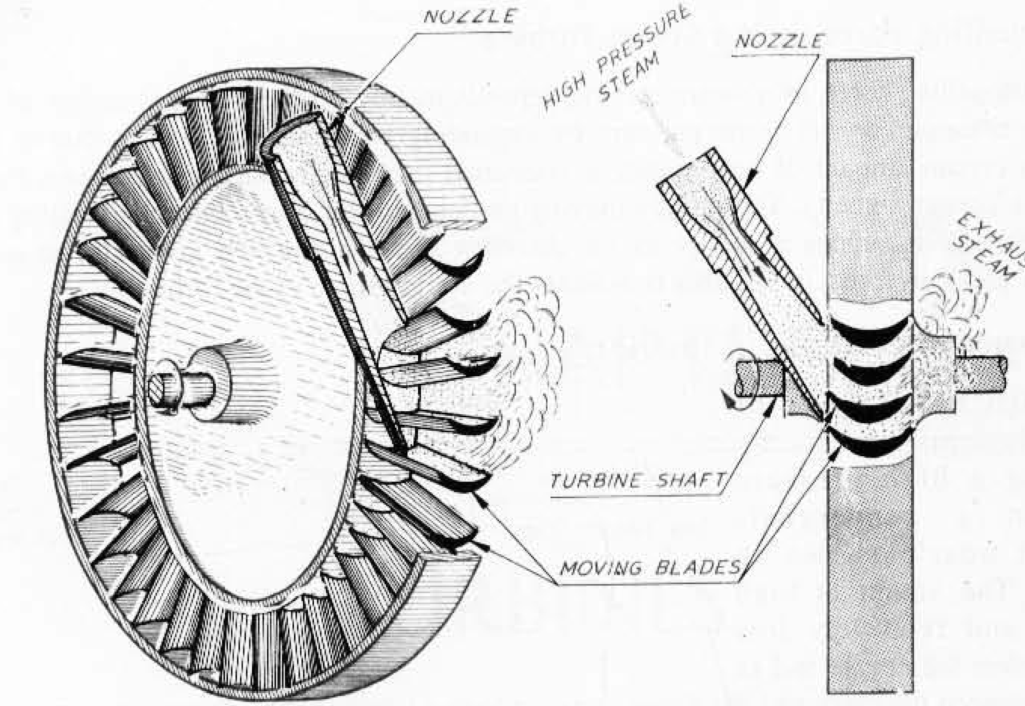
Although the fundamental principle on which all the steam turbines operate is the same, depending on the drop in pressure due to the expansion of the steam that takes place either before it is passed on to the turbine wheel or on the wheel itself and the nature of the resulting propelling force, the steam turbines are classified into ; *(i) De Laval Turbine (Impulse turbine)* and *(ii) Parson's Turbine (Reaction turbine).*

2.6 De Laval Turbine (Impulse Turbine)

In this type of turbine, *the steam is initially expanded in a nozzle* from high pressure to low pressure. The high velocity jet of steam coming out of the nozzle is made to glide over a curved vane, called *blade,* as shown in *Fig 2.2A.* The jet of steam gliding over the blade gets deflected very nearly in the circumferential direction. This causes the particles of steam to suffer a *change in the direction of motion,*



Propelling Force in Impulse Turbine
Fig. 2.2A

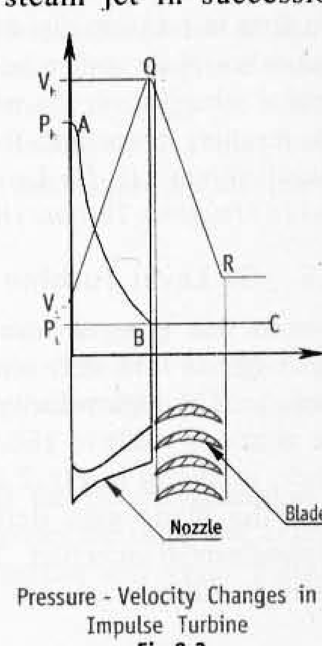


Impulse Turbine
Fig. 2.2B

which gives rise to a *change of momentum* and therefore a *force,* which will be *centrifugal* in nature. The particles of steam exert centrifugal pressures all along their path on the curved surface of the blades as shown in *Fig. 2.2A*. The *resultant* of all these centrifugal forces acting on the entire curved surface of the blade causes it to move. When a number of such blades are fitted on the circumference of a revolving wheel, called *rotor* as shown in *Fig. 2.2B,* they will be moved by the action of the steam, and they in turn sets the rotor in continuous rotation. The rotation of the rotor makes all the blades fitted on the rim to get exposed to the action of the steam jet in succession.

In the impulse turbines the steam is expanded from its high initial pressure to a lower pressure before it is delivered to the moving blades on the rotor. The pressure of the steam over the blades will be at a lower pressure. However, the *velocity of the steam continuously decreases as it glides over the blades* owing to the conversion of kinetic energy into mechanical energy of rotation. Thus in the *impulse turbines the mechanical power is produced by the combined action of the resultant of the centrifugal pressures due the change of momentum and the effect of change of velocity of the steam* as it glides over the blades.

Although there is *no direct impulsive action* on the moving blade *that is causing the turbine rotor to rotate, but the impelling action of the jet of steam on the blades drives the rotor to rotate in the same direction of the propelling force,* this type of turbine is called *impulse turbine.* The examples of impulse turbines are, De Laval, Curtis, Zoelly and Rateau.

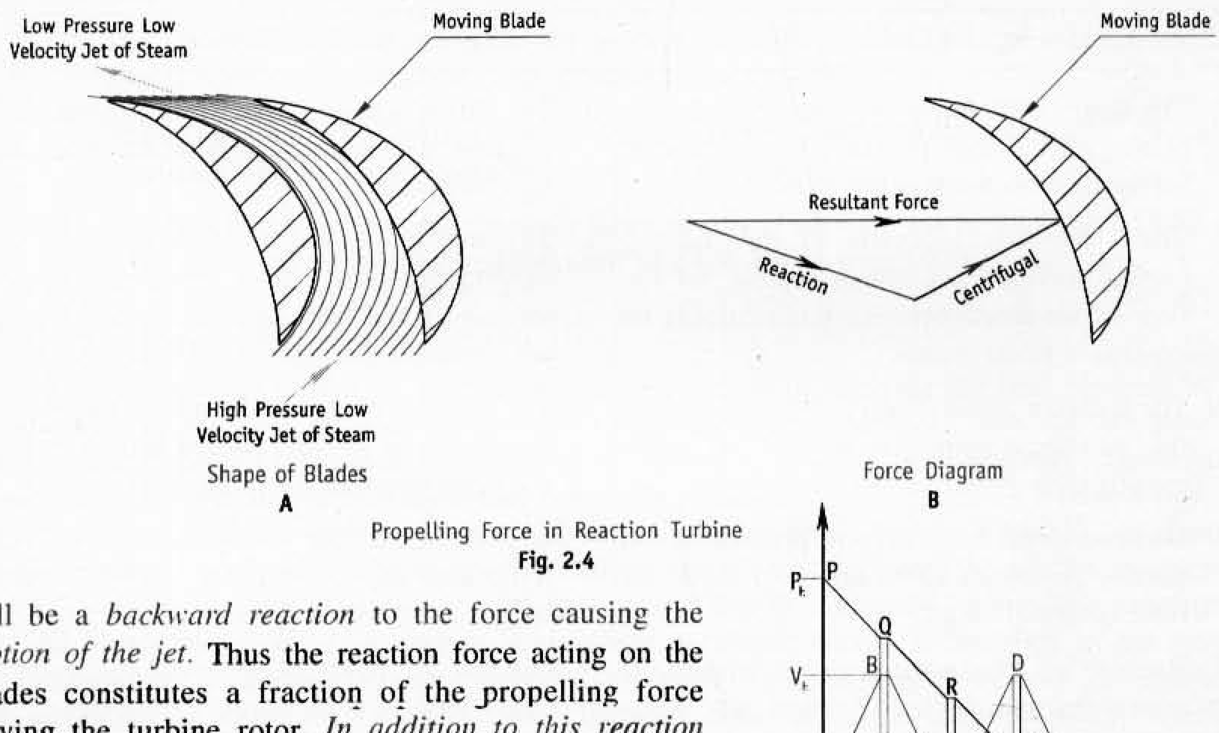


Pressure - Velocity Changes in Impulse Turbine
Fig.2.3

Fig. 2.3 shows the diagrammatic representation of an impulse turbine. The lower portion shows the nozzle and the blade, and the top portion shows the variation of pressure and velocity of the steam as it flows through the nozzle and over the blades. Since the expansion of the steam takes place in the nozzle, the pressure drop is represented by the curve *AB*. As there is no change the in the pressure of the steam that is passing over the blade, this flow is represented by the horizontal line *BC*. Since the velocity of the steam in the nozzle increases due to the expansion of the steam, the increase in the velocity of the steam is represented by the curve *PQ*. As the blades absorb the kinetic energy of the steam as it flows over it, the velocity decreases. This is represented by the curve *QR*.

2.7 Parson's Turbine (Reaction Turbine)

In this type of turbine the high pressure steam *does not initially expand in the nozzle* as in the case of impulse turbine, but instead directly passes onto the moving blades, *Fig. 2.4A*, whose shapes are designed in such a way that the steam flowing between the blades will be subjected to the nozzle effect. Hence the pressure of the steam drops continuously as it flows over the blades causing simultaneous increase in the velocity of the steam. The increase in the velocity of the steam flowing over the blades develops a force within itself which enables it to move further, consequently there

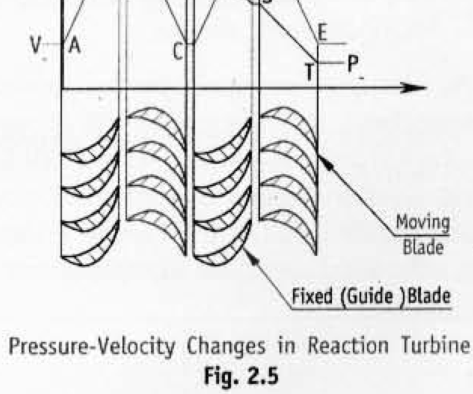


Shape of Blades
A

Force Diagram
B

Propelling Force in Reaction Turbine
Fig. 2.4

will be a *backward reaction* to the force causing the *motion of the jet*. Thus the reaction force acting on the blades constitutes a fraction of the propelling force driving the turbine rotor. *In addition to this reaction force, there is also the centrifugal force exerted by the steam due to the change in the momentum because of the change in the direction of the steam passing over the blades*. This reduces the velocity of the steam. Thus the *net force acting on the moving blades of a reaction turbine is the vector sum of the centrifugal and the reaction forces* as shown by the force diagram shown in *Fig. 2.4B*. This type of turbine is called *reaction turbine*.



Pressure-Velocity Changes in Reaction Turbine
Fig. 2.5

The actual reaction turbine, *Fig. 2.5*, also called impulse-reaction turbine, consists of a number of rows of moving blades fitted on the different rotors keyed to the turbine shaft with alternate rings of fixed blades rigidly fixed to the casing of the turbine. Both the fixed and moving blades are designed in the shape of the nozzles. Therefore the expansion of the steam takes place both in the fixed and moving blades. The fixed blade ring between the two moving blade rotors enables to deflect and guide the steam to enter from one row of moving blades to the next row.

The high pressure steam passing in the first row of fixed blades undergoes a small drop in pressure causing the increase in the velocity of the steam. It then enters the first row of moving blades where it suffers further drop in pressure and the velocity energy is converted into the mechanical energy of rotation of the rotor. Thus the velocity of the steam decreases. This continues in the further rows of moving and fixed blades till the pressure of the steam is almost completely reduced. The changes in the pressure and velocity of the steam as it flows over the moving and fixed blades are shown in the figure.

2.8 Comparison between Impulse and Reaction Steam Turbines

Impulse Turbine	Reaction Turbine
1. The steam completely expands from a high pressure to a low pressure in the nozzle before it enters the moving blades.	1. The high pressure steam continuously expands successively in both the fixed and moving blades.
2. The symmetrical profile of the moving blades provides a uniform section for the flow of the steam between them causing no expansion of the steam.	2. The asymmetrical profile of both the moving and fixed blades provides a varying section for the flow of steam between them which causes the expansion of the steam.
3. The pressure of the steam at both the ends of the moving blades and as well as while passing over them remains constant.	3. The pressure of the steam at both the ends of the fixed and moving blades and as well as while passing over them are different.
4. Because of the large drop in pressure in the nozzle, the steam speed and as well as the rotor speeds are high.	4. Due to the smaller pressure drop over both fixed and moving blades, both the steam speed and the rotor speed are relatively low.
5. Because off the larger pressure drop in the nozzle and less number of stages, size of the impulse turbine for the same power output is comparatively small.	5. Because of the smaller pressure drops in every stage, and more number of stages, the size of the reaction turbine for the same power output is large.
6. Occupies less space per unit power.	6. Occupies more space for the unit power.
7. Suitable for small power generation prime movers.	7. Suitable for medium and high power generation prime movers.
8. Due to high rotor speeds compounding is required to reduce the speed.	8. The speeds are relatively less and hence no compounding is required.

2.9 Advantages of Steam Turbines over Heat Engines

1. From the thermodynamic point of view, the steam turbines are advantageous over heat engines, since relatively large fraction of the heat energy of the steam can be converted into mechanical work.
2. Because of the higher power output and higher operating speeds, the thermal efficiency of steam turbines is higher.
3. From the mechanical point of view, the steam turbines are ideal prime movers when compared to the heat engines since the propelling force is applied directly on the rotating element.
4. It is the best suited prime mover for driving high speed machines such as electric generators, centrifugal gas compressors, etc.
5. The steam turbine is an ideal prime mover for driving machines which require uniform torque and consequent uniform speed as required in certain textile machines.
6. The steam turbines are used for the propulsion of ships of very large tonnage and high speeds which are beyond the range of other prime movers.
7. Steam turbines are ideally suited in thermal power plants as they can take up sudden overloads with only a marginal reduction in their efficiency.
8. Steam turbines can be used for wide range of power applications as they can be built into single units of ratings ranging from units of a few kW to over 1000 kW.

2.10 Gas Turbines

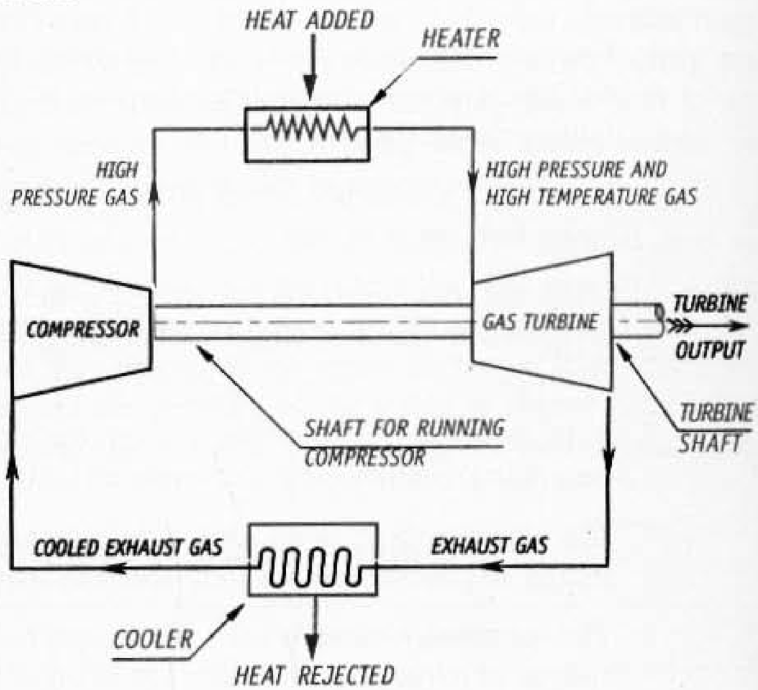
A *gas turbine* is similar to a steam turbine, but instead of applying the heat obtained by the combustion of fuels to produce steam which runs the steam turbines, uses the hot gases of combustion directly to produce the mechanical power. A gas turbine essentially consists of a combustion chamber in which a liquid fuel is burnt in presence of air supplied by a compressor. The air compressor sucks the air from the atmosphere and compresses it, thereby increasing its pressure. In the combustion chamber, the compressed air combines with fuel and the resulting mixture is burnt. The burning gases at very high pressures expand rapidly and made to pass over the rings of moving blades mounted on the turbine shaft where its kinetic energy is absorbed by the moving blades imparting rotary motion to the turbine shaft. In most of the gas turbines, both the air compressor and the turbine are mounted on the same shaft. Therefore, a part of the power developed by the turbine runs the air compressor while the remaining power is utilised for doing the external work.

2.11 Closed and Open Cycle Gas Turbine

Gas turbines work either on closed cycle or on open cycle principle. The fundamental difference between the two cycles is, the course of the flow of the working substance in the cycle of operation. If the flow of the working substance of specified mass is confined within the cycle path, then the gas turbine is said to work on *closed cycle*. Instead, if the entire flow of the working substance comes from the atmosphere and is returned to the atmosphere in each cycle, then the gas turbine is said to work on *open cycle*.

Principle of Operation of Closed Cycle Gas Turbine

Fig. 2.6 shows schematically a simple closed cycle gas turbine plant. It consists of a *compressor,* a *heater,* a *cooler* and the *gas turbine*. Both the compressor and the gas turbine are coupled or mounted on the same shaft. The high compressed gas coming out of the compressor is heated by an external source in the heater which increases the temperature of the gas. The high pressure and high temperature gas is passed to the gas turbine where it expands to lower pressure driving the turbine shaft producing the mechanical energy of rotation. The gas exhausted from the turbine enters the cooler where it is cooled from the external cooling source. The cooled exhaust gas at lower temperature and pressure enters the compressor where it is compressed to higher pressure and relatively higher temperature and the cycle repeats.

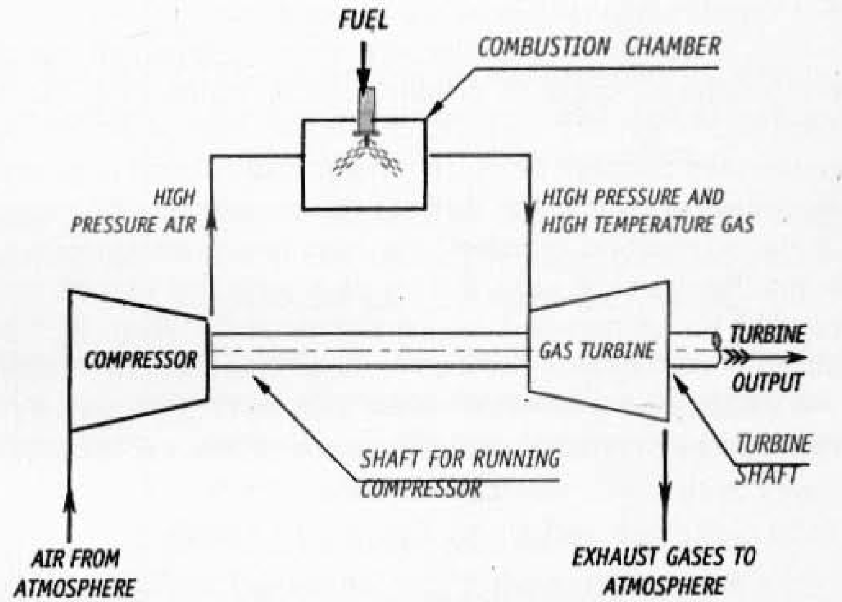


Closed Cycle Gas Turbine

Fig. 2.6

Principle of Operation of Open Cycle Turbine

Fig. 2.7 shows schematically a simple open cycle gas turbine. It consists of a *compressor, combustion chamber* and the *gas turbine*. Both the compressor and the gas turbine are coupled or mounted on the same shaft. The atmospheric air is drawn into the compressor and compressed to high pressures. The high pressure and relatively high temperature air flows to the combustion chamber where heat is added to the air by the combustion of the fuel in the combustion chamber. The high pressure, high temperature gases are then passed to the turbine, where it expands to lower pressure driving the turbine shaft producing the mechanical energy of rotation. The gas from the turbine is exhausted into the atmosphere and is not used any more. Thus the working fluid is replaced in every cycle.



Closed Cycle Gas Turbine

Fig. 2.7

2.12 Difference between Closed and Open cycle Gas Turbines

Closed Cycle	Open Cycle
1. Working substance is continuously re-circulated.	1. Working substance is continuously replaced in every cycle.
2. Exhaust gases from the turbine are fed back into the cycle.	2. Exhaust gases from the turbine exit to the atmosphere.
3. Any fluid may be used as the working substance.	3. The working substance comprises of the mixture of air and products of combustion of the fuel.
4. Since the heat is added externally to the working substance, any type and grade of fuel may be used.	4. Since the products of combustion of fuel and air expand in the turbine only high grade fuels have to be used.
5. There is no loss of the working substance.	5. In every cycle, fresh air is drawn *in every cycle.*
6. There is only heat and work transfer takes place between the system and surrounding.	6. There is mass transfer taking place in addition to heat and work transfer between the system and surrounding.
7. Large amounts of cooling water are required in the cooler.	7. No cooling water is required as the exhaust gases are not cooled.

2.13 Water Turbines

Hydraulic or water turbines are the machines which convert the kinetic and potential energies possessed by water into mechanical rotary motion or power. In other words, water turbines are the prime movers which when coupled to an electric generator produces electric power. Hydro-electric power can be developed whenever continuously flowing high pressure water is available. By constructing dams across flowing rivers, artificial reservoirs are created. Water is carried from these reservoirs to the turbine stations through large pipes, called *penstocks,* and in the turbines its hydraulic energy is converted into mechanical energy which in turn is converted into electrical energy.

2.14 Classification of Water Turbines

Water turbines are classified according to various criteria, of which the classification based on the type of hydraulic action, which converts the hydraulic energy into mechanical energy, is the major method of classification. According to this, the water turbines are classified as :*(i) Impulse Turbine* and *(ii) Reaction Turbine.* Examples of the impulse turbines are *Pelton wheel, Girad Turbine, Banki Turbine* and *Jonval Turbine.* The examples of the reaction turbines are, *Francis Turbine, Kaplan Turbine, Propeller Turbine,* and *Thompson Turbine.*

2.15 Impulse Water Turbine

In an impulse water turbine the whole of the pressure energy of the water is converted into the kinetic energy in one or more number of nozzles *before it is passed on to the turbine wheel*. The water comes out of the nozzle in the form of a jet at very high velocities. This high velocity jet is made to strike a series of curved blades mounted on the periphery of a wheel keyed to the turbine shaft. The impulsive force of the jet exerted on the series of curved blades sets up the wheel in rotation in the direction in which the jet is impinging. The water as it flows over the blades will be at atmospheric pressure. Since the whole of the pressure energy of the water is converted into the kinetic energy before it is passed on to the moving blades, an impulse turbine requires *high head* and *low discharge* at the inlet of the turbine.

2.16 Reaction Water Turbine

A reaction turbine requires low head with high rate or flow. The water supplied to the reaction turbine posses both pressure as well as kinetic energies. All the pressure energy of the water is not completely converted into kinetic energy as in the case of the impulse turbine. First, the water passes to the guide blades which guide or deflect the water to enter the blades, called *moving blades*. mounted on the turbine wheel, without shock. The water from the guide blades are deflected on to the moving blades where its part of the pressure energy is converted into the kinetic energy which will be absorbed by the turbine wheel. The water leaving the moving blades will be at a low pressure. Thus, there is a difference in pressure between the entrance and the exit of the moving blades. This difference in pressure, called *reaction pressure,* acts on the moving blades of the turbine wheel and sets up the turbine wheel into rotation in the opposite direction.

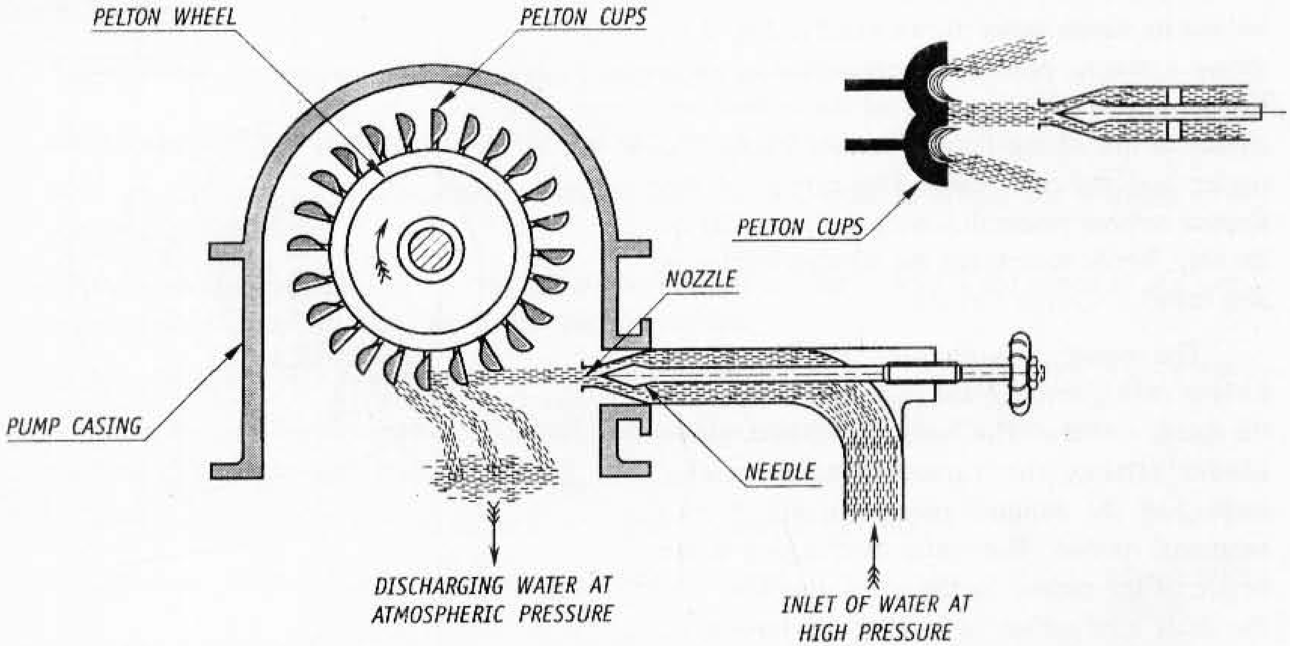
2.17 Difference between Impulse and Reaction Water Turbines

Following are the differences between the impulse and the reaction water turbines.

1. In the impulse water turbine, the whole of the pressure of energy of the water is converted into kinetic energy before it is passed onto the turbine wheel, whereas in a reaction water turbine the water flows with both pressure and kinetic energies over the moving blades where its part of the pressure energy is converted into the kinetic energy.
2. In the impulse water turbine, the pressure of the water will be atmospheric as it flows over the moving blades, whereas in a reaction water turbine, the pressure of the water continuously decreases as it flows over the moving blades.
3. In the impulse water turbine, the *impulsive force* of the jet sets up the rotation of the turbine wheel, whereas in a reaction turbine, the *reaction pressure* sets up the rotation of the turbine wheel.
4. In the impulse water turbine, the water may be admitted over a portion of the circumference, whereas in a reaction turbine, the water must be admitted over the whole of the circumference of the wheel.
5. In an impulse turbine, the water discharges directly from the turbine wheel to the tail race, where as in a reaction water turbine, the water discharges from the turbine into a draft tube from which it discharges finally into the tail race.

2.18 Pelton Wheel

The *pelton wheel* is the most commonly used type of *impulse turbine*. It works under a high head and requires small quantity of water. *Fig. 2.8* shows a schematic sketch of a Pelton Wheel. The water from a high head source is supplied to the *nozzle* provided with a *needle,* which controls the quantity of water flowing out of the nozzle. The pressure energy of water is converted into velocity energy as it flows through the nozzle. The jet of water issuing out of the nozzle at high velocity impinges on the curved blades known as *pelton cups,* at the centre as shown in the adjoining figure. The impulsive force of the jet striking on the Pelton cups sets up the pelton wheel to rotate in the direction of the impinging jet. Thus the pressure energy of the water is converted into mechanical energy. The pressure inside the casing of the turbine will be at atmospheric pressure.

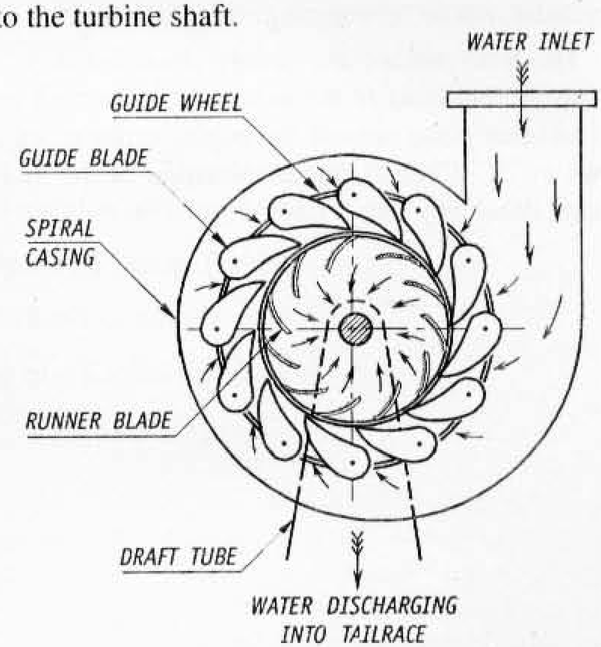


Pelton Wheel
Fig. 2.8

2.19 Francis Turbine

The *Francis turbine* is a medium head reaction turbine in which water flows radially inwards. *Fig. 2.9* shows a simple schematic representation of the Francis turbine. It consists of a *spiral casing* enclosing a number of stationary *guide blades* fixed all round the circumference of an inner ring of *moving vanes* forming the *runner* which is keyed to the turbine shaft.

Water at high pressure enters through the inlet in the casing and flows radially inwards to the outer periphery of the runner through the guide blades. From the outer periphery of the runner the water flows inwards through the moving vanes and discharges at the centre of the runner at lower pressure. During its flow over the moving blades it imparts kinetic energy to the runner to set it into rotational motion. To enable the discharge of water at lower pressure, a diverging conical tube called *draft tube* is fitted at the centre of the runner. The other end of the draft tube is immersed in the discharging side of the water known as *tail race*.

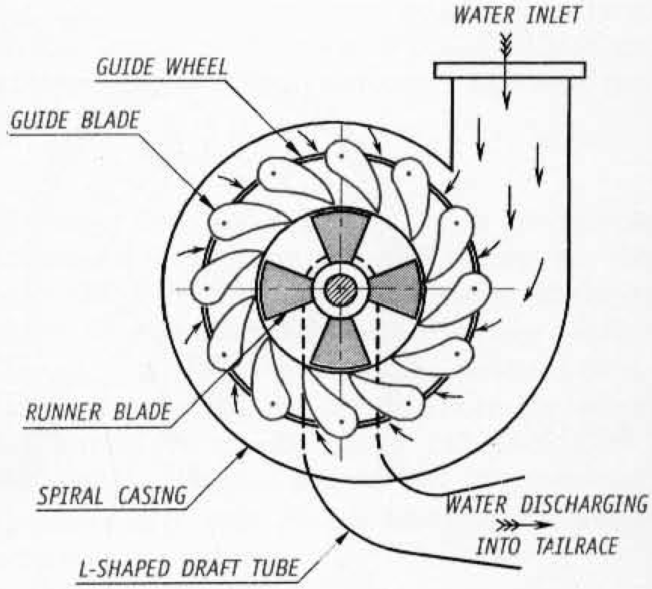


Front view of Francis Turbine
Fig.2.9

2.20 Kaplan Turbine

The *Kaplan turbine* is a low head reaction turbine in which water flows axially. *Fig. 2.10* shows a simple schematic representation of a Kaplan turbine. All the parts of the turbine are similar to that of the Francis turbine except the runner and the draft tube. The runner of the Kaplan turbine resembles with the propeller of the ship, hence sometimes the Kaplan turbine is also called *Propeller turbine.*

The water at high pressure enters the turbine casing through the inlet and flows over the guide blades. The water from the guide blades strikes the runner blades axially imparting the kinetic energy to set it into rotational motion. The water discharging at the centre of the runner in the axial direction into the draft tube which is in L-shape having its discharging end immersed into the tail race.



Top view of Kaplan Turbine
Fig. 2.10

2.21 Heat Engine

A *heat engine* is a prime mover, which derives the heat energy from the combustion of fuels or any other source and converts this energy into mechanical work. In the heat engines, the mechanical work produced is a *linear work* which in turn is converted into *rotational work* by the elements such as cylinder, piston, connecting rod, crank, etc.

The heat engines are mainly classified into : (1) External combustion engines and (2) Internal combustion engines. In the external combustion engines known as *E.C. Engines,* the combustion of the fuel takes place *outside the engine cylinder,* ex : steam engine. In the internal combustion engines, known as *I.C. Engines,* the combustion of the fuel takes place *inside the engine cylinder,* ex : petrol engines, diesel engines.

EXERCISES 2

Steam Turbines

1. What are the advantages of steam turbines over other prime movers ? *(VTU, August 2000)*
2. Sketch and explain the principle of working of a steam turbine.
3. How are the steam turbines classified and differentiated ? Explain briefly the working of any one type of turbine.
4. What is the criterion used in the classification of steam turbine ? Why is the speed of the simple impulse turbine higher than that of the reaction turbine.
5. Explain the principle of working of impulse and reaction turbines. *(VTU, March 1999)*
6. Point out the differences between impulse and reaction steam turbines. Explain with a sketch the working of a single stage impulse turbine.
7. How an actual reaction turbine differ from a purely reaction turbine ?
8. Differentiate between reaction and impulse steam turbines. *(VTU, March 2001)*

Gas Turbines

9. Explain the working principle of a gas turbine working on closed cycle.
10. With a neat sketch the working principle of a gas turbine working on open cycle.
11. Differentiate between open and closed cycle gas turbines.

Water Turbines

12. What is the principle of operation of water turbine ?
13. How are water turbines are classified ?
14. Explain the principle of impulse and reaction water turbine ?
15. What are the differences between impulse and reaction water turbines ?
16. With a neat sketch explain the working principle of a Pelton Turbine.
17. Explain briefly with a sketch the working of Francis turbine.
18. With a schematic diagram explain the working of a Kaplan turbine.

CHAPTER 3

I.C. ENGINES

3.1 I.C. Engines

An internal combustion engine more popularly known as I.C. Engine, is a heat engine which converts the heat energy released by the combustion of the fuel taking place inside the engine cylinder into mechanical work. Its versatile advantages such as high efficiency, light weight, compactness, easy starting, adaptability, suitability for mobile applications, comparatively lower initial cost has made its use as a prime mover universal.

3.2 Classification of I.C. Engines

I.C. Engines are classified according to :

(i) Nature of Thermodynamic Cycle as :

1. Otto cycle engine. 2. Diesel cycle engine. 3. Dual combustion cycle engine.

(ii) Type of the Fuel used as :

1. Petrol engine. 2. Diesel engine. 3. Gas engine. 4. Bi-fuel Engine.

(iii) Number of Strokes as :

1. Four stroke engine. 2. Two stroke engine.

(iv) Method of Ignition as :

1. Spark ignition engine, known as S.I. Engine.
2. Compression ignition engine, known as C.I. engine.

(v) Number of Cylinders as :

1. Single cylinder engine. 2. Multicylinder engine.

(vi) Position of the Cylinder as :

1. Horizontal engine 2. Vertical engine. 3. Vee engine.
4. Bi-fuel Engine. 5. Opposed cylinder engine. 6. Radial engine.

(vii) Method of Cooling as :

1. Air cooled engine. 2. Water cooled engine.

3.3 Parts of I.C. Engine

The various important parts of an I.C. Engine are shown in *Fig. 3.1*.

1. Cylinder

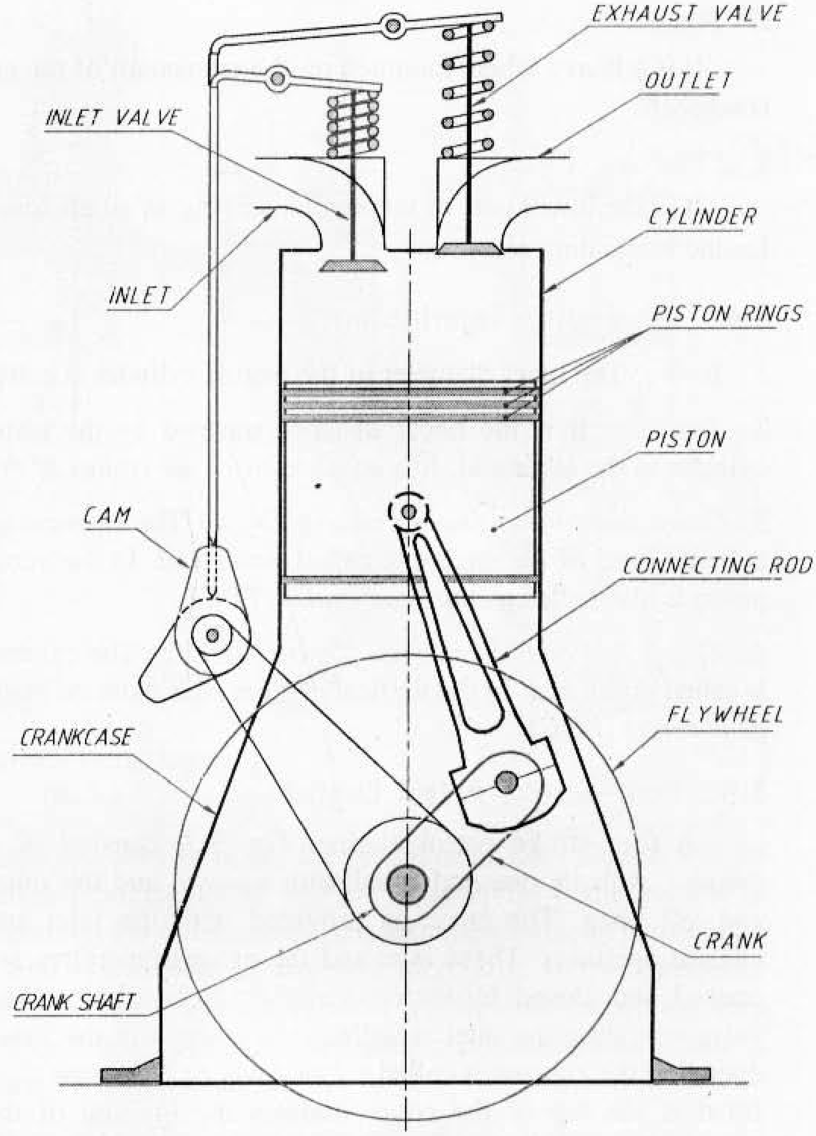
The heart of the engine is the cylinder in which the fuel is burnt and the power is developed. The inside diameter is called *bore*. To prevent the wearing of the cylinder block, a *sleeve* will be fitted tightly in the cylinder. The piston reciprocates inside the cylinder.

2. Piston

The piston is a close fitting hollow-cylindrical plunger moving to-and-fro in the cylinder. The power developed by the combustion of the fuel is transmitted by the piston to the crank -shaft through the connecting rod.

3. Piston Rings

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



Parts of I.C.Engine
Fig. 3.1

4. Connecting Rod

It is a link that connects the piston and the crankshaft by means of pin joints. It converts the rectilinear motion of the piston into rotary motion of the crankshaft.

5. Crank and Crankshaft

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

6. Valves

The *valves* are the devices which controls the flow of the intake and the exhaust gases to and from the engine cylinder. They are also called poppet valves. These valves are operated by means of cams driven by the crankshaft through a timing gear or chain.

7. Flywheel

It is a heavy wheel mounted on the crankshaft of the engine to maintain uniform rotation of the crankshaft.

8. Crankcase

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

3.4 I.C. Engine Terminology

1. Bore : The inner diameter of the engine cylinder is called a *bore.*

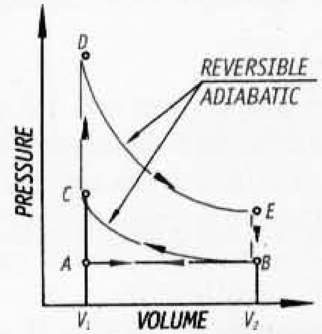
2. Stroke : It is the linear distance traveled by the piston when it moves from one end of the cylinder to the other end. It is equal to *twice the radius of the crank.*

3. Cover End or Top Dead Centre (TDC) : The extreme position of the piston near to the cover or cylinder head of the engine is called *cover end.* In the vertical engines, this extreme position of the piston is also called as *top dead centre (TDC),*

4. Crank End or Bottom Dead Centre (BDC) : The extreme position of the piston near to the crank is called *crank end.* In the vertical engines, this extreme position of the piston is also called as *bottom dead centre (BDC).*

3.5 Four–Stroke Petrol Engine

A four–stroke petrol engine, *Fig. 3.3,* consists of a *cylinder* with its one end fitted with a *cover* and the other end left open. The cover is provided with the inlet and exhaust apertures. These inlet and the exhaust apertures are opened and closed by *mechanically operated valves.* The valve operating the inlet is called *inlet valve* and the valve operating the exhaust is called *exhaust valve*. The *spark plug* fitted at the top of the cover initiates the ignition of the petrol. A freely moving piston reciprocates inside the cylinder. The *connecting rod* and the *crank* convert the reciprocating motion of the piston into the rotary motion.



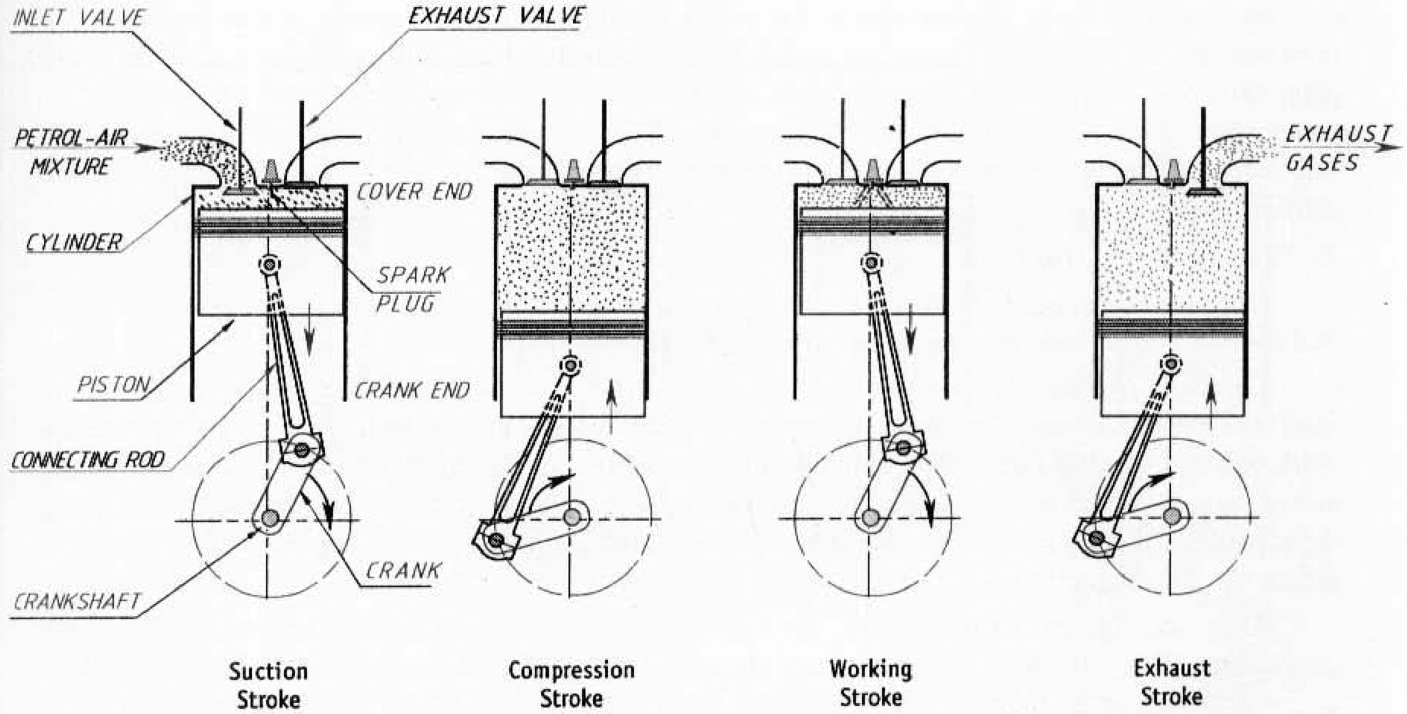
Theoretical Otto Cycle
Fig. 3.2

The petrol engines work on the principle of theoretical *Otto Cycle*, also known as *constant volume cycle,* shown in *Fig. 3.2.* The piston performs four strokes to complete *one working cycle.* The four different strokes are; *(i) suction stroke, (ii) compression stroke, (iii) working or power stroke* and *(iv) exhaust stroke.*

Fig. 3.3 shows the construction and working of a four stroke petrol engine.

Suction Stroke

During this stroke, the *inlet* is *open and the exhaust is closed*, the piston moves from the *cover end to the crank end* and during this travel of the piston the crankshaft revolves by *half rotation.* The energy required to perform this stroke is supplied by *'cranking'* only during the first cycle at the time of starting, and while running, the flywheel supplies the mechanical energy which it had absorbed by it during the working stroke of the previous cycle.



Four Stroke Petrol Engine
Fig. 3.3

At the beginning of this stroke, since the inlet is open, the pressure in the cylinder will be atmospheric. As the piston gradually moves from the *cover end to the crank end*, the volume in the cylinder increases, while simultaneously the pressure decreases. This sets up a pressure differential between the atmosphere and the inside of the cylinder. Due to this pressure differential the petrol-and-air mixture will be drawn into the cylinder through the carburetor. This drawal of the petrol-and-air mixture will be taking place at atmospheric pressure. This stroke is represented by the *horizontal line AB* on the PV diagram shown in *Fig. 3.2.*

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

Compression Stroke

During this stroke, *both the inlet and the exhaust are closed,* the piston moves from the *crank end to the cover end* and the crankshaft revolves further by *half rotation.* The energy required to perform this stroke is supplied by *'cranking '* only during the first cycle at the time of starting, and while the engine is running the flywheel supplies the mechanical energy stored by it during the working stroke of the previous cycle.

As this stroke is being performed, the petrol-and-air mixture contained in the cylinder will be compressed. The ratio of compression in petrol engines ranges from 1:7 to 1:11. The process of compression is theoretically a *reversible adiabatic* or *isentropic,* represented by the *curve BC* and the PV diagram shown in *Fig. 3.2.*

At or near the end of this stroke, the petrol-and-air mixture is ignited by the electric spark given out by the spark plug. Since the ignition of the petrol is by the spark given out by the spark plug, this type of engine is also called as *spark ignition engine* abbreviated as *S.I. engine*. The combustion of the petrol releases the hot gases which will increase the pressure at *constant volume*. This constant volume combustion process is theoretically represented by the *vertical line CD* on the PV diagram shown in *Fig. 3.2.*

Working or Power Stroke

During this stroke, *both the inlet and the exhaust are closed,* the piston moves from the *cover end to the crank end* and the crankshaft revolves by *half rotation.*

The high pressure burnt gases force the piston to perform this stroke, called *expansion* or *working* or *power stroke.* The linear motion of the piston causes the piston to produce the mechanical work or power during this stroke which will be transmitted to the crankshaft by the connecting rod and the crank. As the piston moves, the pressure of the hot gases gradually decreases. Theoretically, the expansion of the burnt gases is considered as *reversible adiabatic process* represented by the *curve DE* on the PV diagram shown in *Fig. 3.2.*

At or near the end of this stroke, the *exhaust opens* which will release the burnt gases to the atmosphere. This will suddenly bring down the cylinder to that of atmosphere. This drop in pressure at *constant volume* is theoretically represented by the *vertical line EB* on the PV diagram shown in *Fig. 3.2.*

Exhaust Stroke

During this stroke, the *exhaust is open and the inlet is closed,* the piston moves from the *crank end to the cover end* and the crankshaft revolves by *half rotation.* The energy required to perform this stroke is supplied by the flywheel from the energy absorbed by it during the previous stroke.

As the piston performs this stroke, the burnt gases will be expelled out of the cylinder at atmospheric pressure. This process is represented by the *horizontal line BA* on the PV diagram shown in *Fig. 3.2.*

Summary

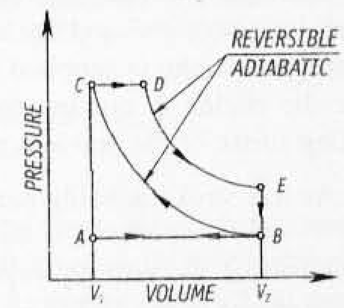
Since this engine requires *four strokes* to complete one working cycle, it is called a *four–stroke engine.* The crankshaft makes *two revolutions to complete one cycle.* The power is developed *in every alternate revolutions of the crankshaft.*

Since the four stroke petrol engines have higher load carrying capacities than two stroke petrol engines, they are generally used in passenger cars and also in some high power-high speed motor cycles.

3.6 Four Stroke Diesel Engine

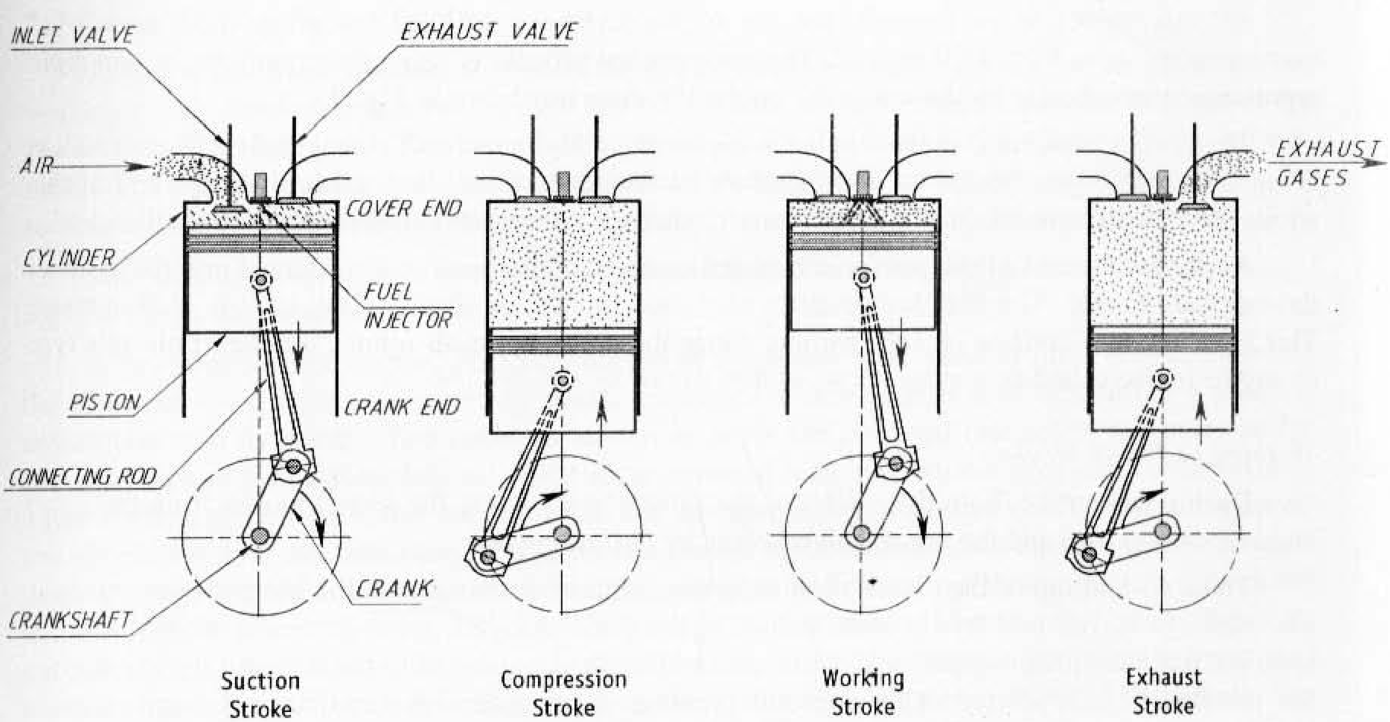
The basic construction of a four stroke diesel engine is same as that of four stroke *petrol* engine, except instead of spark plug, a fuel *injector* is mounted in its place as shown in *Fig. 3.5.* A fuel pump supplies the fuel oil to the injector at higher pressure.

The diesel engines work on the principle of theoretical *Diesel Cycle,* also known as *constant pressure heat addition cycle* shown in *Fig. 3.4.* The four stroke diesel engine cycle also comprises of suction, compression, working and exhaust strokes. *Fig. 3.5* shows the construction and working of a four stroke diesel engine.



Theoretical Diesel Cycle

Fig. 3.4



Four-Stroke Diesel Engine

Fig. 3.5

Suction Stroke

During this stroke, the *inlet is open and the exhaust is closed*, the piston moves from the *cover end to the crank end* and crankshaft revolves by *half rotation*. The energy required to perform this stroke is supplied by *'cranking '* only during the first cycle at the time of starting, and while engine is running, the flywheel supplies the mechanical energy which it had absorbed during the working stroke of the previous cycle.

At the beginning of this stroke, since the inlet is open, the pressure in the cylinder will be atmospheric. As the piston gradually moves from the cover end to the crank end, the volume in the cylinder increases while the pressure decreases. This sets up a pressure differential between the atmosphere and the inside of the cylinder. Due to this pressure differential only the atmospheric air will be drawn into the cylinder through the *air filter* and the inlet. This drawal of air will be taking place at atmosphere pressure. This stroke is represented by the *horizontal line AB* on the PV diagram shown in *Fig. 3.4*.

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

Compression Stroke

During this stroke, both the *inlet and the exhaust are closed*, the piston moves from the *crank end to the cover end* and the crankshaft revolves by *half rotation*. The energy required to perform this stroke is supplied by *'cranking '* only during the first cycle at the time of starting, and while running the flywheel supplies the mechanical energy absorbed by it during the working stroke of the previous cycle.

As this stroke is performed, the air in the cylinder will be compressed. The ratio of compression ranges from 1:20 to 1:22. The compression process is *reversible adiabatic* or *isentropic* represented theoretically by the *curve BC* on the PV diagram shown in *Fig. 3.4.*

The *compression ratio* in this engine is *higher* than the four–stroke petrol engine. The air as it is being compressed gets heated up and therefore its temperature will be increased. At the end of this stroke the air will have attained a temperature greater than the ignition temperature of the diesel oil.

At or near the end of this stroke, a metered quantity of the diesel oil is sprayed into the cylinder through the injector. The high temperature of the air ignites the diesel oil as soon as it is sprayed. This is called *auto-ignition or self-ignition.* Since the compressed air ignites the diesel oil, this type of engine is also called as *compression ignition engine or C.I. Engine.*

Working or Power Stroke

During this stroke, both the *inlet and the exhaust are closed,* the piston moves from the *cover end to the crank end* and the crankshaft revolves by *half rotation.*

The auto-ignition of the diesel oil initiates the combustion as a result, the hot gases are released. The burnt gases released by the combustion of the diesel oil that is continuously injected into the cylinder, force the piston to perform earlier part of this stroke at *constant pressure* till the injection of the diesel oil is completed. This constant pressure expansion with simultaneous combustion is represented theoretically by the *horizontal line CD* on the PV diagram shown in *Fig. 3.4.* The piston is forced further during the remaining part of this stroke only due to the expansion of the burnt gases. The linear motion of the piston causes the piston to produce the mechanical work or power during this stroke which will be transmitted to the crankshaft through the connecting rod and the crank. As the piston moves, the pressure of the hot gases gradually decreases. Theoretically the expansion of the burnt gases is considered as *reversible adiabatic process* represented by the *curve DE* on the PV diagram shown in *Fig. 3.4.*

Exhaust Stroke

During this stroke, the *exhaust is open and the inlet is closed,* the piston moves from the *crank end* to the *cover end* and the crankshaft revolves by *half rotation.* The energy required to perform this stroke is supplied by the flywheel out of the power produced during the previous stroke.

As the piston performs this stroke, the exhaust gases will be expelled out of the cylinder at atmospheric pressure. This process is represented by the *horizontal line BA* on the PV diagram shown in *Fig. 3.4.*

Summary

Since this engine requires *four strokes* to complete *one working cycle,* it is called *four stroke engine.* The crankshaft makes *two revolutions to complete one cycle.* The power is developed *in every alternate revolution of the crankshaft.*

Since four–stroke diesel engines produce higher power than the four–stroke petrol engines, they are generally used in trucks, tractors, jeeps, etc.

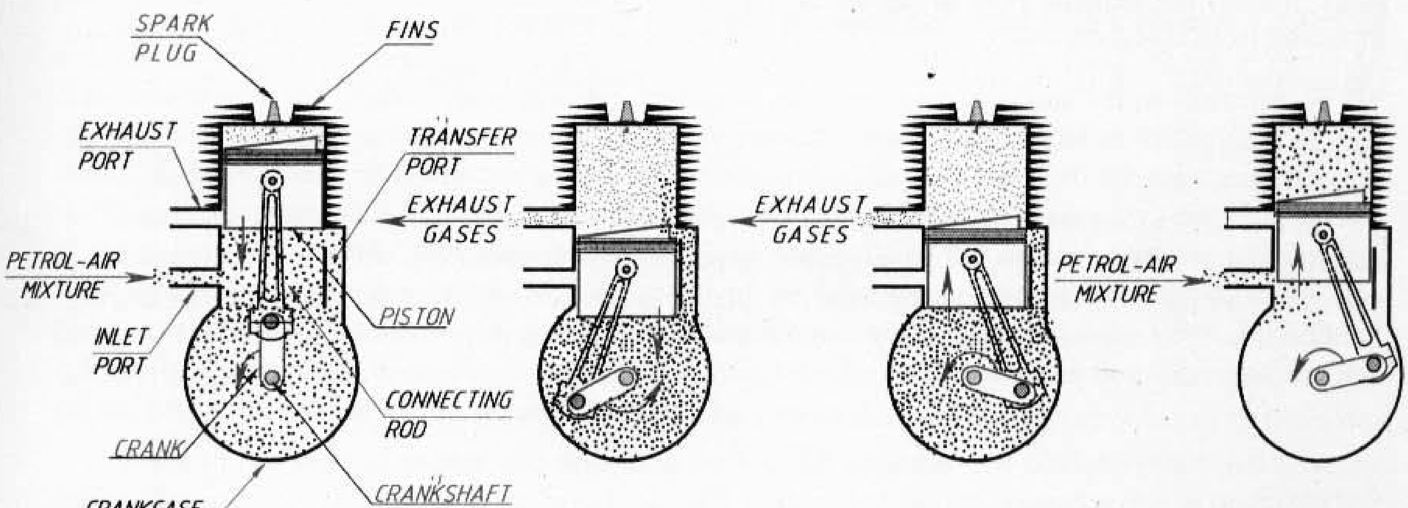
3.7 Two Stroke Petrol Engine

As the name itself implies, a two–stroke engine performs only two strokes to complete one working cycle. Obviously the two strokes out of the four strokes required for the working of the cycle have to be eliminated. The two strokes that are eliminated are, suction stroke and the exhaust stroke. The suction and the exhaust are not performed exclusively in separate strokes, however, the suction and exhaust takes place while the working and the compression strokes are in progress.

Two stroke petrol engines also work on the principle of working of the theoretical *Otto Cycle*. *Fig. 3.6* shows the construction and the working of a two stroke petrol engine.

A two stroke petrol engine, *Fig. 3.6*, consists of a *cylinder* with one end fitted with a cover and the other end fitted with a *hermetically sealed crankcase* which enables it to function as a pump in conjunction with the piston. Two openings known as *ports* are provided one below the other on the *circumference of the cylinder* instead of the valve operated inlet and exhaust provided in the cover of a four stroke engine. The lower one known as the *admission port* or *the inlet port*, admits the petrol-and-air mixture into the crankcase. The upper one known as the *exhaust port* through which the spent gases are expelled out of the cylinder. A *transfer port* provided diametrically opposite to the exhaust port but slightly at a lower level, serves as the passage for the transfer of petrol-and-air mixture from the crankcase to the cylinder. The piston as it reciprocates inside the cylinder periodically covers and uncovers these ports. The *spark plug* fitted on the cover initiates the ignition of the petrol. The *connecting rod* and the *crank* convert the reciprocating motion of the piston into the rotary motion.

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



A
Beginning of the First Stroke

B
Piston uncovers Transfer Port during the First Stroke

C
Transfer Port Covered

D
Compression Commenced

FIRST STROKE

SECOND STROKE

Two Stroke Petrol Engine
Fig. 3.6

The drawing of Petrol-and-Air Mixture

When the piston ascends, as shown in *Fig. 3.6D* a partial vacuum is created in the crankcase until its lower edge uncovers the inlet port completely as shown in *Fig. 3.6A*. The pressure differential setup between the atmosphere and the crankcase will draw the petrol-and-air mixture through the carburetor (not shown in figure) fitted to inlet port, into the crankcase as shown in *Fig. 3.6A*. The drawal of petrol-and-air mixture will be continued till the inlet port is covered by the piston during its next descent stroke. After the inlet port is covered by the piston as shown in *Fig. 3.6B*, its further descent will compress the petrol-and-air mixture in the crankcase and as soon as the top edge of the piston uncovers the transfer port as shown in *Fig. 3.6B*, the compressed petrol-and-air mixture flows from the crankcase through the transfer port into the cylinder. This will continue till the piston covers the transfer port during its next ascending stroke as shown in *Fig.3.6C*.

First Stroke

At the beginning of the first stroke the piston is at the *cover end* as shown in *Fig. 3.6A*. It moves from *the cover end to crank end*. The spark plug ignites the compressed petrol-and-air mixture. The combustion of the petrol will release the hot gases which increases the pressure in the cylinder. The high pressure combustion gases force the piston downwards. The piston performs the power stroke till it uncovers the exhaust port as shown in *Fig. 3.6B*. During the earlier part of this stroke which is performed by the pressure of the combustion gases exerted on it, the power is produced. The combustion gases which are still at a pressure slightly higher than the atmospheric pressure escape through the exhaust port. As soon as the top edge of the piston uncovers the transfer port as shown in *Fig. 3.6B*, the fresh petrol-and-air mixture flows from the crankcase into the cylinder. The fresh petrol-and-air mixture which enters the cylinder drives out the spent exhaust gases through the exhaust port as shown in *Fig. 3.6.B* This driving out of exhaust gases by the incoming fresh charge is called *scavenging*. This will continue till the piston covers both the exhaust and transfer ports during the next ascending stroke. The crankshaft rotates by *half rotation*.

Second Stroke

In this stroke the piston ascends and moves from *the crank end to cover end*. When it covers the transfer port as shown in *Fig.3.6C*, the supply of petrol-and-air mixture is cut off and then when it moves further up it covers the exhaust port completely as shown in *Fig. 3.6D* stops the scavenging. Further ascend of the piston will compress the petrol-and-air mixture in the cylinder. The ratio of compression ranges from 1:7 to 1:11. After the piston reaches the cover end the first stroke as explained earlier repeats again. The crankshaft rotates by *half rotation*.

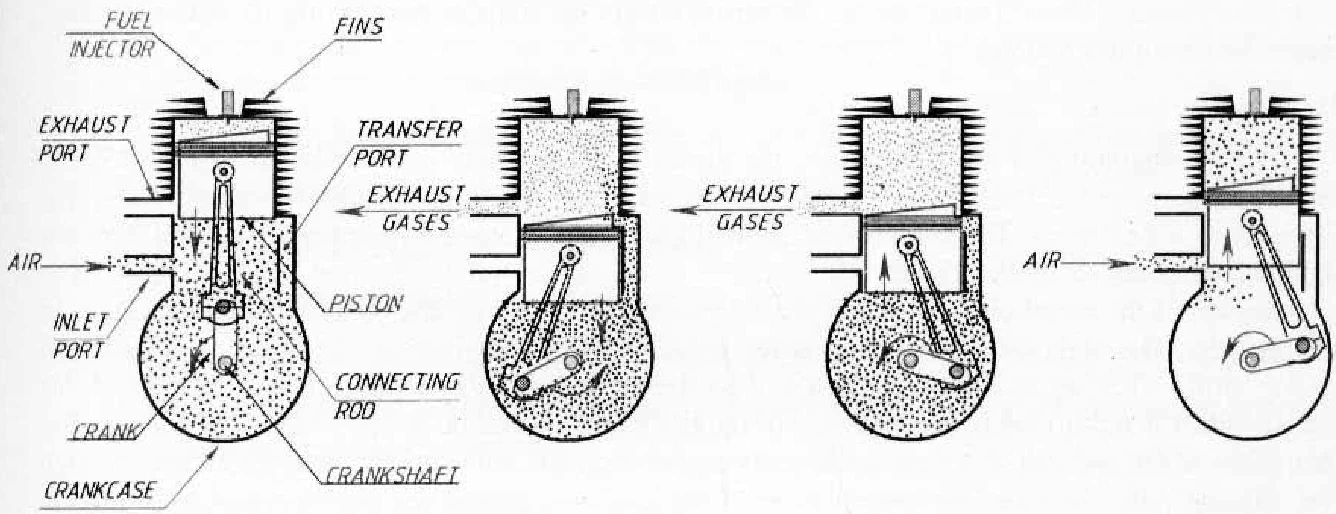
Summary

Since this engine requires only *two strokes* to complete *one cycle*, it is called a *two stroke engine*. The crankshaft makes only *one revolution to complete the cycle. The power is developed in every revolution of the crankshaft.*

The two–stroke petrol engines are generally used in mopeds, scooters, motor-cycles because they run at high speeds with moderate power outputs.

3.8 Two–Stroke Diesel Engine

The two stroke diesel engines also work on the same principle of *Diesel cycle. Fig. 3.7* shows the construction and working of a two stroke diesel engine.



A Beginning of the First Stroke

B Piston uncovers Transfer Port during First Stroke

C Transfer Port Covered

D Second Stroke

FIRST STROKE SECOND STROKE

Two Stroke Diesel Engine
Fig. 3.7

A two–stroke diesel engine consists of a *cylinder* with one end fitted with a cover and the other end fitted with a *hermetically sealed crankcase,* which enables it to function as a pump in conjunction with the piston. Two openings known as *ports* are provided one below the other on the circumference of the cylinder instead of the valve operated inlet and exhaust as in the case of four stroke diesel engine. The lower one known as the *admission port* or *inlet port,* admits the air into the crankcase. The upper one known as the *exhaust port* through which the spent gases are expelled out of the cylinder. A *transfer port* provided diametrically opposite to the exhaust port, but slightly at a lower level serves as the passage for the transfer of air from the crankcase in to the cylinder. The piston as it reciprocates inside the cylinder periodically covers and uncovers these ports. An *injector* is fitted in the cover to inject the diesel into the cylinder. The *connecting rod* and the *crank* convert the reciprocating motion of the piston into the rotary motion.

Since in this type of engine, the drawal of air into the cylinder will not take place in a separate stroke, the method of drawal of air must be well understood before knowing the actual working principle of the two–stroke diesel engine.

Drawing of Air

When the piston ascends, as shown in *Fig. 3.7D* a partial vacuum is created in the crankcase until its lower edge uncovers the inlet port completely as shown in *Fig. 3.7A.* The pressure differential setup between the atmosphere and the crankcase will draw only the air through the inlet port. The drawal of air will be continued till the inlet port is covered by the piston during its next descent stroke. After the inlet port is covered by the piston as shown in *Fig. 3.7B*, its further descent will compress the air in the crankcase and as soon as the top edge of the piston uncovers the transfer port as shown in *Fig. 3.7B*, the compressed air flows from the crankcase through the transfer port into the cylinder. This will continue till the piston covers the transfer port during its next ascending stroke as shown in *Fig.3.7C*.

First Stroke

At the beginning of the first stroke, the piston is at the *cover end* as shown in *Fig. 3.7A*. It moves from *cover end to crank end*. The injector injects a metered quantity of the diesel oil into the cylinder as a fine spray. The compressed air will have been attained a temperature greater than the ignition temperature of the diesel oil. As soon as the diesel oil is injected it auto ignites. The combustion of the diesel oil will release the hot gases which increase the pressure of the hot gases in the cylinder. The high pressure burning gases force the piston downwards. The piston performs the power stroke till it uncovers the exhaust port as shown in *Fig. 3.7B*. During the earlier part of this stroke which is performed by the pressure of the hot gases exerted on it, the power is produced. The hot gases which are still at a pressure slightly higher than the atmospheric pressure escape through the exhaust port. As soon as the top edge of the piston uncovers the transfer port as shown in *Fig.3.7B*, the air flows from the crankcase into the cylinder. The fresh air entering the cylinder through the transfer port drives out the spent exhaust gases as shown in *Fig. 3.7B*. This driving out of the exhaust gases is called *scavenging*. This will continue till the piston covers both the exhaust and the transfer ports during the next ascending stroke. The crankshaft rotates by *half rotation*

Second Stroke

In this stroke the piston ascends and moves from the *crank end to the cover end*. When it covers the transfer port, the air supply from the crankcase is cutoff and when it moves further up it covers the exhaust port completely as shown in *Fig. 3.7D* it stops the scavenging. Further ascend of the piston will compress the air in the cylinder as shown in *Fig. 3.7D*. The ratio of compression ranges from 1:20 to 1:22. After the piston reaches the cover end, the first stroke as explained earlier is repeated again. The crankshaft rotates by *half rotation*.

Summary

Since this engine requires only *two strokes* to complete *one cycle*, it is called *two stroke engine*. The crankshaft makes only *one revolution* to complete the cycle. The power is developed *every revolution of the crankshaft*.

3.9 Advantages of a Two Stroke Engine over a Four Stroke Engine

The following are the advantages of a two stroke engine over a four stroke engine :

1. A two stroke engine has *twice* the number of power strokes than a four stroke engine at the same speed. Hence theoretically a two stroke engine develops *double the power output* per cubic metre of the swept volume than a four stroke engine running at the same speed.

2. The weight of a two stroke engine is less than the four stroke engine because of the lighter flywheel due to more uniform torque on the crankshaft.

3. The scavenging is more complete in slow-speed two stroke engines, since exhaust gases are not left in the clearance volume as in the four stroke engine.
4. Since there are only two strokes in a cycle, the work required to overcome the friction of the suction and the exhaust strokes is saved.
5. Since there are no mechanical valves and valves gears, the construction of a two stroke engine is simple which reduces its initial cost.
6. A two–stroke engine can be easily reversed by a simple reversing gear mechanism.
7. A two–stroke engine can be easily started than a four stroke engine.
8. A two–stroke engine occupies less space.
9. A lighter foundation will be sufficient for two stroke engines.
10. A two–stroke engine has less maintenance cost since it has less number of moving parts.
11. Since the engine is light in weight and its speed is high, two stroke engines are preferred in motor cycles, scooters, etc.
12. Since there are two strokes per cycle, the frictional losses are less.

3.10 Disadvantages of Two Stroke Engines

The following are some of the disadvantages of a two stroke engine when compared with a four stroke engine :

1. Since the firing takes place in every revolution, the time available for cooling will be less than a four–stroke engine, which results in overheating of the piston and other engine parts.
2. Incomplete scavenging results in mixing of the exhaust gases with the fresh charge which will dilute it, hence lesser power output and hence low thermal efficiency.
3. Since the transfer port is kept open only during a short period, it is likely that less quantity of the charge may be admitted into the cylinder which will reduce the power output.
4. Since both the exhaust and the transfer ports are kept open during the same period, there is a possibility of the escape of the fresh charge through the exhaust port which will also reduce its thermal efficiency.
5. For a given stroke and clearance volume, the effective compression stroke is less in a two-stroke engine than in a four stroke engine.
6. In a crankcase compression type of two–stroke engine, the volume of the charge drawn into the crankcase is reduced due to the reduction in the crankcase volume because of the rotating parts in the crankcase.
7. A fan-scavenged two–stroke engine has less mechanical efficiency since some power is required to run the scavenging fan.
8. A two–stroke engine needs better cooling arrangement because of high operating temperature.

Coninued in page 89

3.11 Comparison between Petrol and Diesel Engines

Sl. No.	Principle	Petrol Engine (S.I. Engine)	Diesel Engine (C.I. Engine)
1.	Theoretical Cycle of Operation	It works on *Otto Cycle* which is also called as *constant volume cycle.*	It works on *Diesel Cycle* which is also called as *constant pressure cycle.*
2.	Fuel used	Petrol.	Diesel.
3.	Admission of the Fuel	During the suction stroke itself the petrol is first admitted in to the carburettor, where it gets mixed with the air and then mixture enters the cylinder.	The diesel oil is pressurised by the fuel pump and then injected into the engine cylinder by the fuel injector at the end of compression stroke.
4.	Charge drawn during the Suction Stroke	Air and petrol mixture is drawn during the suction stroke.	Only air is drawn during the suction stroke.
5.	Compression Ratio	Low compression ratio ranging from 7 : 1 to 12 : 1	High compression ratio ranging from 16 : 1 to 20 : 1
6.	Ignition of the Fuel	The compressed air and petrol is ignited by the *spark plug.* This type of ignition is called *spark ignition.*	The ignition of the diesel is accomplished by the compressed air which will have been heated due to high compression, to the temperatures higher than the ignition temperature of the diesel. This type of ignition is called *compression ignition* or *auto ignition.*
7.	Governing	The *quantitative* method of governing is employed in petrol engines.	The *qualitative* method of governing is employed in diesel engines.
8.	Engine Speed	High engine speeds of about 3000 rpm.	Low engine speeds ranging from 500 to 1500 rpm.
9.	Power Output Capacity	Because of the low compression ratio the power developed will be less.	Due to high compression ratio the power developed will be more.

Coninued in next page

Sl. No.	Principle	Petrol Engine (S.I. Engine)	Diesel Engine (C.I. Engine)
10.	Thermal Efficiency	The *thermal efficiency* of petrol engines is *lower* due to lower compression ratio.	The *thermal efficiency* of diesel engines is *higher* due to high compression ratio.
11.	Noise and Vibration	Because of operating pressure is less the noise and vibrations are almost nil.	Because of higher operating pressures the noise and vibration are high.
12.	Weight of the Engine	Due to low compression ratio, the maximum pressure and the temperature of firing is less therefore the engine need not be of robust construction, hence the *weight of the engine is less.*	Due to higher compression ratio, and higher maximum pressure and temperature, the engine will have to be strong and sturdy hence the *weight of the engine is more.*
13.	Initial Cost	For the same power output the *initial cost of the engine is less* because it is lighter in construction.	*The initial cost of diesel engines is more* due to costlier fuel injection systems and robust design.
14.	Operating Fuel Cost	The *running* or *operating cost is high* because the petrol is costlier.	The *running* or *operating cost is less* because the diesel is cheaper.
15.	Maintenance Cost	Less.	Slightly higher.
16.	Starting of the Engine	The petrol engines can easily be started even in cold weather.	The diesel engines are difficult to start in cold weather.
17.	Exhaust Gas Pollution	The *exhaust pollution is more* in petrol engines, because the unburnt hydrocarbon and carbon monoxide are significant in the exhaust gases due to the constant air-fuel ratio and quantitative governing employed.	*The exhaust gas pollution is less* because there will be a large amount of excess air which results in a wide range of air-fuel ratios ranging from very lean mixture to very rich mixture. A well maintained diesel engine has very little carbon monoxide and hence less amount of smoke.
18.	Uses	Used in Scooter, Motor Cycle, Cars, etc.	Used in as Trucks, Tractors, Buses, Bulldozers.

3.12 Comparison between Two–Stroke and Four–Stroke I.C. Engines

Sl. No.	Principle	Four–Stroke Engine	Two– Stroke Engine
1.	Number of Strokes per Cycle	Requires *four* seperate strokes of the piston to complete one cycle of operation.	Requires only *two* strokes of the piston to complete one cycle of operation.
2.	Number of Cycles per min	The number of cycles per min is *equal to half* the speed of the engine. Number of Cycles / min $n = \frac{N}{2}$	The number of cycles per minute will be *equal* to the speed of the engine. Number of cycles / min $n = N$
3.	Power	Power is developed in *every alternate revolution* of the crankshaft.	Power is developed in *every revolution* of the crankshaft.
4.	Flywheel	The torque will *not be uniform* because the power is produced in every alternate revolution, hence *heavy flywheel* is required.	The torque will be *more uniform* because the power is produced in every revolution of the crankshaft hence a *lighter* flywheel is required.
5.	Admission of the Charge	The charge is *directly admitted into the engine cylinder* during the suction stroke.	The charge is *first admitted into the crankcase* and then transferred to the engine cylinder.
6.	Exhaust Gases	The exhaust gases are driven out through the outlet by the piston during the exhaust stroke.	The exhaust gases will be expelled out of the cylinder by scavenging operation by the incoming fresh charge.
7.	Valves	The inlet and the exhaust are opened and closed by *mechanical valves.*	The *piston itself opens and closes the inlet, transfer and the exhaust ports.*
8.	Crankcase	Although the crankcase of a four stroke engine is closed, it will *not be hermetically sealed.*	Since the charge is admitted into the crankcase it is *hermetically sealed.*

Coninued in next page

Sl. No.	Principle	Four–Stroke Engine	Two–Stroke Engine
9.	Engine Cooling	The cooling can be made more effective since the combustion takes place in alternate revolution of the crankshaft.	The rate of cooling must be very high since the combustion takes place in every revolution of the crankshaft.
10.	Direction of Rotation of the Crankshaft	The crankshaft *rotates only in one direction.*	The crankshaft can *rotate in either directions.*
11.	Lubricating Oil Consumption	Less.	More.
12.	Fuel Consumption	Since there is no mixing of fresh charge with the exhaust gases, the *fuel consumption is less.*	There will be mixing of the fresh charge with the exhaust gases, hence there is a loss of fresh charge, hence the *fuel consumption is more.*
13.	Mechanical Efficiency	The *mechanical efficiency is low* because of the increased number of strokes and more number of mechanical parts.	The *mechanical efficiency is high* because there are only two strokes per cycle and absence of the mechanical parts such as cams, camshafts, valves, valve gears, etc.
14.	Noise	Since the exhaust takes place gradually during the exhaust stroke, the *noise will be less.*	The opening of the exhaust port releases the exhaust gases suddenly, *and hence noise will be more.*
15.	Uses	Four stroke engines are used in *slow speed high power applications* like, cars, trucks, tractors, jeeps, buses, etc.	Two stroke engines are used for *high speed and low power applications* such as mopeds, scooters, motor cycles, etc.

Coninued from page 85

9. A two–stroke engine consumes more lubricating oil.
10. The exhaust in a two–stroke engine is noisy due to the sudden release of the burnt gases.
11. The lubricating oil consumption is more.
12. Due to the sudden release of the exhaust gases, the noise will be more.

3.13 Specific fuel consumption

Specific fuel consumption (SFC) is defined as the amount of fuel consumed by an engine for one unit of energy that is produced. SFC is used to express the fuel efficiency of an IC engine. It measures the amount of fuel required to provide a given power for a given period. It is expressed in Kg/MJ or kg/kW-hr.

Diesel engines have better SFCs than petrol engines. This is because, the Diesel engines have much higher compression ratios (from 16:1 to 20:1) than petrol engines (from 7:1 to 12:1) and hence can convert more of the heat produced into power.

3.14 Simple Calculations in I.C. Engines

The scope of this book will not permit dealing of all the calculations of I.C engines. However some important simple calculations pertaining to simple problems have been dealt.

1. Indicated Power

It is the power produced inside the cylinder and calculated by finding the actual mean effective pressure. The actual mean effective pressure is found as follows.

Let a = Area of the actual indicator diagram, **Sq.cm**

l = Base width of the indicator diagram, **cm**

s = Spring Value of the spring used in the indicator, **N/m²/cm**

If p_m = Actual Mean Effective Pressure, **N/m²**

$$\boxed{p_m = \frac{sa}{l} \text{ N/m}^2}$$

The indicated power of the four–stroke and two stroke engines are found as follows :

(a) Indicated Power of a Four–Stroke Engine

Let p_m = Mean Effective Pressure, **N/m²**

L = Length of Stroke, **m**

A = Area of Cross section of the Cylinder, **sq m**

N = RPM of the Crankshaft.

n = Number of cycles per minute.

$$\text{Work produced by the piston / Stroke or / Cycle} = \begin{bmatrix}\text{Mean Force acting}\\ \text{on the Piston}\end{bmatrix} \times \begin{bmatrix}\text{Piston displacement}\\ \text{in One Stroke}\end{bmatrix}$$

$$= p_m \times A \times L \quad \text{Nm}$$

$$= p_m L A \quad \text{Nm}$$

$$\text{Work produced by the Piston / min} = \begin{bmatrix}\text{Work produced by}\\ \text{the Piston/Cycle}\end{bmatrix} \times \begin{bmatrix}\text{Number of}\\ \text{Cycles / min}\end{bmatrix}$$

$$= p_m L A \times n$$

$$= p_m L A n \quad \text{Nm/min}$$

In four stroke I.C. engines, one cycle will be completed in *two revolutions* of the crank shaft. Therefore the work will be produced in every *alternate revolutions of* the crankshaft. Thus the *number of cycles per minute will be equal to half the number of revolutions per minute.*

ie., $$n = \frac{N}{2}$$

$$\text{Work produced by the Piston/min} = p_m L A \times \frac{N}{2} \quad \text{Nm/min}$$

ie., $$\text{Indicated Power} = \frac{p_m L A N}{60 \times 2} \quad \text{Nm/sec or Joule/sec}$$

$$= \frac{p_m L A N}{60 \times 2} \quad \text{W}$$

$$= \frac{p_m L A N}{60 \times 2 \times 1000} \quad \text{kW}$$

When p_m is expressed in N/m^2, the indicated power of a Four stroke engine is given by,

$$\boxed{\text{Indicated Power} = \frac{p_m L A N}{60 \times 2 \times 1000} \quad \text{kW}}$$

When p_m is expressed in bar, the indicated power of a Four stroke engine is given by,

$$\boxed{\text{Indicated Power} = \frac{100\, p_m L A N}{60 \times 2} \quad \text{kW}}$$

(b) Vacuum Grippers: These grippers are used to hold objects that are flat. The gripping device is the vacuum cups as shown in *Fig 5.2 (b)*.

(c) Magnetic or Magnetized Grippers: These are used to grasp ferrous materials. Magnetic grippers can be of two types

a. Grippers with permanent magnets

b. Grippers with electromagnets

(d) Adhesion Grippers: These are grippers that grasp objects by sticking to them. The adhesive used in these grippers help hold objects, particularly when used in the textile industry to hold fabrics.

(e) Simple Mechanical Grippers: These are grippers of simplest forms and examples include hooks, scoops and inflatable bladders.

2. ***Tools***: Tools for processing operations such as spot welding, spray painting, drilling, milling, etc can be used as end-effectors to move relative to the workpiece and perform the required operations. Example: A spray painting gun can be an end-effector that is used by the robot to perform spray painting on the work surface. Other examples of tools include spot welding gun, plasma torch, a rotating spindle on which various tools such as drill bits, milling cutters, etc can be mounted and so on.

5.6 Types of Robot joints

There are various types of joints that are used in the construction of a robot. These joints are called the *robot joints*. There are majorly five types of robot joints:

1. *Rotational joint or the R-joint*: This type of joint allows rotary relative motion where the axis of the rotation is perpendicular to the axes of the input link and the output link. This is shown in *Fig 5.3 (a)*
2. *Linear joint or the L-Joint*: This type of joint allows a translational sliding motion between the input and the output links with the axes of the links parallel as shown in the *Fig.5.3 (b)*.
3. *Orthogonal joint or the O-joint*: This type of joint allows a translational sliding motion between the input link and the output link with the axis of the output link perpendicular to the input link as shown in *Fig. 5.3 (c)*.
4. *Twisting joint or the T-joint*: This type of joint allows rotary motion where the axis of rotation is parallel to the axes of the input and output links as shown in the *Fig.5.3 (d)*.
5. *Revolving joint or the V-joint*: In this type of joint, the input link axis is parallel to the rotational axis of the joint whereas the output link axis is perpendicular to the rotational axis of the joint as shown in the *Fig.5.3 (e)*.

(b) Indicated Power of a Two–Stroke I.C. Engine

In two stroke IC engines, *one cycle* will be completed in *every revolution* of the crank shaft. Therefore the work will be produced in *every revolution of the crank shaft*. Thus, the number of *cycles per minute will be equal to the number of revolutions per minute.*

ie., $$n = N$$

When p_m is experessed in N/m² the indicated power of a Two–Stroke engine is given by,

$$\boxed{\text{Indicated Power} = \frac{p_m\, L\, A\, N}{60 \times 1000} \text{ kW}}$$

When p_m is experessed in bar, the indicated power of a Two Stroke engine is given by,

$$\boxed{\text{Indicated Power} = \frac{100\, p_m\, L\, A\, N}{60} \text{ kW}}$$

2. Brake Power

The indicated power produced inside the IC engine cylinder will be transmitted through the piston, connecting rod and crank. Since these mechanical parts are moving relative to each other, they will have to encounter resistance due to friction. Therefore a certain fraction of the indicated power produced inside the cylinder will be lost due to friction of the moving parts of the engine. Therefore the net power available at the crankshaft will be equal to the *difference between the indicated power produced inside the engine cylinder and the power lost due to friction*. The net power available at the crankshaft is measured by applying the brake and is therefore called *brake power.*

The amount of the power lost in friction is called *friction power.* The *friction power is the difference between the indicated power and the brake power.*

$$\textit{Friction Power} = \textit{Indicated Power} - \textit{Brake Power}$$

The brake power is calculated as follows :

Let W = Net load acting on the brake drum, **kg**

R = Radius of the brake drum, **m**

N = R.P.M. of the crankshaft

T = Torque applied due to the net load W on the brake drum, **kNm**

$= W \times R$

$$\boxed{\text{Torque} = T = \frac{9.81}{1000} W R \text{ kNm}}$$

$$\therefore \quad \boxed{\text{Brake Power} = \frac{2\pi N T}{60} \text{ kW}}$$

3. Mechanical Efficiency

It is the efficiency of the moving parts of the mechanism transmitting the indicated power to the crankshaft. Therefore it is *defined as the ratio of the brake power and the indicated power.* It is expressed in percentage.

$$\therefore \quad \eta_{Mech} = \frac{Brake\ Power}{Indicated\ Power} \times 100$$

$$= \frac{Indicated\ Power - Friction\ Power}{Indicated\ Power} \times 100$$

$$= \frac{Brake\ Power}{Brake\ Power + Friction\ Power} \times 100$$

4. Thermal Efficiency

It is the efficiency of conversion of the heat energy produced by the actual combustion of the fuel into the power output of the engine. Therefore *it is defined as the ratio of the power developed by the engine to the heat supplied by the fuel in the same interval of time.* It is expressed in percentage

$$\therefore \quad \eta_{Thermal} = \frac{Power\ Output}{Heat\ Energy\ Supplied\ by\ the\ Fuel} \times 100$$

The power output to be used in the above equation may be *brake power* or *indicated power,* accordingly the thermal efficiency is called *brake thermal efficiency* or *indicated thermal efficiency.*

*The **brake thermal efficiency** is defined as the ratio of brake power to the heat supplied by the fuel.* It is expressed in percentage.

$$\therefore \quad \eta_{B\ Thermal} = \frac{Brake\ Power}{Heat\ Energy\ Supplied\ by\ the\ Fuel} \times 100$$

i.e.,

$$\boxed{\eta_{B\ Thermal} = \frac{BP}{CV \times \dot{m}} \times 100}$$

Where, m = Mass of the fuel supplied, **kg/s**

CV = Calorific Value of the fuel, **kJ/kg**

BP = Brake Power, **kW**

*The **indicated thermal efficiency** is defined as the ratio of indicated power to the heat supplied by the fuel.* It is expressed in percentage.

$$\eta_{I\ Thermal} = \frac{Indicated\ Power}{Heat\ Energy\ Supplied\ by\ the\ Fuel} \times 100$$

i.e.,

$$\boxed{\eta_{I\ Thermal} = \frac{IP}{CV \times m} \times 100}$$

3.15 Simple Problems

Problem 3.1

A single cylinder, two–stroke cycle I.C. Engine has a piston diameter 105 mm and stroke length 120 mm. The mean effective pressure is 6 bar. If the crank shaft speed is 1500 rpm, calculate the indicated power of the engine.

(VTU, March 1999)

Solution :

D = 105 mm L = 120 mm p_m = 6 bar N = 1500rpm N = N (two stroke)

The indicated power of a two stroke engine is given by

$$IP = \frac{100\, p_m\ L\ A\ n}{60}\ \text{kW}$$

$$= \frac{100 \times 6 \times 0.12 \times \pi\,(0.105)^2 \times 1500}{60 \times 4}\ \text{kW}$$

$$= \mathbf{15.58\ kW}$$

Problem 3.2

A four–stroke I.C. engine running at 450 rpm has a bore diameter of 100 mm and stroke length 120 mm. The indicator diagram details are ; area of the diagram 4 cm², length of indicator diagram 6.5 cm and the spring value of the spring used is 10 bar / cm. Calculate the indicated power of the engine.

(VTU, Aug/Sep 1999)

Solution :

N = 450 rpm D = 100 mm a = 4 cm² L = 120 mm l = 6.5 cm s = 10 bar / cm

The indicated power of a two stroke engine is given by

$\therefore$ Mean Effective Pressure p_m

$$= \frac{sa}{l}$$

$$= \frac{10 \times 4}{6.5}$$

$$= \mathbf{6.15\ bar}$$

$\therefore$ Indicated power IP

$$= \frac{100\, p_m\ L\ A\ n}{60}$$

$$= \frac{100 \times 6.15 \times 0.12 \times \pi\,(0.1)^2 \times 450}{4 \times 60 \times 2}$$

$$= \mathbf{2.17\ kW}$$

Problem 3.3

A two–stroke internal combustion engine has a stroke length of 150 mm, and cylinder diameter 100mm. Its mean effective pressure is 5.4×10^5 N/m² and crankshaft speed is 1000, find the indicated power.

Solution :

$L = 150$ mm $\quad D = 100$ mm $\quad p_m = 5.4 \times 10^5$ N/m² $\quad N = 1000$

The indicated power of a two–stroke engine is given by

$$IP = \frac{p_m \; L \; A \; N}{60 \times 1000} \text{ kW}$$

$$= \frac{5.4 \times 10^5 \times 0.15 \times \pi (0.1)^2 \times 1000}{4 \times 60 \times 1000}$$

$$= \mathbf{10.6 \text{ kW}}$$

Problem 3.4

A six cylinder 4 stroke I.C. Engine develops 50 kW of indicated power at mep of 7 bar. The bore and stroke of the engine cyliner is 70 mm and 100 mm respectively. If the engine speed is 3700 rpm, find the average misfires per minute.

Solution :

Indicated Power developed / cylinder $= \dfrac{50}{6}$ kW

$$IP = \frac{100 \, p_m \; L \; A \; N}{60 \times 2} \text{ kW}$$

$$\frac{50}{6} = \frac{100 \times 7 \times 0.1 \times \pi (0.07)^2 \; N}{4 \times 60 \times 2}$$

$$\therefore \quad N = \mathbf{3712 \text{ rpm.}}$$

$\therefore$ Number of Cycles / min $n = \dfrac{3712}{2}$

$= \mathbf{1856}$

i.e., Number of Explosions per minute $= 1856$

Actual Explosions per minute $= \dfrac{3700}{2}$

$= \mathbf{1850}$

$\therefore$ Number of Misfires $= 1856 - 1850$

$= 6$ / min

$$\text{Brake Power} = \frac{2\pi\ N\ T}{60}\ \text{kW}$$

$$= \frac{2\pi \times 200 \times 0.7}{60}\ \text{kW}$$

$$= \mathbf{14.66\ kW}$$

Problem 3.7

A four–stroke single cylinder I.C. engine of 250 mm cylinder diameter and 400 mm stroke runs at a piston speed of 8 m/s. If the engine develops 50 kW indicated power, find its mean effective pressure and the crankshaft speed.

Solution :

$D = 250$ mm $\quad L = 400$ mm $\quad IP = 50$ kW $\quad$ *Piston Speed* $= 8$ m/s

$$\text{Piston Speed} = 2\ L\ N\ \text{m/min}$$

$$8 \times 60 = 2 \times 0.4\ N$$

$$\therefore \quad N = \mathbf{600\ rpm}$$

The indicated power of a four–stroke engine is given by,

$$IP = \frac{100\, p_m\ L\ A\ N}{60 \times 2}$$

$$50 = \frac{100 \times p_m \times 0.4 \times \pi\ (0.25)^2 \times 600}{4 \times 60 \times 2}$$

$$\therefore \quad p_m = \mathbf{5.09\ bar}$$

Problem 3.8

During the test on a four–stroke diesel engine, the following readings were taken when running at full load.

Area of the indicator diagram	$= 3\ cm^2$
Length of the indicator diagram	$= 5\ cm$
Spring constant	$= 100\ N/cm^2/cm$
Engine crankshaft speed	$= 500$ *R.P.M.*
Diameter of the engine cylinder	$= 150\ mm$
Stroke of the piston	$= 200\ mm$

Find the indicated power of the engine.

Solution :

$a = 3\ \text{cm}^2 \quad l = 5\ \text{cm} \quad s = 100\ \text{N/cm}^2\text{/cm} \quad N = 500$ R.P.M

$D = 150\ \text{mm} \quad L = 200\ \text{mm} \quad = 10^6\ \text{N/m}^2\text{/cm}$

The mean effective pressure is given by,

$$p_m = \frac{sa}{l} \text{ N/m}^2$$

$$= \frac{10^6 \times 3}{5}$$

$$= 0.6 \times 10^6 \text{ N/m}^2$$

The indicated power of a four stroke engine is given by,

$$IP = \frac{p_m \ L \ A \ N}{60 \times 2 \times 1000}$$

$$= \frac{0.6 \times 10^6 \times 0.2 \times \pi (0.15)^2 \times 500}{4 \times 60 \times 2 \times 1000}$$

$$= 8.83 \text{ kW}$$

Problem 3.9

Find the indicated power of a four–stroke petrol engine of swept volume of 6 litres and running at 1000 rpm. The mean effective pressure is 600 kN/m².

Solution :

p_m = 600 kN/m² Swept volume LA = 6 litres

= 6 bar = 6×10^{-3} m³

The indicated power of a four stroke engine is given by,

$$IP = \frac{100 \, p_m \ L \ A \ N}{60 \times 2 \times 1000} \text{ kW}$$

$$= \frac{100 \times 6 \times 6 \times 10^{-3} \times 800}{60 \times 2}$$

$$= 24 \text{ kW}$$

Problem 3.10

A four cylinder four–stroke engine running at 1000 rpm develops an indicated power of 15 kW. The mean effective pressure is 5×10^5 N/m². Find the diameter of the cylinder and the stroke of the piston when the ratio of diameter to stroke is 0.8.

Solution :

IP = 15 kW $p_m = 5 \times 10^5$ N/m² = 5 bar N = 1000 rpm $\frac{D}{L} = 0.8$

$$\text{Indicated Power developed / cylinder} = \frac{\textit{Total Engine Power}}{\textit{Number of Cylinders}}$$

$$= \frac{15}{4} \text{ kW}$$

$$= 3.75 \text{ kW}$$

$$IP = \frac{100\, p_m \; L \; A \; N}{60 \times 2}$$

$$3.75 = \frac{100 \times 5 \times 1.25D \times \pi D^2 \times 1000}{4 \times 60 \times 2}$$

$$\therefore \quad D^3 = 9.167 \times 10^{-4} \text{ m}^3$$

$$\therefore \quad D = 0.09714 \text{ m}$$

$$= 97.14 \text{ mm}$$

$$\frac{D}{L} = 0.8$$

$$\therefore \quad L = \frac{97.14}{0.8}$$

$$= 121.42 \text{ mm}$$

Problem 3.11

A four–stroke petrol engine of 100 mm bore and 150 mm stroke consumes 1 kg of fuel per hour. The mean effective pressure is 7 bar and its indicated thermal efficiency is 30%. The calorific value of the fuel is 40 × 10³ kJ/kg. Find the crankshaft speed.

Solution :

$p_m = 7$ bar $\qquad \eta_{\text{I Thermal}} = 30\% \qquad CV = 40 \times 10^3$ kJ/kg

$L = 150$ mm $\qquad D = 100$ mm $\qquad m = 1$ kg/hour

$= 0.15$ m $\qquad = 0.1$ m $\qquad = \frac{1}{3600}$ kg/s

For a four–stroke engine, the indicated power is given by,

$$IP = \frac{100\, p_m \; L \; A \; N}{60 \times 2} \; kW$$

$$= \frac{100 \times 7 \times 0.15 \times \pi (0.1)^2 \times N}{4 \times 60 \times 2}$$

$$= 6.87 \times 10^{-3} N \;\; kW$$

The indicated thermal efficiency is given by,

$$\eta_{\text{B Thermal}} = \frac{IP}{CV \times m}$$

$$0.3 = \frac{6.87 \times 10^{-3} N}{40 \times 10^{3} \times \frac{1}{3600}}$$

$$\therefore \qquad N = 485.2 \text{ RPM}$$

Problem 3.12

The following data refers to a single cylinder 4 stroke petrol engine.

Cylinder diameter	= *20 cm*
Stroke of the piston	= *40 cm*
Engine speed	= *400 rpm*
Indicated mean effective pressure	= *7 bar*
Fuel consumption	= *10 litres / hour*
Calorific value of the fuel	= *45000 kJ/kg*
Specific gravity of the fuel	= *0.8*

Find the indicated thermal efficiency.

Solution :

D	= 20 cm	Fuel Consumption	= 4 litres /hour
L	= 40 cm	Specific gravity	= 0.8
N	= 400 rpm	Calorific value of fuel	= 45000 kJ/kg
p_m	= 7 bar	Calorific value of fuel	= 45000 kJ/kg

The indicated power of a four–stroke engine is given by,

$$IP = \frac{100\, p_m \; L \; A \; N}{60 \times 2} \text{ kW}$$

$$= \frac{100 \times 7 \times 0.4 \times \pi (0.2)^2 \times 400}{4 \times 60 \times 2}$$

$$= 29.32 \text{ kW}$$

The indicated thermal efficiency is given by,

$$\eta_{B\ Thermal} = \frac{IP}{CV \times m} \times 100$$

$$= \frac{29.32}{45000 \times 10 \times \frac{0.8}{3600}} \times 100$$

$$= 29.32\ \%$$

Problem 3.13

On a single cylinder four–stroke petrol engine, the following readings were taken :

Load on the brake drum	*= 40 kg*
Spring balance reading	*= 5 kg*
Diameter of the brake drum	*= 120 cm*
Fuel consumption	*= 3 kg/hour*
Calorific value of the fuel	*= 42000 kJ/kg*
Engine Speed	*= 500 rpm*

Find the brake thermal efficiency.

Solution :

$$\text{Net Load on brake durm} = (40 - 5)$$

$$= 35 \text{ kg}$$

$$\text{Radius of the brake durm} = \frac{120}{2} = 60 \text{ cm} = 0.6\text{m}$$

$$\text{Torque on the brake durm} = \frac{9.81\ WR}{1000} \text{ kNm}$$

$$= \frac{9.81 \times 35 \times 0.6}{1000}$$

$$= 0.206 \text{ kNm}$$

The Brake Power is given by,

$$BP = \frac{2\,\pi N T}{60} \text{ kW.}$$

$$= \frac{2\,\pi \times 500 \times 0.206}{60}$$

$$= 10.78 \text{ kW}$$

The Brake thermal efficiency is given by,

$$\eta_{B\ Thermal} = \frac{BP}{CV \times m} \times 100$$

$$= \frac{10.78 \times 100 \times 3600}{42000 \times 3}$$

$$= 30.8\%$$

Problem 3.14

A two–stroke diesel engine has a piston diameter of 200 mm and a stroke of 300 mm. It has mean effective pressure of 2.8 bar and a speed of 400 rpm. The diameter of the brake drum is 1 metre and the effective brake load is 64 kg. Find the indicated power, the brake power, the mechanical efficiency of the engine and the average piston speed.

Solution :

$$\text{Indicated Power} = \frac{100\, p_m\ L\ A\ N}{60}\ \text{kW}$$

$$= \frac{100 \times 2.8 \times \frac{300}{1000} \times \pi \frac{(0.2)^2}{4} \times 400}{60}$$

$$= \mathbf{17.6\ kW}$$

$$\text{Brake Power} = \frac{2\pi\ N\ T}{60}\ \text{kW}$$

$$= \frac{2 \times \pi \times 400 \times 9.81 \times 64 \times 0.5}{60 \times 1000}$$

$$= \mathbf{13.15\ kW}$$

$$\text{Mechanical Efficiency} = \frac{Brake\ Power}{Indicated\ Power} \times 100$$

$$= \frac{13.15}{17.6} \times 100$$

$$= \mathbf{74.7\ \%}$$

$$\text{Average Piston Speed} = 2\,LN$$

$$= 2 \times 0.3 \times 400$$

$$= 240\ \text{m/min}$$

$$= \mathbf{4\ m/s}$$

Problem 3.15

A gas engine working on a four-stroke cycle has a cylinder of 250 mm diameter, length of stroke 450 mm, and is running at 180 rpm. Its mechanical efficiency is 80% when the mean effective pressure is 0.65 MPa. Find (i) indicated power, (ii) brake power and (iii) friction power.

Solution :

$$\text{Indicated Power} = \frac{p_m \; L \; A \; n}{60} \text{ W}$$

$$= \frac{0.65 \times 10^6 \times 0.45 \times \pi \dfrac{(0.25)^2}{4} \times \dfrac{180}{2}}{60 \times 1000} \text{ kW}$$

$$= 21.53 \text{ kW}$$

$$\text{Mechanical Efficiency} = \frac{\textit{Brake Power}}{\textit{Indicated Power}} \times 100$$

$$\text{Brake Power} = \frac{\textit{Mechanical Efficiency} \times \textit{Indicated Power}}{100}$$

$$= \frac{80 \times 21.53}{100}$$

$$= 17.23 \text{ kW}$$

$$\textit{Friction Power} = \textit{Indicated Power} - \textit{Brake Power}$$

$$= 21.53 - 17.23$$

$$= 4.3 \text{ kW}$$

Problem 3.16

A single cylinder four-stroke engine has a swept volume of 4.5 litre. The m.e.p. is 0.65 MPa and the engine speed is 505 rpm. If there are 250 explosions per minute and the brake torque is 176 Nm, find indicated power and brake power of the engine.

Solution :

In the indicated power equation, L will be in metre and A will be in sq.m. Therefore the product LA will be in m^3. The product LA is equal to the stroke volume. The stroke volume of 4.5 litre is now expressed in m^3.

$$LA = 4.5 \text{ litre}$$

$$= 4.5 \times 1000 \text{ cm}^3$$

$$= 0.0045 \text{ m}^3$$

Now

$$\text{Indicated Power} = \frac{p_m \; L \; A \; n}{60} \text{ W}$$

Where, n = number of cycles per min

$$= \frac{N}{2} \text{ for 4 stroke engine}$$

$$= \frac{505}{2}$$

$$= 252.5 \text{ cycles per min}$$

But, there are only 250 explosions per min. Although 252.5 cycles are performed every minute, only in 250 cycles firing will take place, the remaining, 252.5 – 250 = 2.5 cycles per min, will be idle cycles. Therefore in the indicated power equation, substitute n = 250 cycles per min instead of 252.5 cycles per min.

$$\text{Indicated Power} = \frac{p_m \ L \ A \ n}{60} \text{ W}$$

$$= \frac{0.65 \times 10^6 \times 0.0045 \times 250}{60 \times 1000} \text{ kW}$$

$$= 12.18 \text{ kW}$$

$$\text{Brake Power} = \frac{2 \pi \ N \ T}{60} \text{ W}$$

$$= \frac{2 \times \pi \times 505 \times 176}{60 \times 1000} \text{ kW}$$

$$= 9.3 \text{ kW}$$

Note : **In the Brake Power equation N = 505.**

Problem 3.17

A single cylinder four–stroke engine runs at 1000 r.p.m. and 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 machanical efficiency is 80 percent. Calculate brake power and mean effective pressure.

Solution :

$$\text{Brake Power} = \frac{2 \pi \ N \ T}{60} \text{ W}$$

$$= \frac{2 \times \pi \times 1000 \times 6 \times 9.81 \times 0.6}{60}$$

$$= 3698.3 \text{ W}$$

$$\text{Mechanical Efficiency} = \frac{\textit{Brake Power}}{\textit{Indicated Power}} \times 100$$

$$\text{Indicated Power} = \frac{\textit{Brake Power}}{\textit{Mechanical Efficiency}} \times 100$$

$$= \frac{3698.3}{80} \times 100$$

$$= 4622.9 \text{ W}$$

$$\text{But Indicated Power} = \frac{p_m \ L \ A \ n}{60 \times 2} \text{ W}$$

$$\therefore \quad p_m = \frac{\textit{Indicated Power} \times 60 \times 2}{L \ A \ N} \text{ N/m}^2$$

$$= \frac{4622.9 \times 60 \times 2}{\frac{140}{1000} \times \pi \frac{(0.115)^2}{4} \times 1000}$$

$$= 381500 \text{ N/m}^2$$

$$= 3.815 \text{ bar}$$

Problem 3.18

The following observations were obtained during a trial on a four–stroke diesel engine.

Cylinder diameter	= 25 cm
Stroke of the Piston	= 40 cm
Crankshaft speed	= 250 rpm
Brake load	= 70 kg
Brake drum diameter	= 2 m
Mean effective pressure	= 6 bar
Diesel oil consumption	= 0.1 m^3/min
Specific gravity of diesel	= 0.78
Calorific Value of diesel	= 43900 kJ/kg

Find :

1. *Brake Power*
2. *Indicated Power*
3. *Frictional Power*
4. *Mechanical Efficiency*
5. *Brake Thermal Efficiency*
6. *Indicated Thermal Efficiency*

Solution :

1. *Brake Power :*

$$\text{Torque applied} \quad T = \frac{9.81\ WR}{1000} \ \textbf{kNm}$$

$$= \frac{9.81 \times 70 \times 1}{1000} \ \textbf{kNm}$$

$$= 0.686 \ \text{kNm}$$

$$\text{Brake Power} = \frac{2\pi N T}{60}$$

$$= \frac{2\pi \times 250 \times 0.686}{60 \times 1000}$$

$$= \textbf{17.95 kW}$$

2. *Indicated Power :*

$$\text{Indicated Power} = \frac{100\ p_m\ L\ A\ N}{60 \times 2} \ \textbf{kNm}$$

$$= \frac{100 \times 6 \times 0.4 \times \pi (0.25)^2 \times 250}{4 \times 60 \times 2}$$

$$= \textbf{24.54 kW}$$

3. Frictional Power :

$$\text{Frictional Power} = \text{Indicated Power} - \text{Brake Power}$$

$$= 24.54 - 17.95$$

$$= 6.59 \text{ kW}$$

4. Mechanical Efficiency :

$$\eta_{\text{Mech}} = \frac{\text{Brake Power}}{\text{Indicated Power}} \times 100$$

$$= \frac{17.95}{24.54} \times 100$$

$$= 73.14\%$$

5. Brake Thermal Efficiency :

$$\eta_{\text{B.Thermal}} = \frac{\text{Brake Power}}{CV \times m} \times 100$$

$$= \frac{17.95}{43900 \times \frac{0.1 \times 0.78}{60}} \times 100$$

$$= 31.45\%$$

6. Indicated Thermal Efficiency :

$$\eta_{\text{I.Thermal}} = \frac{24.54}{43900 \times \frac{0.1 \times 0.78}{60}} \times 100$$

$$= 43\%$$

EXERCISES 3

1. How are I.C. Engines are classified ? *(VTU, March 2001)*
2. Classify the I.C. Engines based on the thermodynamic cycle.
3. Draw the theoretical PV diagrams of a spark and compression ignition engines and name all the processes.
4. Explain with a neat sketch, naming all the parts, the working of a single cylinder four stroke petrol engine.
5. Explain the working of a two stroke petrol engine. What is the function of the carburetor in such an engine ?
6. With the help of a PV diagram explain the working of a four–stroke diesel engine. *(VTU, March 2001)*
7. Draw a neat sketch of a two– stroke petrol engine and describe the working principle in brief.
8. Explain the working of a two– stroke diesel engine with a neat sketch.
9. Distinguish between two– stroke and four stroke I.C. engines.
10. What are the advantages of a two stroke engine over a four stroke engine ?
11. Compare a two–stroke engine with a four stroke engine.
12. Compare a petrol engine with a diesel engines.
13. Distinguish between spark ignition and compression ignition.
14. Why diesel engines have a higher compression ratio ?
15. What is specific fuel consumption?
16. Derive an expression for the indicated power of a four–stroke I.C. engine. *(VTU, March 2001)*
17. Define indicated power, brake power and mechanical efficiency.
18. Define Brake Thermal Efficiency and Indicated Thermal Efficiency.
19. Which type of I.C. engines are employed in (i) mopeds, (ii) scooters, (iii) motorcycles (iv) autorickshaws, (v) passenger cars, (vi) jeeps, and (vii) trucks. How is the capacity of these vehicles is specified ? What are the approximate values of the brake power in each of these vehicles ?
20. A two–stroke internal combustion engine has a piston diameter 110 mm and stroke length of 140 mm. The mean effective pressure on the head of the piston is 6 bar. If it runs at a speed of 1000 rpm, find the indicated power. **(13.30 kW)**

20. A four–stroke I.C. engine has a piston diameter of 150 mm and the average piston speed is 3.5 metre per second. If the m.e.p. is 0.786 MPa, find the indicated power of the engine. **(12.15 kW)**

22. Calculate the indicated power of a four–stroke diesel engine, given the following data

Mean effective pressure = 8 bar	Stroke = 300 mm
Diameter of the cylinder = 200 mm	Speed = 250 rpm

(15.7 kW)

23. Determine the brake power output of an engine given the following :

Speed of the engine = 200 rpm	Weight suspended = 100 kg
Diameter of the brake wheel = 1500 mm	Spring balance reading = 10 kg

(13.86 kW)

24. The brake wheel of an engine runs at 300 rpm and is 500 mm in radius. The spring balance pull is 0.2 times the dead load. Find the dead load if the brake power output is 16.5 kW. **(133.75 kg)**

25. In a single cylinder two–stroke petrol engine, the mean effective pressure is 0.55 MPa. Its cylinder diameter is 200 mm and stroke is 300 mm. If the engine runs at 350 rpm, find its indicated power. If its mechanical efficiency is 80 percent, what will be its brake power output ? **(30.23 kW, 24.18 kW)**

26. Calculate the brake power output of a single cylinder four–stroke petrol engine given :

Diameter of brake wheel	=	600 mm
Brake rope diameter	=	30 mm
Dead weight	=	24 kg
Spring balance reading	=	4 kg
R.P.M.	=	450

(2.91 kW)

27. The following details refer to a four–stroke engine.

Cylinder diameter	=	200 mm
Stroke	=	300 mm
Speed	=	300 rpm
Effective brake load	=	50 kg
Mean circumference of the brake drum	=	400 mm
Mean effective pressure	=	6 bar

Calculate : (i) indicated power, (ii) brake power, and (iii) mechanical efficiency. **(14.13kW, 9.8 kW, 69.35%)**

28. A four–stroke petrol engine is running at 2500 rpm. The stroke of the piston is 1.5 times the bore. If the mean effective pressure is 0.915 MPa, and the diameter of the piston is 140 mm. Find the indicated power of the engine. If the friction power is 13 kW, find the brake power output and the mechanical efficiency. **(61.62 kW, 48.62 kW, 78.9%)**

29. A four–stroke diesel engine has a piston diameter 200 mm and stroke 300 mm. It has a mean effective pressure of 2.75 bar and a speed of 400 rpm. The diameter of the brake drum is 1000 mm, and the effective brake load is 32 kg. Find the indicated power, brake power, and frictional power of the engine. **(8.64 kW, 6.57 kW, 2.07 kW)**

30. A four–stroke diesel engine with a cylinder diameter 200 mm and stroke length 250 mm, runs at 300 rpm. Find the indicated power of the engine. Also find brake power and friction power, if the mechanical efficiency is 80 percent and mean effective pressure is 787 kPa. **(15.45 kW, 12.36 kW, 3.09 kW)**

CHAPTER 4

MACHINE TOOLS OPERATIONS

4.1 Introduction

Several metal cutting operations are carried out to produce a mechanical part of required shape and size. The metal cutting operations may be carried out either, manually by using hand tools such as chisels, files, saws, etc, or using metal cutting machines. When machines perform the metal cutting operations by the cutting tools mounted on them, they are called "machine tools". *A machine tool may be defined as a power driven machine which accomplishes the cutting or machining operations on it.* The fundamental machine tools that are used for most of the machining processes are, *lathe, drilling, tapping, planing, milling* and *grinding machines.* The working principles of machine tools such as lathe, drilling machine and milling machine are discussed in this chapter.

4.2 Lathe

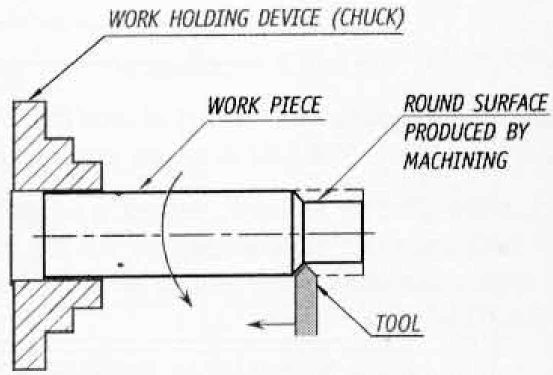
A lathe is a machine tool employed generally to produce circular objects. It is said to be the mother of all the machine tools, since it is so versatile, that almost all the machining operations which are performed on other machine tools like, drilling, grinding, shaping, milling, etc, can be performed on it. Various types of lathes are being used in practice to perform variety of machining operations. Depending on their characteristics functions, lathes are classified as : (1) Engine Lathe, (2) Speed Lathe, (3) Turret Lathe, (4) Capstan Lathe, (5) Automatic Lathe, (6) Computer Numerically Controlled (CNC) Lathe. All of these, except the engine lathe are out of purview of this book.

Engine Lathe

The most commonly used general purpose lathe used in engineering workshops is known as *Engine Lathe, or Centre Lathe, or* simply called as *Lathe.* The term engine used for this kind of lathes, simply means that it is a machine driven by a prime mover used for producing circular objects by manual operations.

4.3 Principle of Working

A lathe, basically a *turning machine* works on the principle that a cutting tool can remove material in the form of chips from the rotating workpieces to produce circular objects. This is accomplished in a lathe which holds the workpieces rigidly and rotates them at high speeds while a cutting tool is moved against it.



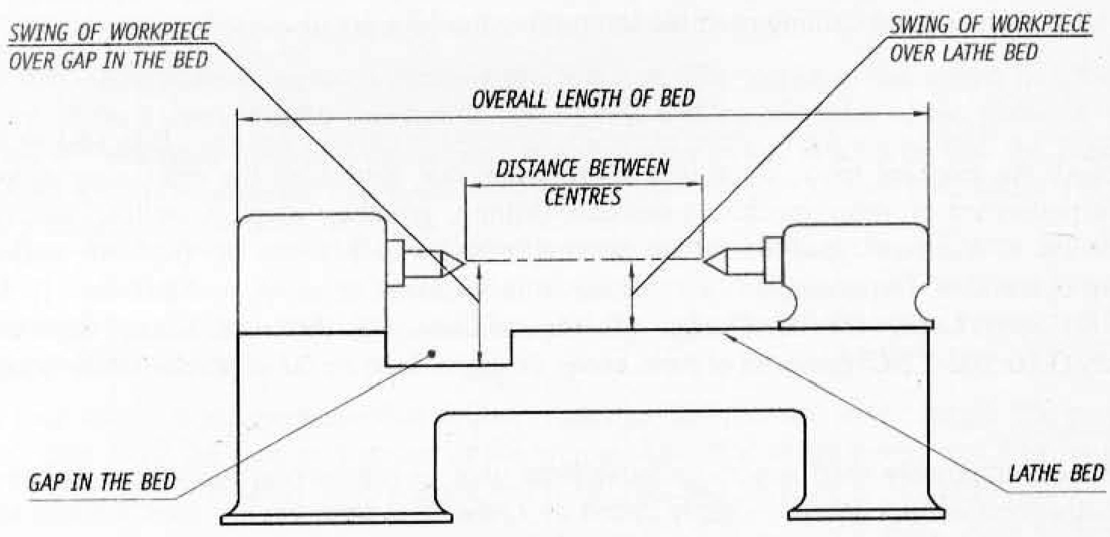
Principle of Working of a Lathe
Fig. 4.1

Fig. 4.1 shows a workpiece held rigidly by one of the workholding devices, known as chuck, and is rotated at very high speeds. A V-shaped cutting tool held against the workpiece opposite to its direction of rotation when moved parallel to the axis of the workpiece produces circular surfaces as shown in figure. The material of the tool will be harder and stronger than the material of the workpiece.

4.4 Lathe Specifications

The size of a lathe is specified by the following as shown in *Fig. 4.2*

1. Maximum diameter of the workpiece that can be revolved over the lathe bed. Instead of this sometimes, the height of the centres above the lathe bed is also specified. One of these specifications is given by the manufacturers, however both of them are loosely called as "Swing of the lathe".
2. The Maximum diameter and the width of the workpiece that can swing when the lathe has a gap bed.
3. The maximum length of the workpiece that can be mounted between the centres.
4. Overall length of the bed. It is the total length of the lathe itself.

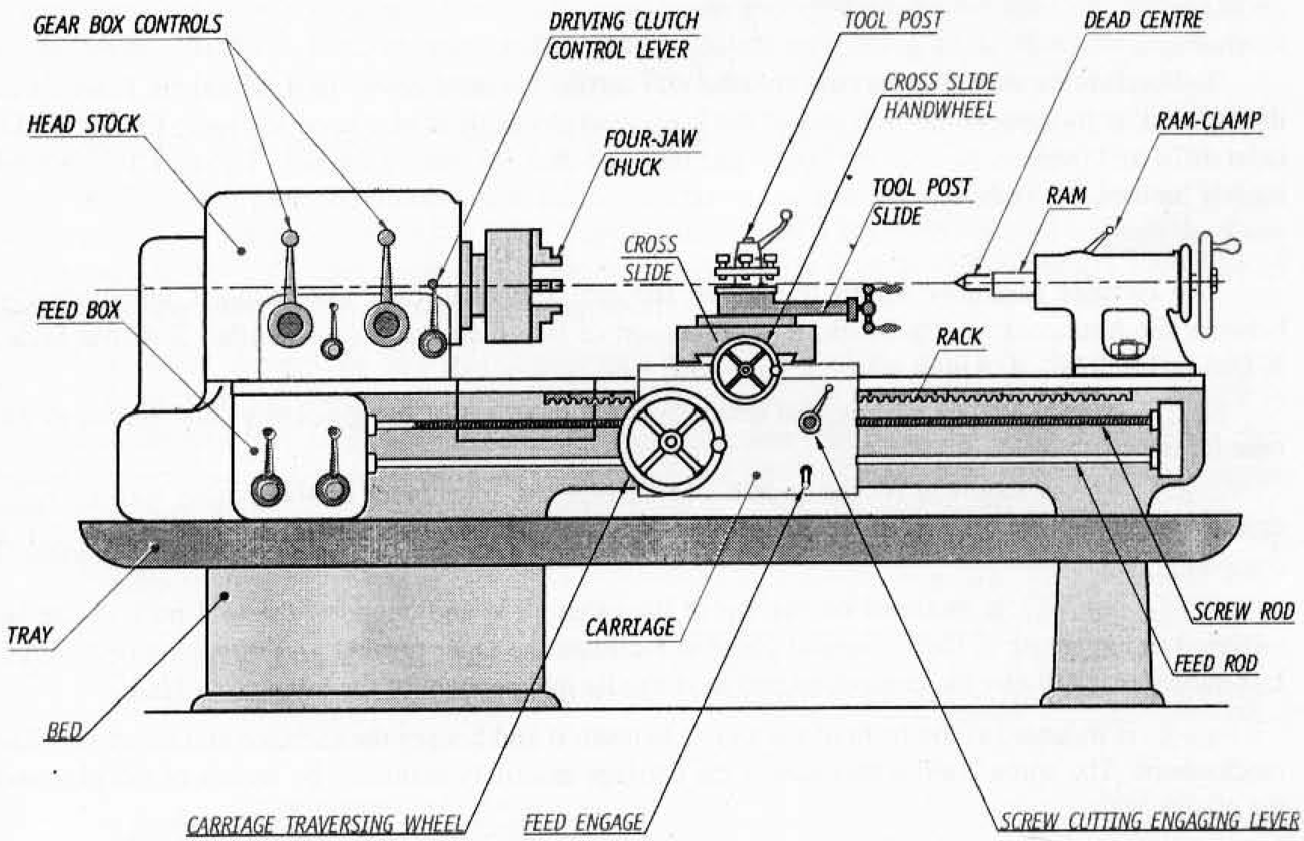


Specifications of a Lathe
Fig. 4.2

4.5 Major Parts of a Lathe and their Functions

Fig. 4.3 shows a lathe. Its major parts are :

1. Bed
2. Main Drive
3. Cone Pulley and Back Gear
4. Headstock
5. Tailstock
6. Lead Screw
7. Feed Rod
8. Carriage Assembly consisting of :
   (a) Saddle
   (b) Cross-slide
   (c) Compound Rest
   (d) Apron



Parts of a Lathe
Fig. 4.3

1. Bed

The bed is the foundation part of a lathe and supports all its other parts. The top of the bed is formed by precision machined guideways. There will be two sets of guideways, viz., outer ways and innerways. The headstock and the tailstock are mounted on the inner ways which keep them perfectly aligned with each other. The outerways guide the longitudinal movement of the carriage assembly and align it with the centre line of the lathe.

2. Main Drive

An electric motor mounted in the left leg of the lathe in conjunction with the transmission system like belt or gear drive from the motor to the spindle that form the main drive of the lathe.

3. Cone Pulley and Back Gear

The cone pulley which drives the main spindle through belting is driven by the motor. Various spindle speeds can be obtained by shifting the belt on the different steps of the cone pulley. Spindle speeds can be further varied using a back gear arrangement.

4. Headstock

The housing comprising of the feed gear box and the cone pulley is called headstock of the lathe. The main spindle projects out from the headstock. The headstock will be rigidly mounted on the lathe bed at its left end.

5. Tailstock

Tailstock is the movable part of the lathe that carries the dead centre in it. The main function of the tailstock is to support the free end of the long workpieces. It is also used to clamp the tools like twist drills and reamers for making holes, and taps and dies for cutting threads. Tailstock is mounted loosely on the lathe bedways and can be moved and locked in any desired position.

6. Carriage Assembly

The carriage assembly serves to support the tool and rides over the bedways longitudinally between the headstock and tailstock. It is composed of five main parts : 1. Saddle, 2. Cross Slide, 3. Compound Rest, 4. Apron, and 5. Tool Post.

Saddle is an H shaped casting that slides over the outer set of the guideways and serves as the base for the cross slide.

Cross Slide is mounted on the saddle and enables the movement of the cutting tool laterally across the lathe bed by means of cross-feed hand wheel. It also serves as the support for a compound rest.

Compound Rest is mounted on the top of the cross slide and supports the tool post. It can be swiveled to any angle in the horizontal plane to facilitate the taper turning and threading operations. It is moved manually by the compound rest feed handle independent of the lathe cross feed.

Apron is mounted at the front of the saddle beneath it and houses the carriage and the cross slide mechanisms. The apron hand wheel moves the carriage assembly manually by means of the rack and the pinion gears.

Tool Post is mounted in the T slot of the compound rest. The tool post clamps the tool holder in the proper position for machining operations.

7. Lead Screw

Lead screw is a screw rod which runs longitudinally in front of the lathe bed. The rotation of the lead screw moves the carriage to and fro longitudinally during thread cutting operations.

8. Feed Rod

The feed rod is a stationary rod mounted in front of the lathe bed and facilitates longitudinal movement of the carriage during turning, boring and facing operations.

9. Feed Gear Box

The feed gear box is mounted on the left side of the lathe bed and below the headstock. It houses the necessary gears and other mechanisms that transmit various feed gear ratios from the headstock spindle to either the lead screw or the feed rod.

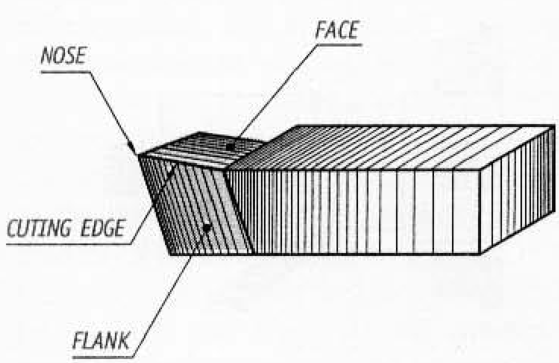
4.6 Nomenclature of a Single Point Lathe Tool

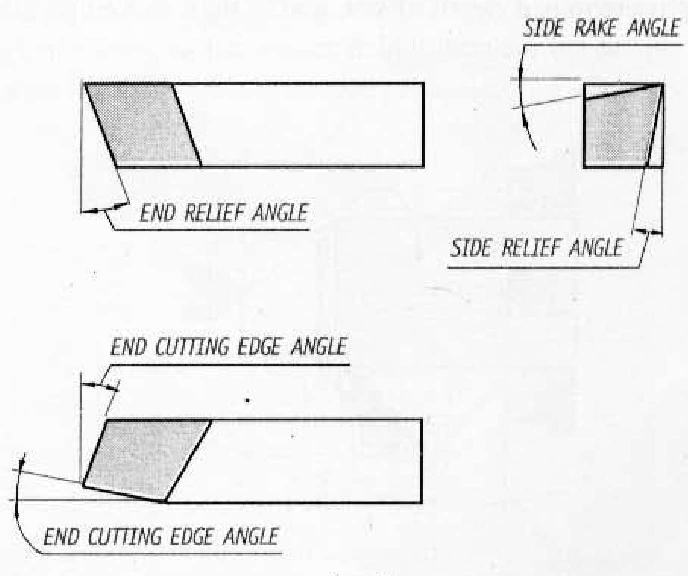
In a single point cutting tool, there will be a point contact between the cutting tool and the workpiece. Obviously the cutting tool should be provided with the clearances on the top, underside and the side faces. *Fig. 4.4* shows the nomenclature of a general purpose single point lathe cutting tool. The cutting portion of the tool is formed by a *face, cutting edge, flank, nose* and *base* as shown in *Fig. 4.4A.* The *face* is the top of the tool and is the surface over which the chip glides over it and passes away from the workpiece. The *cutting edge* is the part of the tool that does the actual cutting of the metal. The *flank* is the tapered surface directly below the cutting edge. The *nose* is the tip of the tool bit formed by the side and the end edges. The *base* is the bottom surface of the tool.

The functions of the different cutting tool angles are as follows :

Relief or *clearance angles* are ground on both the end and side faces of a tool to prevent it from rubbing on the workpiece. *Side relief* is the angle ground directly below the cutting edge on the flank of the tool. *End relief* is the angle ground from the nose of the tool. *Relief angles* are necessary to enable only the cutting edge to touch the workpiece.

Rake angles are ground on a tool to provide a smooth flow of the chip over the tool bit so as to move it away from the workpiece. A lathe tool generally uses *side* and *back rakes. Side rake angle* is ground on the tool face away from the cutting edge. Side rake influences the angle at which the chip leaves the workpiece. A general purpose lathe tool has a 14° side rake. *Back rake* is ground on the face of the tool. Back rake angle influences the angle at which the chip leaves the nose of the tool. Generally 8 to 10° back rake is provided.





Single Point Lathe Tool
Fig. 4.4

End and *side cutting edge angles* are ground on a tool so that it can be mounted in the correct position for various machining operations. The *end-cutting edge angle,* usually 20 to 30°, allows the cutting tool to machine close to the workpiece during turning operations. The *side-cutting edge angle,* approximately 15°, allows the flank of the tool to approach the workpiece first, thus reducing the initial shock of the cut to the tip point. This angle spreads the material over a greater distance on the cutting edge, thereby thinning out the chip.

The *nose radius* is the rounded tip on the point of the tool. The nose radius has two functions ; to prevent the sharp fragile tip from breaking during use, and to provide a smoother finish on the workpiece during machining operations. A nose radius of 0.8 mm works well with most of the operations.

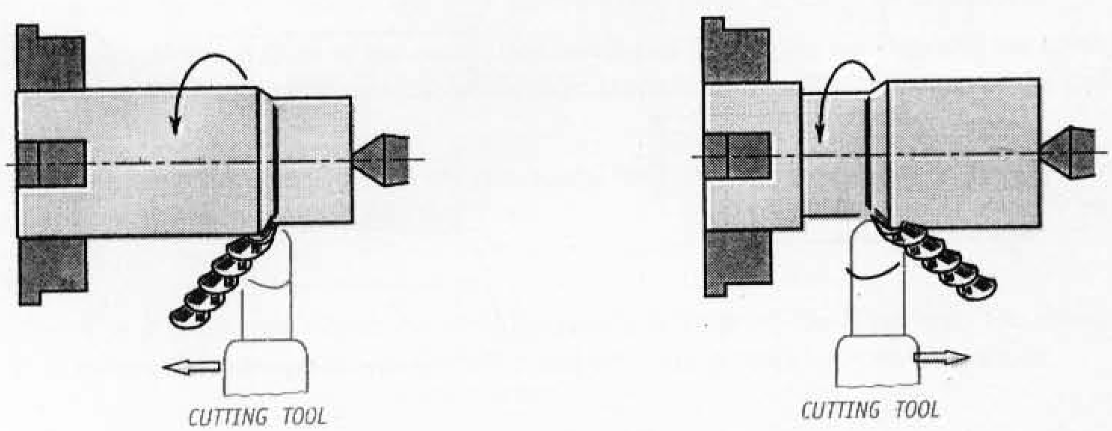
4.7 Lathe Operations

All most all the basic machining operations can be performed on a lathe. Some of the very important and generally performed lathe operations are :

1. **Turning**
2. **Taper turning**
3. **Thread cutting**
4. **Boring**
5. **Facing**
6. **Drilling**
7. **Reaming**
8. **Knurling**
9. **Milling**
10. **Grinding**

1. Plain Turning

Fig. 4.5 shows the principle of a metal cutting operation using a single-point tool on a lathe. The workpiece is supported in-between the two centres which permit the rotation of the workpiece. A single point cutting tool is fed perpendicular to the axis of the workpiece to a known predetermined depth of cut, and is then moved parallel to the axis of the workpiece. This operation will cut the material which comes out as shown in *Fig. 4.5.* This method of machining operation in which the workpiece is reduced to the cylindrical section of required diameter is called *'turning'*



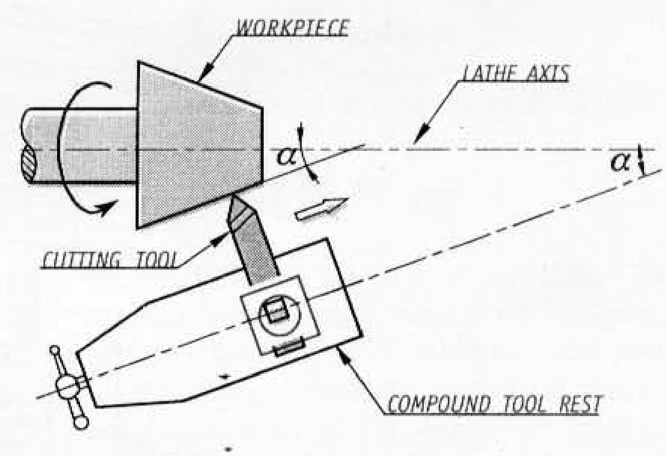
Turning
Fig. 4.5

2. Taper Turning

Taper turning is an operation on a lathe to produce conical surface on the workpieces. It is accomplished either, (1) with the workpiece mounted coaxial with the axis of the lathe centres and the cutting tool being moved linearly inclined to it, or (2) the workpiece itself is mounted so as to have its axis inclined to the axis of the lathe centres and the cutting tool being moved linearly parallel to the axis of the lathe bed. In the first method, the taper is obtained either by, (a) swiveling the compound rest, or (b) using a taper turning attachment. In this second method, the taper is obtained by the offsetting the tailstock.

3. Taper Turning by the Swiveling the Compound Tool Rest

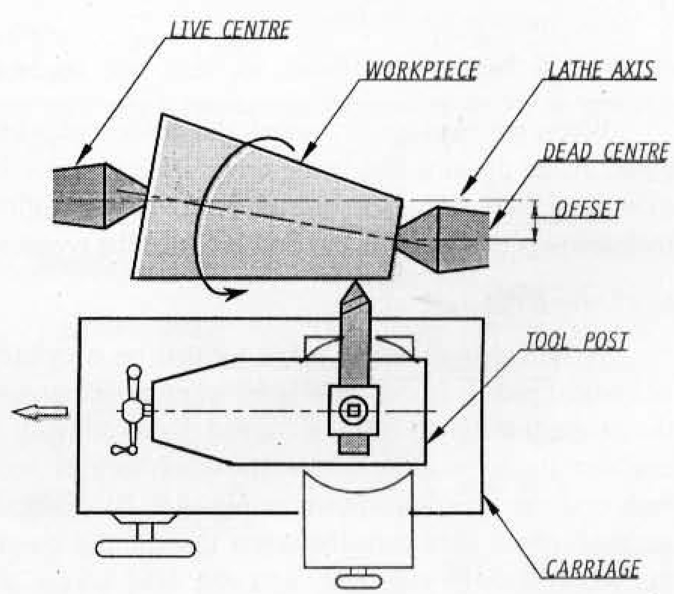
This method of taper turning shown in *Fig. 4.6* is more suitable for workpieces which require steep taper for short lengths. The compound tool rest is swiveled to the required taper angle and then locked in the angular position. The carriage is also locked at that position. For taper turning, the compound tool rest is moved linearly at an angle so that the cutting tool produces the tapered surface on the workpiece. This method is limited to short tapered lengths due to the limited movement of the compound tool rest.



Swiveling Compound Tool Rest
Fig. 4.6

4. Taper Turning by Offsetting the Tailstock (or Tailstock Set over method)

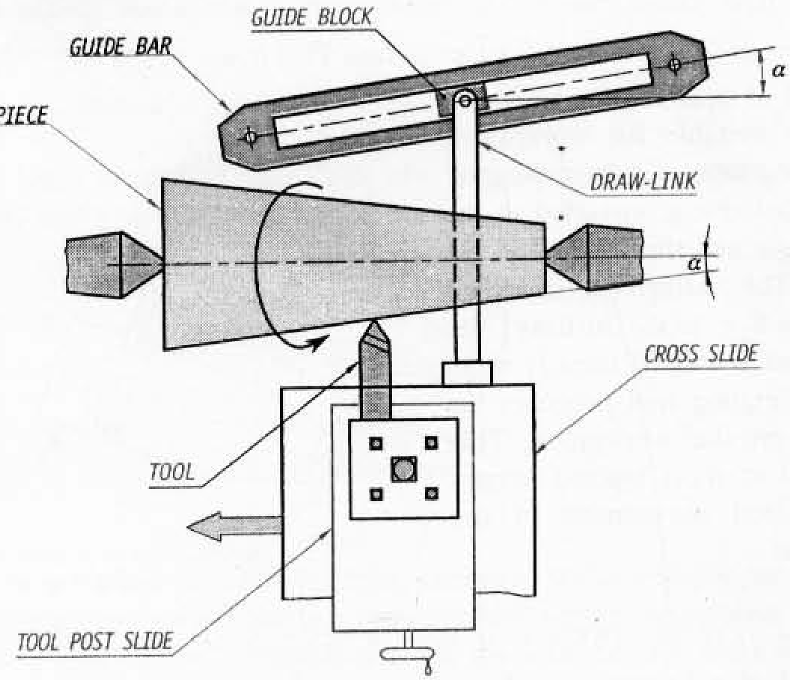
This method also known as *setover tailstock* method, shown in *Fig. 4.7,* is the most commonly method employed for taper turning. When the tailstock centre is set out of alignment, the workpiece gets taper turned because its axis will be inclined at an angle with the longitudinal movement of the tool which will be parallel to the lathe bed. The entire carriage is to be moved parallel to the lathe bed to cut the taper. Since the amount of offset is limited by the size of the tailstock, this method is more suitable for jobs having less taper. As the carriage is moved to cut the taper, it will be possible to produce taper on the long workpieces. Thus this method is best suited for long workpieces having less taper. Only external tapers can be produced by this method.



Offsetting Tail Stock
Fig. 4.7

5. Taper Turning by Taper Turning Attachment

A taper turning attachment is used to cut both internal and external tapers. The taper turning attachment shown in *Fig. 4.8* consists of a bracket (not shown in figure) which will be connected to the rear side of the lathe bed. A guide bar which can be swiveled in the horizontal plane and locked in position, is mounted over the bracket. A guide block pivoted to a draw-link will slide in the longitudinal slot in the guide bar. The draw-link is connected firmly to the cross slide. The tool is mounted on the tool post slide. The cross slide is allowed to move freely on its ways by loosening the cross feed screw and the engaging nut.



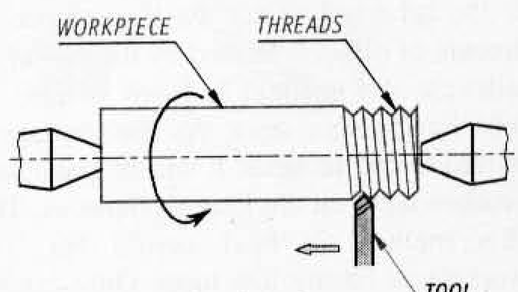
Taper Turning Attachment

Fig. 4.8

When the carriage is moved, the guide slides inside the slot in the guide bar. The sliding of the guide inside the slot forces the cross slide to move in the traverse direction. The combined traverse motion of the cross slide and the longitudinal motion of the carriage moves the tool parallel to the inclined axis of the guide bar and produce the required taper on the workpiece.

6. Thread Cutting

A *thread* is a helical ridge formed on a cylindrical or conical rod. It is cut on a lathe when a tool ground to the shape of the thread, is moved longitudinally with uniform linear motion while the workpiece is rotating with uniform speed as shown in *Fig. 4.9.* By maintaining an appropriate gear ratio between the spindle on which the workpiece is mounted, and the lead screw which enables the tool to move longitudinally at the appropriate linear speed, the screw thread of the required pitch can be cut. The pointed tool shown in *Fig. 4.9* is employed to cut *V-threads.* When *square threads* are to be cut, the tool is ground to a squared end.

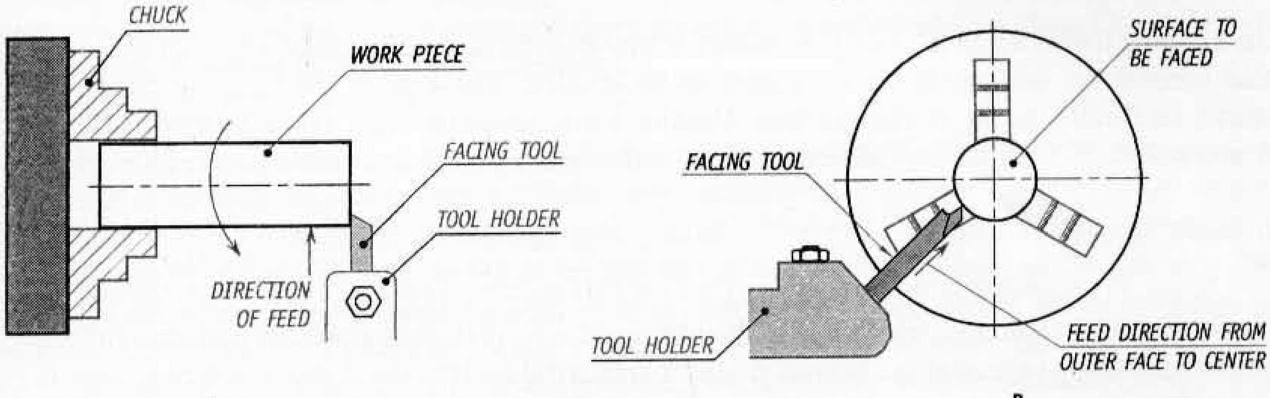


Thread Cutting

Fig. 4.9

7. Facing

Facing is defined as an operation performed on the lathe to generate either flat surfaces or shoulders at the end of the workpiece. A typical facing operation is as shown in *Fig. 4.10* below.

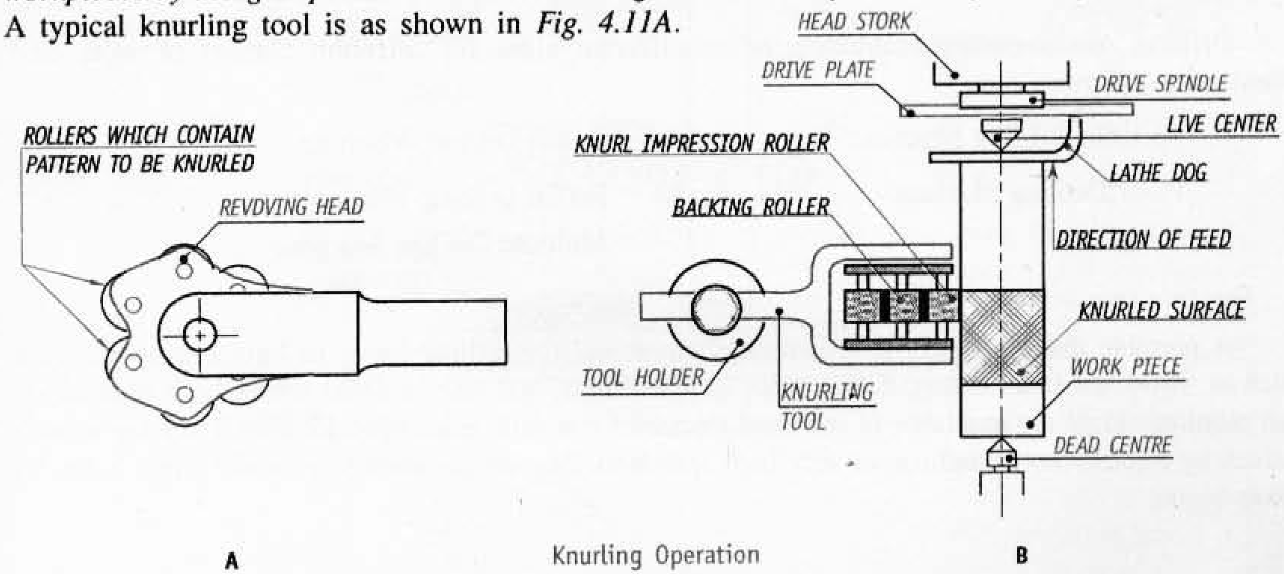


Facing Operation
Fig. 4.10

In facing operation, the direction of feed given is perpendicular to the axis of the lathe. The workpiece is held in the chuck and the facing tool is fed either from the outer edge of the workpiece progressing towards the centre or vice versa. The cutting tool is held by a tool holder in a tool post. Axial movement of the tool can be avoided by locking of the carriage. From the jaws of the chucks, the length extended should not be more than 1.5 times the diameter of the work. The finishing speeds and feeds are calculated w.r.t the largest workpiece diameter. Note that *the roughing cuts can be given either from outer surface of the workpiece to the centre or vice versa*. But the finishing cuts must always be given from centre to the outer edge of the workpiece.

8. Knurling

Knurling is defined as an operation performed on the lathe to generate serrated surfaces on workpieces by using a special tool called knurling tool which impresses its pattern on the workpiece. A typical knurling tool is as shown in *Fig. 4.11A*.



Knurling Operation
Fig. 4.11

It consists of one upper roller and one lower roller on which the desired impression pattern can be seen. The serration or impression pattern can be straight lines or diamond pattern. The serrated surface on the workpiece formed by knurling is used for applications where grip is required to hold the part. A typical knurling operation is as shown in *Fig. 4.11B*.

The knurling tool is set in the tool post in such a way that the upper and lower rollers of the knurling head touches the surface of the workpiece to be knurled. The axis of the knurling head will of course, be parallel to the workpiece axis. Usually a low speed of about 60 to 80 rpm with a feed of about 0.38 to 0.76 mm/revolution of the spindle is prescribed for knurling operation.

4.8 Drilling Machine

Drilling is a metal cutting process carried out by a rotating cutting tool to make circular holes in solid materials. The tool which makes the hole is called a *drill.* It is generally called as *twist drill,* since it has a sharp twisted edges formed around a cylindrical tool provided with a helical groove along its length to allow the cut material to escape through it. The sharp edges of the conical surfaces ground at the lower end of the rotating twist drill cuts the material by peeling it circularly layer by layer when forced against a workpiece. The removed material chips get curled and escapes through the helical groove provided in the drill. A liquid coolant is generally used while drilling to remove the heat of friction and obtain a better finish for the hole.

4.9 Drilling Machine

A power operated machine tool, which holds the drill in its spindle rotating at high speeds and when manually actuated to move linearly simultaneously against the workpiece produces a hole, is called *drilling machine*. In a drilling machine the holes can be produced to the sizes as small as *thousandth of a centimetre and upto 7.5 cm diameter.* The various other operations that can be performed on a drilling machine are : reaming, counterboring, countersinking, spot facing, thread tapping, etc.

4.10 Types of Drilling Machines

Drilling machines are manufactured in different sizes for different classes of work and classified as follows :

1. Portable Drilling Machine
2. Bench Drilling Machine
3. Pillar Drilling Machine
4. Radial Drilling Machine
5. Gang Drill
6. Multiple Drilling Machine

1. Portable Drilling Machine

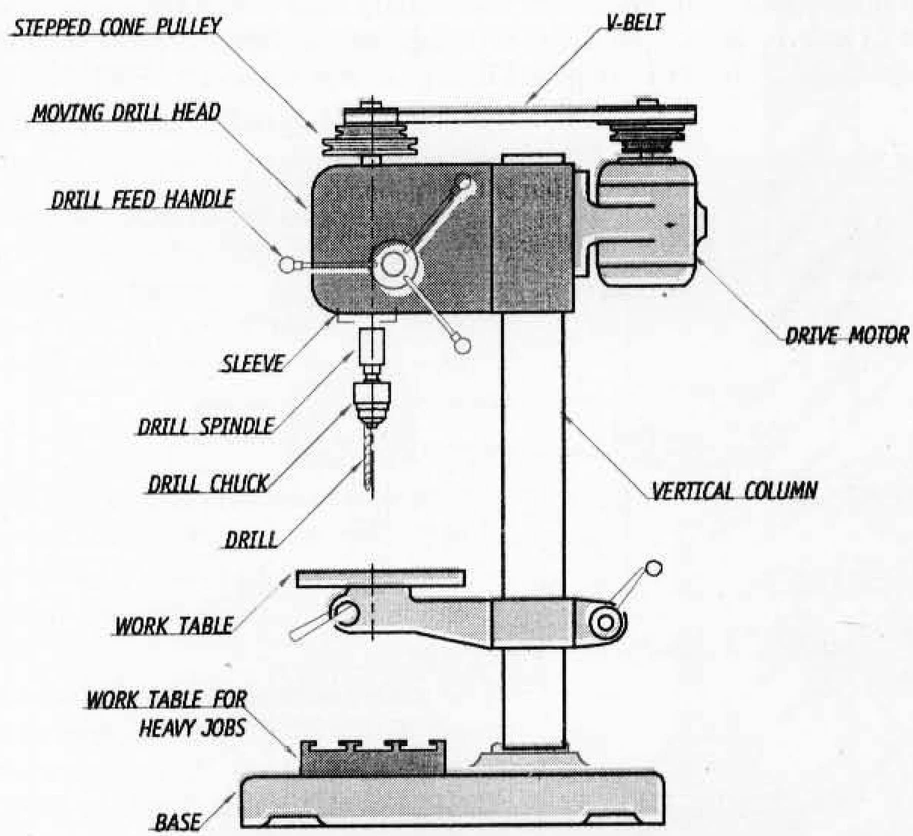
A portable drilling machine is generally employed for drilling holes in light classes of work such as, structural fabrications, fitting work in assemblies, and also in cases where high accuracy is not required. They are available in different sizes and can drill holes upto 12 mm. They are usually driven by electric motor and run at very high speeds as they are required to produce small holes for short depths.

2. *Bench Drilling Machine*

Bench drilling machines are light duty drilling machines widely used in small workshops. They are usually placed on workbenches, hence the name. This type of drilling machines are also called *sensitive drilling machines* because of its accurate and well balanced spindle, which enable the operator to sense or feel the cutting action and apply the required pressure while drilling. Generally holes of sizes upto 15 mm are drilled in these machines.

Parts of a Bench Drilling Machine

Fig. 4.12 shows a bench drilling machine. It consists of a *vertical main column* mounted over a *base*. The vertical column carries a *moving head* housing in it a *speed gear box and spindle feeding mechanism*, and a job mounting table, called *work table* which can also be raised or lowered An *electric motor* is mounted at the top end of the vertical column on its rear side. The power is transmitted to the main spindle through the stepped cone pulley drives and gearing systems. A drill chuck for small size drills is fitted in the spindle at its lower end. For bigger sizes the drill itself will be fitted directly in the spindle. The workpiece will be mounted on the work table and is clamped to it.



Bench Drilling Machine

Fig. 4.12

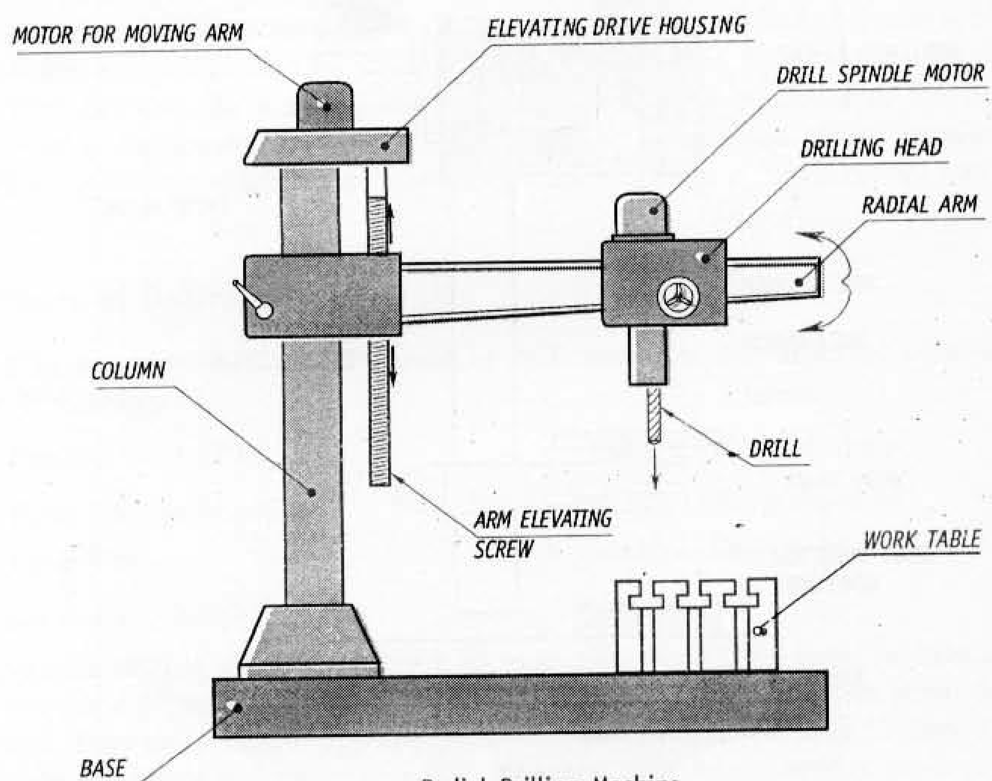
The work table can be moved up and down over the arm and locked in the required position. The centre of the hole to be drilled will be punched with a mark initially on the workpiece. Before drilling, the tip of the drill will be aligned with the centre punch mark and by the feed-wheel the rotating spindle is lowered to perform the drilling operation.

3. *Pillar Drilling Machine*

Pillar drilling machines are generally employed for both medium and heavy duty jobs and are used for drilling holes upto 50 mm diameter. A pillar drilling machine consists of a robust pillar erected over a sturdy base which is fixed on the floor. The pillar carries an adjustable table and the drill mechanism.

4. *Radial Drilling Machine*

A radial drilling machine shown in *Fig. 4.13* is used to perform the drilling operations on the workpieces which are too heavy and also may be too large to mount them on the work table of the vertical spindle drilling machine. It consists of a heavy *base* and a *vertical column* with a long *horizontal arm* extending from it and can be rapidly raised, lowered and swung in the horizontal plane about the main column to any desired location. The *drilling head* can move to and fro along the arm and can be swiveled only in the universal radial drilling machines, to drill holes at an angle. The combination of motions of the radial arm and drilling head offers a great deal of flexibility in moving the drill to any position. The main advantage of the radial drilling machine is that the drilling can be carried out on heavy work pieces in any position without moving them.



Radial Drilling Machine
Fig. 4.13

5. Multiple Spindle Drilling Machine

The multiple spindle drilling machines permit drilling of several holes of different diameters simultaneously. Generally the spindles numbering 2 to 3 or even more are driven by only one gear in the head through universal joint linkages. Each spindle is mounted with a twist drill. A jig is used to guide the twist drills. This machine finds its application in mass production.

6. Gang Drill

A gang drill is made up of many drilling heads placed side by side and the workpieces mounted on a long common work table. A gang drilling machine mounted with a drill, a reamer, a countersinking tool and a tapping attachment on its successive spindles, a threaded hole with some portion reamed and countersunk can be made by moving the workpiece mounted with a jig successively to the successive spindles to perform first drilling, secondly reaming, thirdly countersinking and finally tapping operations. Thus with a gang drilling machine various operations can be performed without changing the tools and the spindle speeds.

4.11 Nomenclature of a Twist Drill

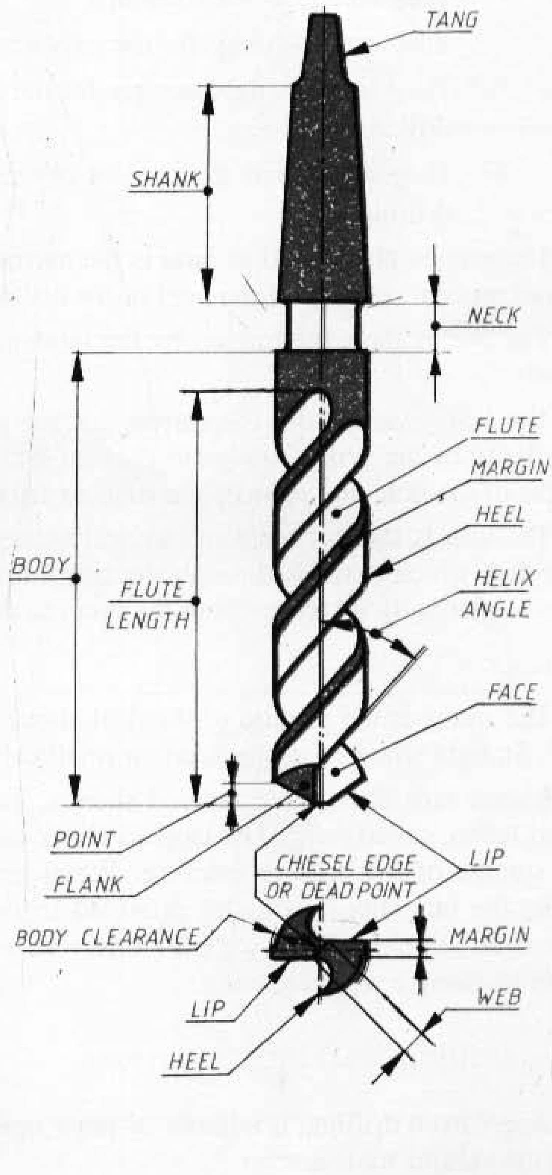
A *twist drill* shown in *Fig. 4.14* is the cutting tool that is employed in the drilling machines. Two long diametrically opposite helical flutes are formed throughout its effective length. A twist drill is composed of three major parts — *point, body* and *shank*. The functions of these are as follows.

1. Point

The *point* is the cone shaped end of the drill which cuts the material to produce the hole. It is produced by grinding the end of the drill to a conical shape so that the *chisel edge, flank* and *lips* are formed.

The *chisel edge* also known as *dead centre,* is the sharp edge formed at the extreme tip of the drill by the intersection of the two conical portions. The chisel edge will be aligned with the centre punch mark made in the workpiece at the point where the centre of the hole will lie when the hole is drilled.

The *flank* is the conical surface of the point of the drill which extends from the lip to the flute.



Nomenclature of a Twist Drill
Fig. 4.14

The *lip* is the cutting edge formed at the intersection of the flank and the inner surface of the flute. Since there are two flutes and two flanks, two lips are formed at their intersection. When the drill rotates both the lips cut the material to produce the hole.

2. Body

The *body* is the portion of the drill that extends from the tip of the drill to the lower edge of the neck. It consists of *flutes, margin, heel, web* and *body clearance.*

The *flutes* are the helical grooves that are cut on the cylindrical surface of the drill. The flutes serve the following functions.

1. They enable to form the lips.
2. They curl the chips for the easy removal of the material.
3. They serve as the passages for the flow of the curled chips out of the hole as it is being drilled.
4. They also allow the coolant or the lubricant to flow down the body of the drill while drilling.

The *margin* also called as *land* is the narrow strip along side of the flute. The margin guides the drill and prevent rubbing of the heel in the drilled hole.

The *heel* is the edge formed by the intersection of the flute surface and the undercut surface of the body.

The *body clearance* is the narrow surface gap left between the margin and the undercut portion of the body of the drill. It helps to prevent the rubbing of the entire body surface with the internal surfaces of the hole and reduces the rubbing friction.

The *web* is the thickness of the drill between the two flutes. It is the thin portion in the centre of the drill which extends through the entire length of the flutes. It is the backbone of the drill. Its thickness gradually increases from the point to the shank and makes the drill stronger at the shank.

3. Shank

The *shank* is the portion of the drill above the neck. Twist drills have either *straight* or *tapered shank*. Straight shanks are provided on small drills, i.e., less than 15 mm.

Bigger size drills have tapered shanks. The shank end of the drills is provided with a small tapered tenon, called *tang*. The tapered shank drills are mounted directly into the tapered bore of the main spindle of the drilling machine. When the drill is inserted into the tapered bore of the main spindle, the tang fits into a slot provided in the tapered bore. It drives the drill and prevents the shank from slipping. The tang also offers as a means of removing the taper shank drill from the spindle by using a wedge piece.

4.12 Drilling Machine Operations

Apart from drilling, a number of other operations that can be performed on a drilling machine using the various tools are :

1. Boring
2. Counterboring
3. Countersinking
4. Spot facing
5. Tapping
6. Reaming

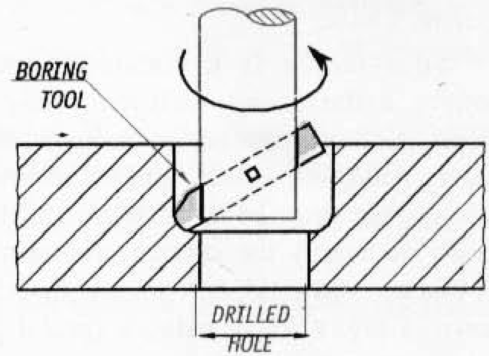
1. Reaming

Reaming is the process of smoothing the surface of the drilled holes with a reamer. A *reamer* is similar to the twist drill, but has straight flutes. After drilling the hole to a slightly smaller size, the reamer is mounted in place of twist drill and with the speed reduced to half of that of the drilling, reaming is done in the same way as drilling. It removes only a small amount of material and produces a smooth finish on the drilled surfaces.

2. Boring

Boring is done on a drilling machine to increase the size of an already drilled hole. When a suitable size drill is not available, initially a hole is drilled to the nearest size and using a single point cutting tool, the size of the hole is increased as shown in *Fig. 4.15*.

By lowering the tool while it is continuously rotating, the size of the hole is increased to its entire depth. *Fig. 4.15* shows when the boring operation is in progress. It will be continued till the lower surface of the workpiece.



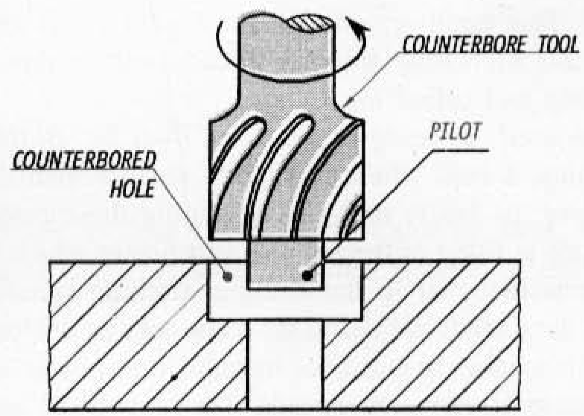
Boring

Fig. 4.15

3. Counterboring

Counterboring is to increase the size of a hole at one end only through a small depth as shown in *Fig. 4.16*. The counterboring forms a larger sized recess or a shoulder to the existing hole. The cutting tool will have a small cylindrical projection known as pilot to guide the tool while counterboring. The diameter of the pilot will always be equal to the diameter of the previously drilled hole. Interchangeable pilots of different diameters are also used for counterboring holes of different diameters. The *speeds for counterboring must be two-thirds of the drilling speed the corresponding size of the drilled hole.*

Generally the counterboring is done on the holes to accommodate the socket head screws, or grooved nuts, or round head bolts.

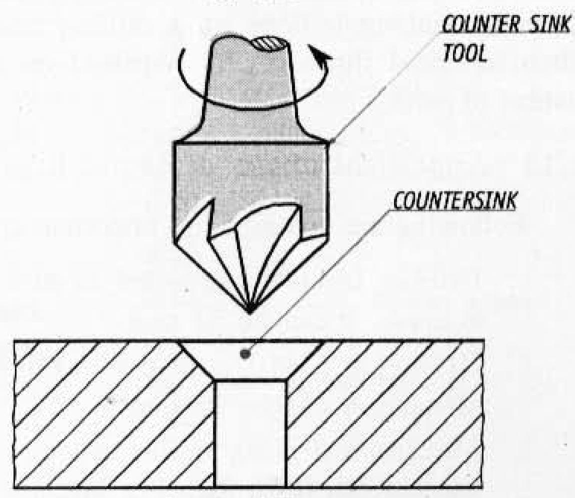


Counterboring

Fig. 4.16

4. Countersinking

Countersinking shown in *Fig. 4.17* is the operation of making the end of a hole into a conical shape. It is done using a countersinking tool shown in figure. The countersinking process may also be employed for deburring the holes.



Countersinking

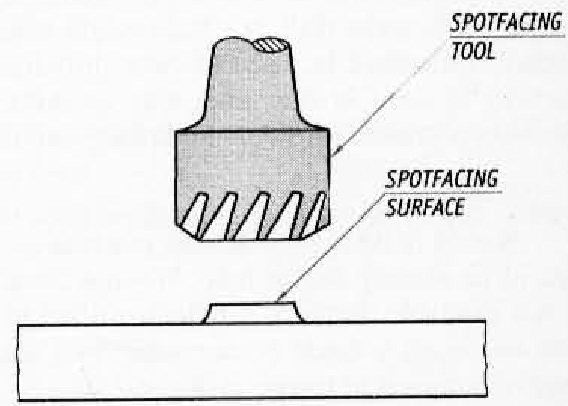
Fig. 4.17

The *cutting speeds for countersinking must be about one-half of that used for similar size drill.*

The countersunk holes are used when the countersunk screws are to be screwed into the holes so that their top faces have to be in flush with the top surface of the workpiece.

5. Spot Facing

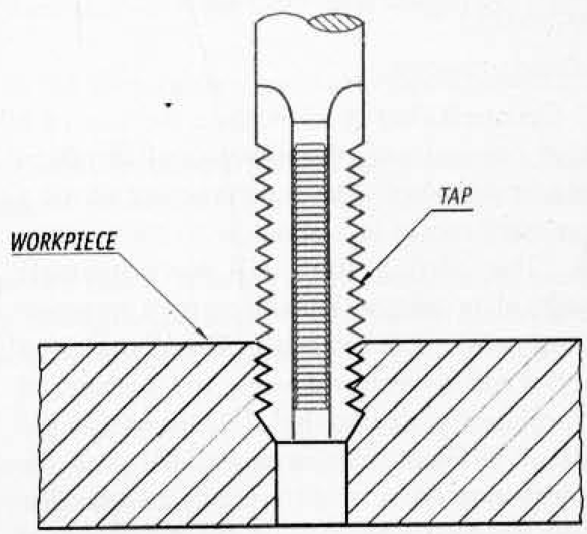
Spot facing is a finishing operation to produce a flat round surface usually around a drilled hole, to give a good bearing surface for the proper seating of a bolt head or a nut. The spot that is faced may be a circular raised pad on a casting or merely the surface around a bolt hole. Spot facing may be done with a counterboring tool shown in *Fig. 4.16,* or using a special spot facing tool shown in *Fig. 4.18.*



Spot Facing
Fig. 4.18

6. Tapping

The tapping, shown in *Fig. 4.19* is the process of cutting internal threads with a thread cutting tool called *tap. A tap is a fluted threaded tool used for cutting internal threads.* Before tapping, a hole which is slightly smaller than the size of the tap is drilled. For cutting the threads, the tap is fitted in the tapping attachment which in turn is mounted in the drilling machine spindle, and the threads are cut in the same way as drilling. While tapping in a drilling machine the spindle has to rotate at very slow speeds. The tap will be held in a collapsible type of tapping chuck, which is inserted in the spindle of the drilling machine. Generally tapping is done on a drilling machine when identical threading is required on large number of parts.



Tapping
Fig. 4.19

4.13 Specifications of a Radial Drilling Machine

Following are some of the important specifications of a Radial Drilling Machine:

1. **Drilling in steel expressed in mm** : This is the depth that can be drilled in steel. For example, it can be 32 mm.
2. **Drilling in Cast Iron expressed in mm** : This is the depth that can be drilled in steel. For example, it can be 35 mm.
3. **Maximum drilling radius expressed in mm** : It is the maximum extent of radius of the job that can be drilled. For instance it can be 900 mm.

4. **Minimum drilling radius expressed in mm** : It is the minimum extent of radius of the job that can be drilled. For instance it can be 350 mm.
5. **Vertical power movement of arm expressed in mm** : It is the distance of the vertical distance by which the arm moves. For instance it can be 500 mm
6. **Horizontal power movement of head expressed in mm** : It is the distance by which the head holding the spindle can traverse horizontally. For instance it can be 600 mm.
7. **Drilling motor power expressed in kW** : It is the power capacity of the drilling motor. For instance it can be 1.5 kW
8. **Spindle speed range expressed in rpm** : It is the range of speed within which the spindle rotates for the given design. For instance it can be 50-2800 rpm
9. **Swing of arm expressed in degrees** : It is the angular swing of the arm of the machine. It will be usually 360 degrees.
10. **Stroke of spindle expressed in mm** : It is the vertical distance by which the spindle can traverse. For instance it can be 250 mm
11. **Power feed range expressed in mm/rev** : It is the range of feed that can be given per revolution of the spindle. For example: 0.030-0.315 mm per revolution.

4.14 Specifications of a Drilling Machine

A Drilling machine can be specified by the following Specifications :

1. Drilling Capacity in Steel :

This denotes the capacity of the drilling machine to drill into jobwork mode of steel. It is usually expressed by the depth upto which drilling is done. Drilling machines capable of drilling upto a depth of 20 mm are available in the market.

2. Spindle Traverse :

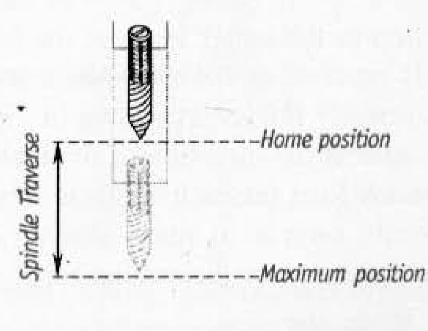
This is the extent by which the rotating spindle of the drilling machine can traverse vertically from its home position of position of rest to the maximum vertical distance downwards. This is expressed in mm.

3. Spindle Speed Range :

This is the range of speed by which the Spindle of the drilling machine is able to rotate. This is expressed in revolutions per minute or RPM. For example, the range can be from 500 – 2000 rpm.

4. Table Overall Size :

This is the area on the work table where the targeted jobs are to be clamped to the table. They are usually expressed as Length X width (mm × mm) of the table for instance, the table size is 280 × 280 sq.mm.



Spindle Traverse
Fig. 4.20

5. Table Working Surface

This is the area available out of the overall size of the table for carrying out the desired work. For instance, as shown in the above figure, the Working surface is 200 × 200 sq.mm out of 280 × 280 sq.mm

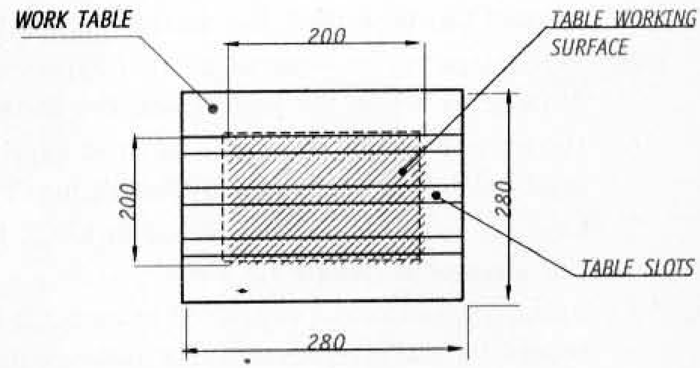


Table Working Surface
Fig. 4.21

6. Power and Speed of the Motor :

Power, usually expressed in kW (or HP) and its speed in RPM is helpful in power calculations and cost calculations. For instance, the power and speed can be 1 HP/ 1440 rpm in Standard Bench Drilling Machines.

4.15 Milling Machine

Milling is a metal cutting operation in which the operating tool is a slow revolving cutter having cutting teeth formed on its periphery. The milling cutter is a *multipoint cutting tool.* The work piece is mounted on a movable work table which will be fed against the revolving milling cutter to perform the cutting operation.

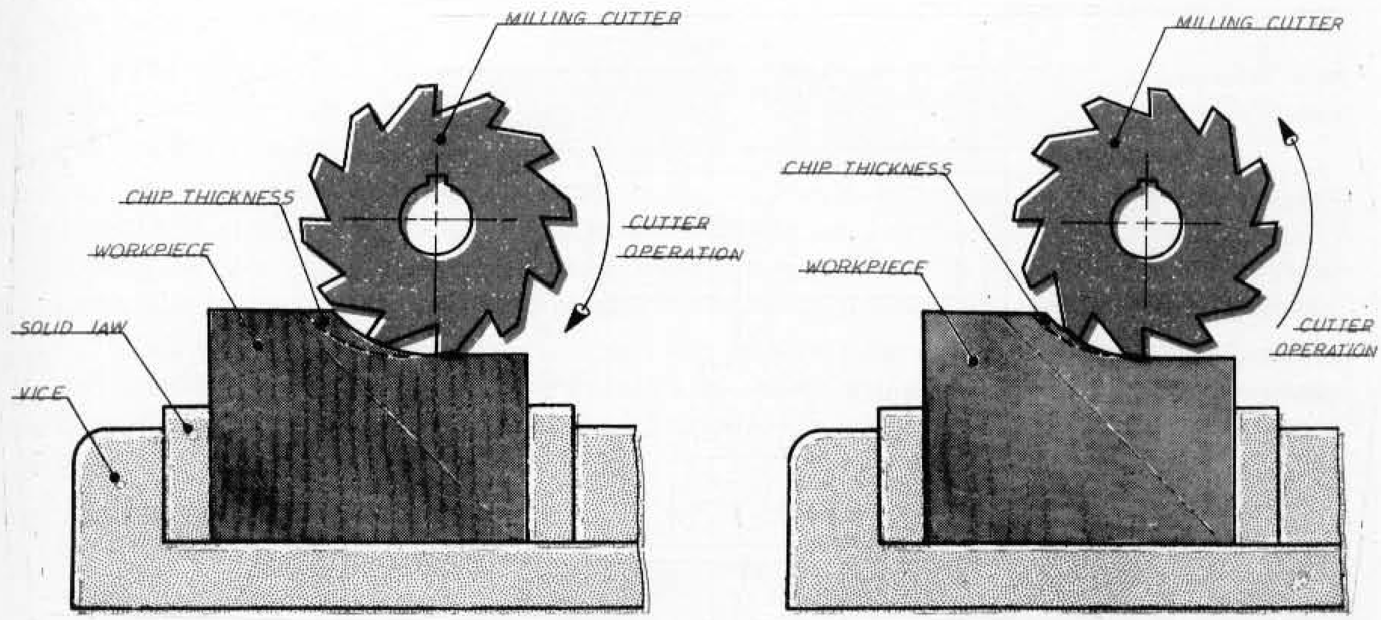
The difference between drilling and milling is that, in *drilling a rotating drill is fed against a stationary workpiece, while in milling the workpiece is fed against a milling cutter which only revolves.* Similarly, it also differs from the lathe operation because the *lathe tool is fed against rotating workpiece.*

A *milling machine* is a power operated machine tool in which the workpiece mounted on moving table is machined to various shapes when moved under a slow revolving serrated cutter.

4.16 Principle of Milling

Fig. 4.22 shows the principle of cutting action of the milling cutter. The milling cutter is mounted on a rotating shaft known as *arbor. The workpiece which is mounted on the table can be fed either in the direction opposite to that of the rotating cutter* as shown in *Fig. 4.22A* or *in the same direction of that of the cutter* as shown in *Fig. 4.22B*. When the workpiece is fed in the opposite direction to the cutter tooth at the point of contact, the process is called *conventional or up milling.* In this process, as the workpiece advances against the rotating cutter, the chip that is removed gets *progressively thicker* as shown in *Fig. 4.22A* . The action of the cutter forces the workpiece and the table against the direction of the table feed, thus each cutter tooth enters a clean metal gradually thus the shock load on each tooth is minimised. The disadvantage of this method is that when making deep cuts, such as in heavy slotting operations, the cutter tends to pull the workpiece out of the vice or the fixture since the cutting force is directed upward at an angle.

When the workpiece is fed in the same direction as that of the cutter tooth at the point of contact, as shown in *Fig. 4.22B,* the process is called *climb or down milling.* In this process, the cutter enters the top of the workpiece and removes the chip that gets *progressively thinner* as the cutter tooth rotates. Generally, more metal can be removed for each cut than the conventional up milling. Climb milling is used only on materials that are free of scale and other surface imperfections that would damage the cutters.



A B

Principle of Milling
Fig. 4.22

4.17 Classification of Milling Machine

The milling machines are broadly classified into :

1. Plain or Horizontal Type of Milling Machine
2. Vertical Milling Machine
3. Universal Milling Machine
4. Planer Type Milling Machine
5. Profile Cutting Milling Machine

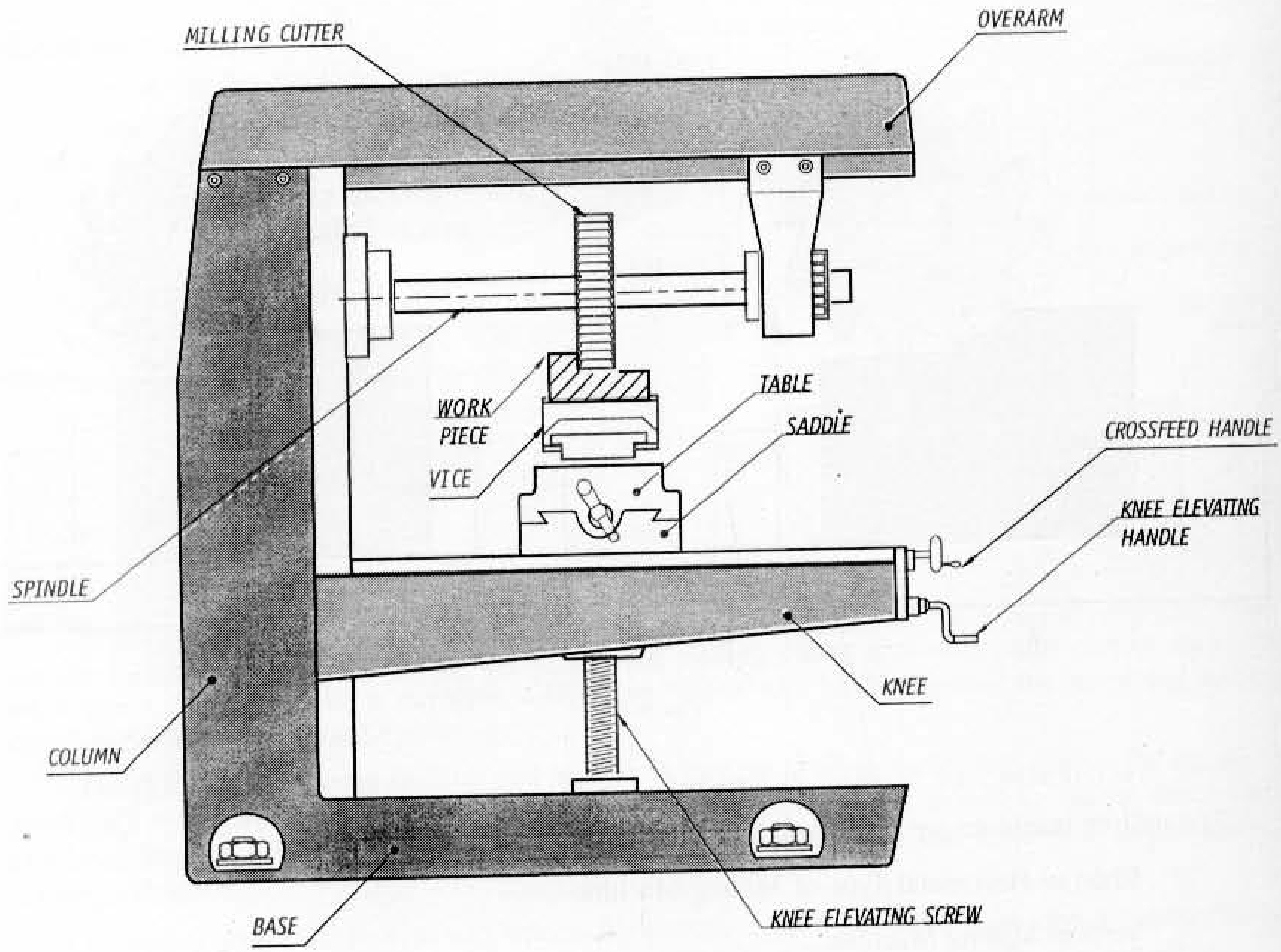
4.18 Horizontal Milling Machine

Fig. 4.23 shows the different parts of a horizontal milling machine. They are :

1. Column	3. Arbor	5. Saddle
2. Spindle	4. Knee	6. Table

1. Column

The column is usually combined with the base into a single casting. The column houses the spindle, transmission systems from the electric motor to the spindle and it enables to mount the table control and lifting mechanisms. The front vertical face of the column is provided with a vertical slide which may be of square or dovetail type. The knee moves up and down on this slide. At the top of the column, an internal dovetail slide accommodates a cast overarm. The overarm supports the arbor.



Horizontal Milling Machine

Fig. 4.23

2. Arbor

The arbor is a horizontal shaft provided with a straight body and tapered shank. On the straight portion of arbor rotary cutters are mounted. The tapered end of the arbor fits into the tapered hole of the spindle. The other end of the arbor is mounted in a bearing housed in the projecting overarm.

The knee is a casting mounted on the front vertical slide of the column and is moved up or down by an elevating screw. The upper face of the knee is provided with guideways so as to mount the saddle.

3. Knee

The knee is a casting mounted on the front vertical slide of the column and is moved up or down by an elevating screw. The upper face of the knee is provided with guideways so as to mount the saddle.

4. Saddle

The saddle is a casting provided with two slides one at the top and the other at the bottom which are exactly at 90° to each other. The lower slide fits within the guideways on the top of the knee and the upper slide receives the dovetail guides provided on the bottom of the table.

5. Table

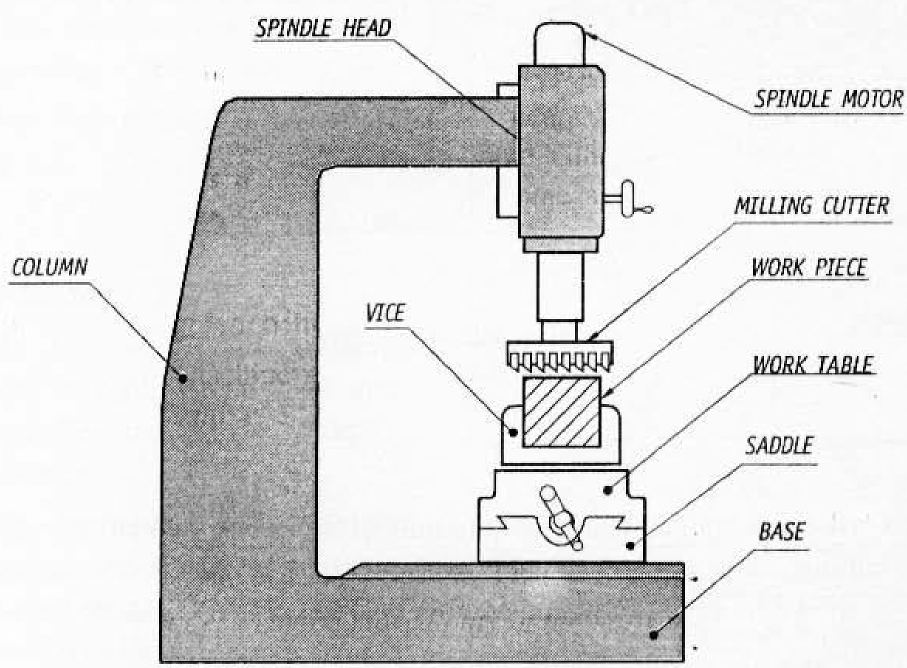
The table is mounted on the top of the saddle. The bottom of the table has a dovetail slide which fits in the slide ways on the top of the saddle. The top of. the table is machined with several full length T-slots for mounting vices or other work-holding fixtures.

The horizontal milling machine shown in *Fig. 4.23* has its cutter axis horizontal. The workpiece is held in a vice mounted on the machine table which is fitted over a saddle. The feed is given by moving the table against the horizontal axis of the revolving cutter. The cross feed handle enables the entire table to move across the knee. The knee can be raised or lowered by the knee elevating handle.

This type of milling machine is commonly employed for milling operations which can be performed by feeding the workpiece in a straight line, either vertically or horizontally. Few examples of milling operations carried on this type of machine are : keyways, grooves, gear teeth, spline shafts, etc.

4.19 Vertical Milling Machines

In a vertical milling machine shown in *Fig. 4.24,* the *spindle is mounted with its axis vertical perpendicular to the work table.* The *column* and the *base* are formed into an integral casting. The *spindle head* is fitted vertically in the guideways provided in the projecting end of the column. The spindle can be moved up and down over the guideways. A *saddle* is mounted over the guideways provided on top of the base. The saddle can be moved in the *transverse direction.* The *work table* will be mounted over the saddle and can be moved *longitudinally.* In this machine, unlike the horizontal milling machine, the *workpiece can be moved only in the horizontal plane both longitudinally and in the transverse direction, but not vertically.*



Vertical Milling Machine
Fig. 4.24

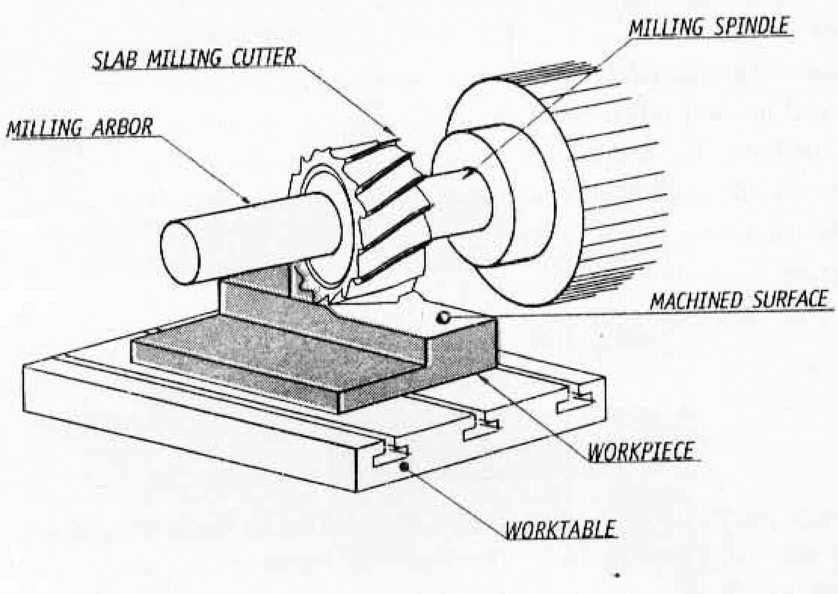
The rotating cutter can be either raised or lowered to give the required depth of cut. The vertical milling machines will be more suitable for cutting long grooves and slots and also to produce flat faces. In this type of milling machine the face milling and the end milling cutters are the most commonly used type of cutters.

4.20 Milling Processes

1. Plain Milling

Plain Milling or slab milling is a process used to mill flat surfaces of workpieces in such a way that the milling cutter axis is parallel to the surface that is being milled. The figure below illustrates plain milling operation carried out on a horizontal milling machine with the milling cutter mounted on the standard milling arbor.

In plain milling, the surface of the workpiece is parallel to the table surface as shown in *Fig 4.25*.

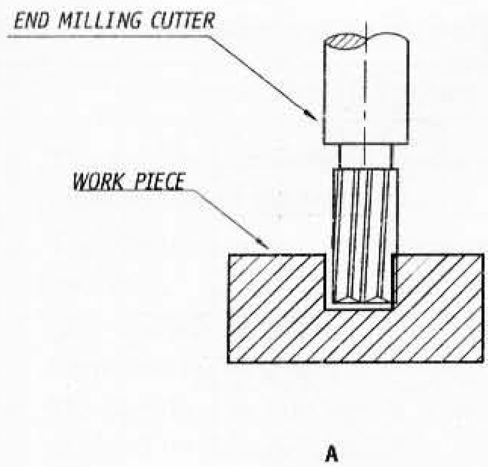


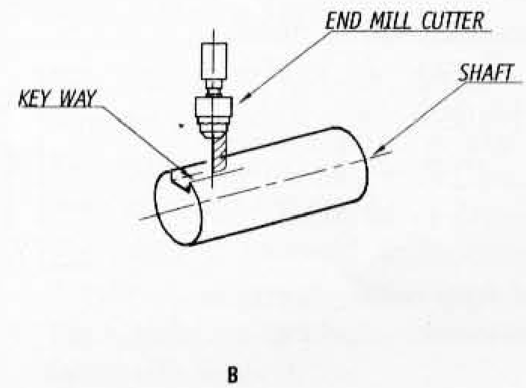
Plain Milling
Fig. 4.25

2. End Milling

End Milling is a process of milling that is used to mill slots, pockets and keyways in such a way that the axis of the milling cutter is perpendicular to the surface of the workpiece. A typical end milling operation is as shown in *Fig. 4.26A*. End Milling operation when used for keyway cutting is as shown in the *Fig 4.26B*.

The advantage of the End Milling Operation is that we can achieve depth of cut of nearly half the diameter of the mill.



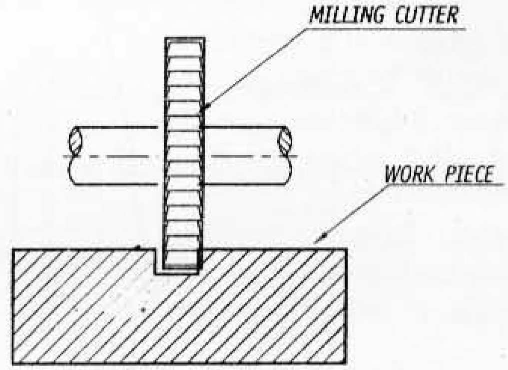


End Milling
Fig. 4.26

3. *Slot Milling*

Slot Milling is the process of milling slots using a different type of cutter called "Slot drill" which has the capacity to cut into solid material. Slot drill is used majorly in cases where it takes a lot of time to pre-drill a hole for an end mill and there is not enough room for the end mill to plunge using a helical motion.

A typical slot milling operation is shown in *Fig.4.27*.

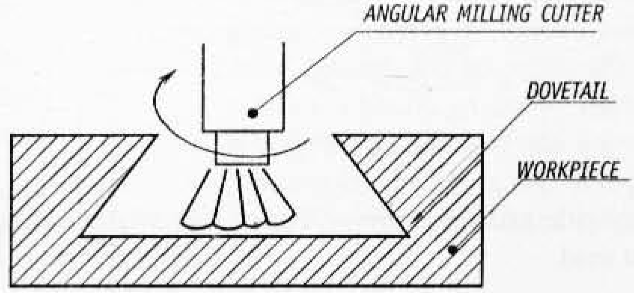


Slot Milling
Fig. 4.27

4. *Angular Milling :*

Angular Milling is the milling operation used to mill flat surfaces that are neither parallel nor perpendicular to the milling cutter axis.

Angular surfaces like dovetail grooves, chamfers and serrations are done through this operation. The most popular is milling of dovetails as shown in the *Fig.4.28*.

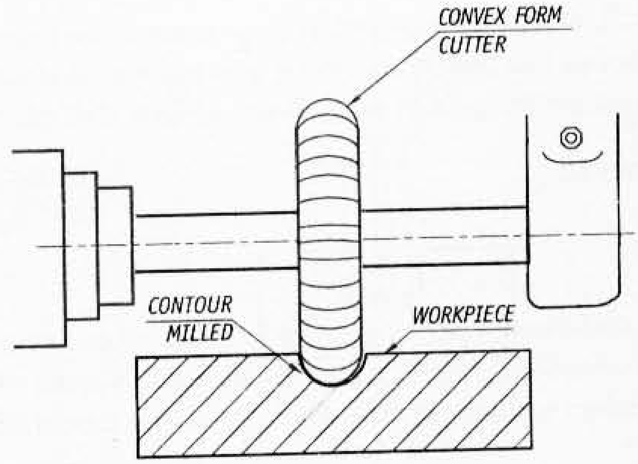


Angular Milling
Fig. 4.28

5. Form Milling

Form Milling is a milling process used to machine special forms / contours consisting of curves and /or straight lines by using a special "form mill cutter" which are shaped exactly to the contour that is to be form-milled.

A typical form milling operation is as shown in the *Fig. 4.29*.

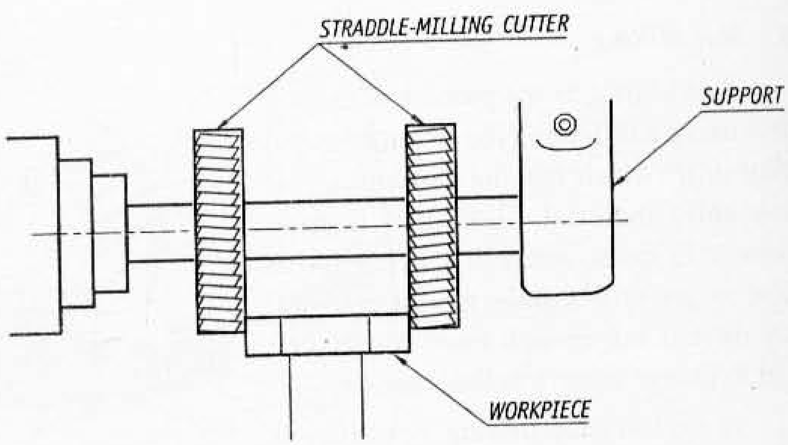


Form Milling
Fig. 4.29

6. Straddle Milling

Straddle Milling is a milling operation that is used to machine two or more parallel vertical surfaces at a single time by mounting two side milling cutters on the same standard milling arbor separated by a calculated spacing.

A typical straddle milling operation used to mill sides of a hexagon is as shown in the *Fig. 4:30*.

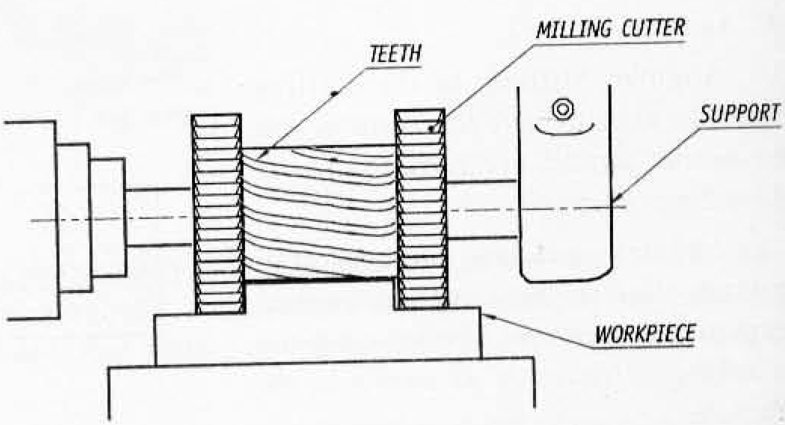


Straddle Milling
Fig. 4.30

7. Gang Milling

Gang Milling is a process of milling which is similar to the Straddle Milling, but the machining is done with several types of milling cutters according to the shape of the desired work surface. But, in straddle milling (which can be called as a special type of gang milling operation) only side and face milling cutters are used.

A typical Gang Milling operation is as shown in the *Fig. 4.31*.



Gang Milling
Fig. 4.31

4.21 Differences between Horizontal and Vertical Milling machines

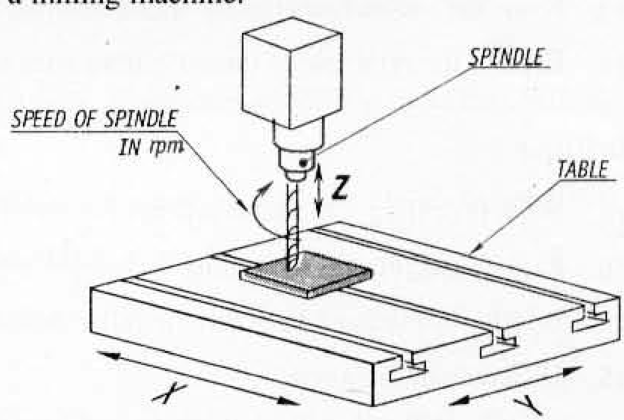
Horizontal Milling Machine	Vertical Milling Machine
1. The spindle is horizontal and in the same plane as that of the worktable.	1. The spindle is vertical and in a plane perpendicular to that of the worktable.
2. The milling cutter can rotate about its own axis.	2. The milling cutter can be moved up and down along the vertical axis.
3. The cutter is mounted on an arbor supported by an overarm.	3. The cutter is mounted on to the spindle directly .
4. The spindle can only rotate about its own axis and no tilting is possible.	4. The spindle can be tilted to the left or right for specific applications.
5. The operations that can be done are gear teeth cutting, plain milling, straddle milling, gang milling, form milling, etc.,	5. The operations that can be done are slot milling, T-slot milling, angular milling, key way milling, end milling, etc. In addition it can also do drilling, boring and reaming.

4.22 Milling Machine Specifications :

Just as any other machine tool, milling machine should also be specified by some general Specifications. It is only through these specifications that the milling machines can be selected to optimally suit the applications or jobs. These specifications act as guidelines for expressing the capacity of the Milling machine.

The following are the general specifications of a milling machine.

1. *Clamping Area* : This is the area on the work table where the targeted jobs are to be clamped to the table. They are expressed as length X width of the table.
2. *Longitudinal Movement* : This is the distance along the X-axis by which the table along with the job moves longitudinally. This is expressed in mm.
3. *Transverse Movement* : This is the distance along the Y-axis by which the table travels in the transverse direction expressed in mm.



Axes Interpretation in Milling

Fig. 4.32

4. *Vertical Movement*: This is the distance vertically along the X-axis by which the spindle travels. It is expressed in mm.
5. *Speed*: This is the speed of the spindle rotation expressed in revolutions per minute (rpm).
6. *Power of the Milling Spindle motor* : This is the power capacity of the motor of the spindle expressed in kW.
7. *Power of the Feed Motor*: This is the power capacity of the feed motor expressed in kW. *Fig. 4.32* shows the axes interpretation in Milling Machines.

EXERCISES 4

Lathe

1. Define a machine tool
2. What is the function of a lathe ?
3. Write a neat sketch of a single point lathe tool and name all its parts and as well as the angles.
4. Explain with a neat diagram the principal parts of an engine lathe.
5. Explain how the size of a lathe is specified.
6. Explain with neat sketches any three parts of a lathe. *(VTU, March 2001)*
7. What are the provisions made on a lathe to obtain different speeds ?
8. With a neat sketch highlight the specification of a lathe. *(VTU, September 1999)*
9. Explain the principle of taper turning with necessary sketches.
10. Briefly explain the following operations performed on a lathe:
    a. Plain turning b. Taper turning c. Thread cutting d. Facing e. Knurling
11. Explain the swiveling of tool post method of taper turning. *(VTU, September 2000)*
12. Explain briefly taper turning by tailstock set over method. *(VTU, March 1999)*
13. Name the various machining operations that can be conducted on a lathe.
14. Explain the principle of thread cutting with necessary sketches.

Drilling

15. What is drilling ? Mention different types of drilling machines. *(VTU, September 2000)*
16. Explain the process of drilling ?
17. Briefly differentiate between the pillar drilling machine and universal drilling machine.
18. Differentiate between :
    (a) Portable drilling machine and Sensitive drilling machine
    (b) Multiple spindle drilling machine and Radial drilling machine
19. With necessary sketches, name the different elements and angles of a twist drill.
20. Explain with a neat sketch the parts of a bench drilling machine.
21. Explain with a neat sketch the parts and working of a radial drilling machine.
22. What is the main advantage of a radial drilling machine ?

23. Name the various operations that can be performed on a drilling machine.
24. Differentiate between :
    (a) Drilling and Reaming.
    (b) Boring and Counterboring.
    (c) Countersinking and Spot facing.
25. Differentiate between :
    (a) Drilling and Boring.
    (b) Countersinking and counterboring. *(VTU, March 2001)*
26. Explain countersinking operation on a drilling machine with simple sketch. *(VTU, March 2001)*
27. Explain how and when a thread cutting is performed on a drilling machine.
28. Briefly explain the specifications of a radial drilling machine.
29. Briefly explain the general specifications of a drilling machine.

Milling

30. What is milling ? Explain. Classify the different types of Milling Machines.
31. What is the difference between milling, drilling and turning ?
32. With the help of a neat sketch explain the working of a horizontal milling machine.
33. Explain with a neat diagram, principle of working of a milling machine.
34. With the help of sketches differentiate between up and down milling operations.
35. Differentiate between :
    (a) Climb Milling and Conventional Milling (b) Conventional Milling and Gang Milling
    (c) Horizontal and Vertical Milling Machine
36. List out the various operations that can be performed on a milling machine. *(VTU, March 2001)*
37. Explain briefly the specifications of a Milling Machine.

CHAPTER 5

ROBOTICS

5.1 History and Development of Robotics

The word "Robot" was first coined by the Czech novelist Karel Capek in his 1920s play called "Rassum's Universal Robots (RUR)". In Czech, the word Robot means a servant or a worker. However, this was just a word coined. But the actual technological development in the field of Robotics was first noted in 1957 when the English inventor Cyril Walter Kenward developed a manipulator that could move in x-y-z axes system. The significant development that laid foundation of today's robotics industry came when an American inventor George Devol joined hands with a physicist an engineer called Joseph Engelberger to form an organization called Unimation Inc. from where they unveiled the first digitally operated and programmable Robot called the "Unimate" in the year 1954. This became the foundation stone for future development of the Robotics industry. The first Unimate was sold to General Motors in 1961 to perform repetitive tasks and unloading a die-casting machine. Since then there have been immense advancements in Robotics such as the "Shaky" robot developed by Stanford Research Institute in 1966. The Shaky Robot was a mobile robot created to know and react to its own actions. The German company KUKA developed first robot with six electromechanically driven axes in the 1970s. This was called the FAMULUS. In 1981, Takeo Kanade, a Japanese scientist built the "direct drive arm" which used motors and was faster than the earlier robots. In recent times, Honda in the year 2000 unveiled the World's most advanced humanoid robot called ASIMO (**A**dvanced **S**tep in **I**nnovative **Mo**bility). In 2003, NASA launched Mer-a-spirit which is a robotic rover intended for exploration of the planet Mars. In 2012, GM and NASA came together and developed the Robonaut 2.

5.2 Robot and Robotics

Robot definition: The Robot Institute of America in 1979 defined a Robot as follows:

A Robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions of performance of a variety of tasks.

A robot that is used to perform tasks in industries is called as an "industrial robot". An industrial robot can perform wide range of industrial tasks like loading, unloading, welding, painting, inspection, assembly, material transfer, etc.

Robotics definition: *Robotics can be defined "as a field of technology that deals with the conception, design, construction, operation and application of robots".*

Robots possess anthropomorphic characteristics (meaning human-like characteristics) such as mechanical arm (resembling human arm) to perform variety of tasks, capability to respond to sensory inputs, communication, interaction and taking decisions.

But why a robot is required when a human can perform the tasks? That is because of the following qualities:

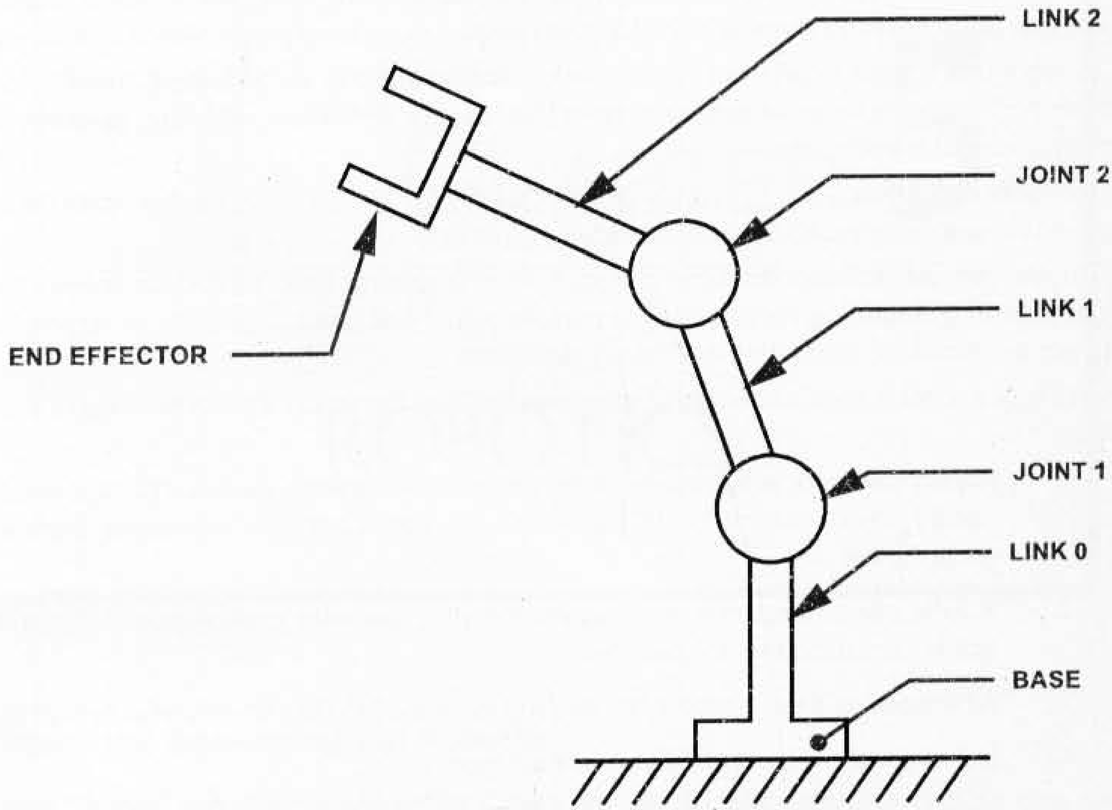
1. Robots can work in hazardous or dangerous environments such as a nuclear reactor, behind enemy lines, outside earth's atmosphere, etc. They can substitute humans in such environment.
2. Robots can consistently work as per the program with great repeatability and accuracy that is unmatched by the humans.
3. At the end of a task, robots can be reprogrammed to take up different task altogether.
4. Robot parts can be replaced when damaged.
5. In industries, Computer Integrated Manufacturing can be realized by connecting robots to computer system and carrying out the different tasks.

5.3 Basic terms related to Industrial Robots

In the study of Robotics, few basic terms are used quote often and their meanings are quite important. The terms used in relation to Industrial Robots are as below:

1. *Manipulator*: manipulator is an arm-like mechanism which is designed to manipulate or move materials, parts or tools without direct human contact.
2. *Joint*: A joint is the one that integrates two or more links to provide controlled relative movement between input link and the output link.
3. *Link*: The link is a rigid member that connects the joints. Link can be an input link and an output link. The movement of the input link causes various motions of the output link.
4. *Degrees of freedom (d.o.f)*: The degrees of freedom describes a robot's freedom of motion in the three-dimensional space.
5. *End effector*: End effector or end-of-arm tool is the device at the end of the robotic arm which is shaped like a hand or as a special tool depending upon the application.
6. *Base*: The support for the robot arm is called as the base.

Using the above terms, a simple robot construction is shown in *Fig 5.1* below:



Simple Robot Construction
Fig. 5.1

5.4 Elements of a Robotic System

A Robotic system has the following basic elements:

1. **The Robot**: This consists of
   a. The *Manipulator* which includes the base and the arm assembly.
   b. *End-of-the-arm tooling* which is the end-effector.
   c. *Actuators* which convert stored energy into movement. Common actuators include electric motors and linear actuators.
   d. *Transmission elements* such as ball screws, pulleys, belts, gears, etc.

2. **Control System**: The control system generates the required signals to co-ordinate and execute the robot movements. The Control System comprises of:
   a. *Controls* such as Mechanical control, hydraulic control, pneumatic control, electrical or electronic control. The control techniques can be an open-loop (non-servo) control, feedback control, feed forward control and adaptive control.

b. *Sensors* that allows robots to collect information about a certain measurement of the environment or internal components. The sensors can be touch sensors or vision sensors.

c. Equipment Interfaces

3. **Computer System**: The Computer system is used to program the robots according to the tasks required to be performed. The necessary software must be installed in the computer to develop robot programs.

4. **Power Source**: Power source supplies electrical energy for the robot. The commonly used power source is the battery which can be a lead-acid battery or a silver-cadmium battery.

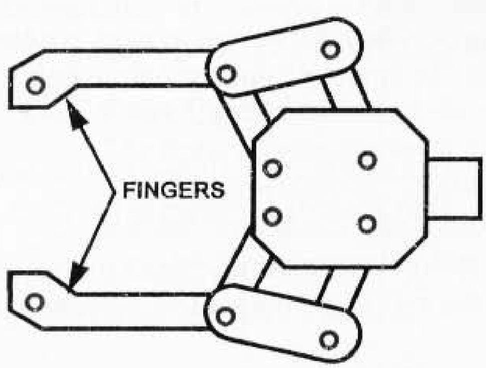
5.5 Types of End Effectors

There are broadly two types of end-effectors:

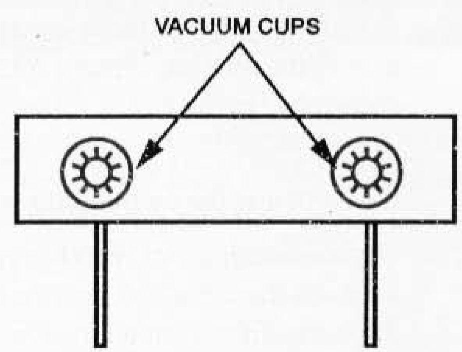
1. Grippers
2. Tools

Let us get into few details of the above types as explained below:

1. Grippers: Gripper is a component of a robot that is used to grasp the object/s to be manipulated. Grippers are either actuated pneumatically or by using servomotors. The design of a gripper depends on the shape, size and weight of the part to be gripped.



(a) Mechanical Gripper

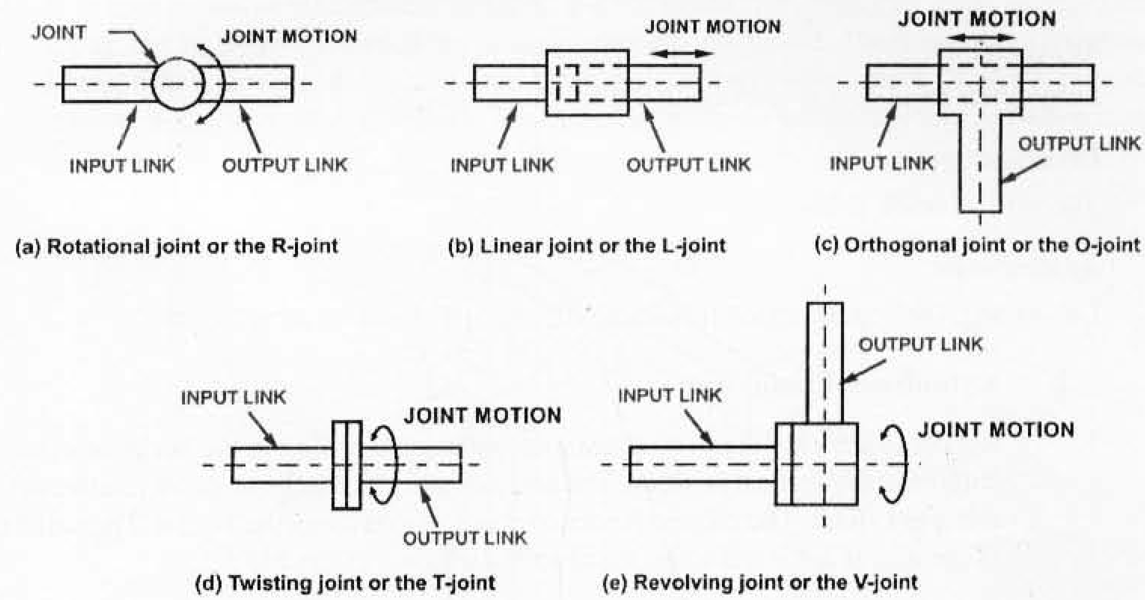


(b) Vacuum Gripper

Types of Grippers
Fig. 5.2

There are various types of grippers available:

(a)Mechanical Grippers: As shown in *Fig 5.2 (a)*, in its simplest form, a mechanical gripper consists of two fingers that can open and close to pick up and let go of the parts. The Robot uses hydraulic, electric or pneumatic drive system to produce the input power which is transmitted to the gripper to make the fingers react.

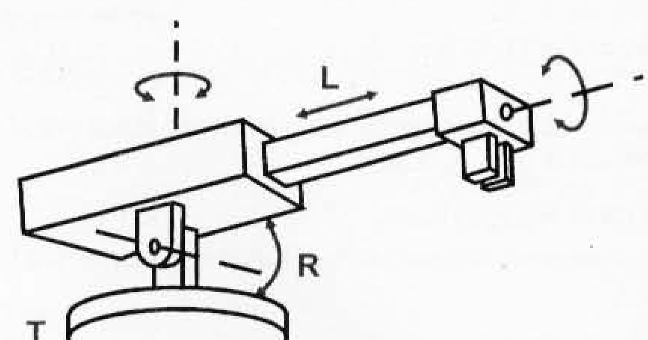


Types of Robot joints
Fig. 5.3

5.7 Classification of Robot based on Robot Configurations

Though there are various ways to classify robots, in this section we take up the classification based on robot configurations. The robot types can be classified based on the robot configurations as:

1. **Polar Configuration (Spherical Configuration):**
   The Polar configuration robots also called as the spherical configuration robots consists of a sliding arm (L-joint) that is actuated relative to the body and a rotational base along with a pivot, which can rotate about a horizontal axis (R joint) and the vertical axis (T Joint). This is shown in the *Fig.5.4*.



Polar Configuration Robot
Fig. 5.4

The one linear and the two rotary joints creates a spherical work volume in which the robot operates. Example: The Unimate 2000 series robot. (*Courtesy: Unimation Inc.*)

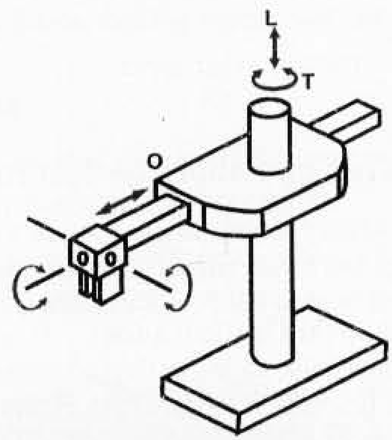
Advantage:
Long reach capability is realized in the horizontal position

Disadvantage:
The vertical reach is low.

Applications:
Die casting, forging, injection moulding, dip coating, cleaning of parts, etc.

2. **Cylindrical Configuration:**

Robots of the cylindrical configuration consists of a slide in the horizontal position and a column in the vertical position. The arm assembly moves up or down relative to the column using as L-joint. The column is rotated about its axis using the T-joint. The radial movement of the arm is achieved using the O-joint as shown in the *Fig 5.5*.



Cylindrical Configuration Robot
Fig. 5.5

Example: Model 1A Robot of GMF Robotics Corp. *(Courtesy: GMF Robotics Corp.)*

Advantages:

1. Rigidity is increased and is quite robust.

2. Has the capacity to carry high payloads.

Disadvantages:

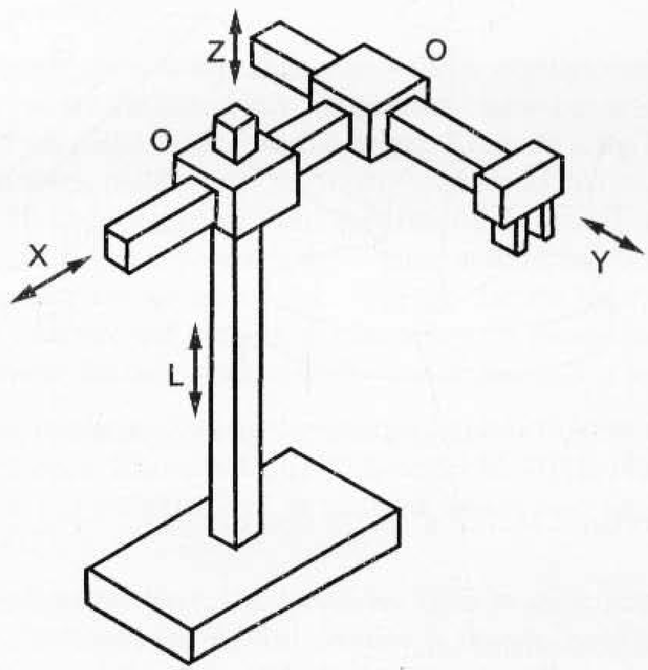
1. Work volume is less.

2. Occupies more floor space.

Applications: Foundry and forging applications, investment casting, conveyor pallet transfers, machine loading and unloading

3. Cartesian Co-ordinate Robot:

It is also called as a rectilinear robot or a XYZ Robot. It consists of three sliding joints along the X, Y and Z directions in three dimensional space. There are two orthogonal joints. Since movement can stop and start simultaneously along the X, Y and Z axes, the motion of the tool tip is smoother. A typical Cartesian co-ordinate Robot is shown in the *Fig. 5.6*.



Cartesian Co-ordinate Robot

Fig. 5.6

Example: The IBM 7565 Robot *(Courtesy: IBM)*

Advantages:

- Allows for simpler controls.
- Possess a high degree of mechanical rigidity, accuracy and repeatability.
- They can carry heavy loads and the weight lifting capacity do not vary within the work envelope.

Disadvantages:

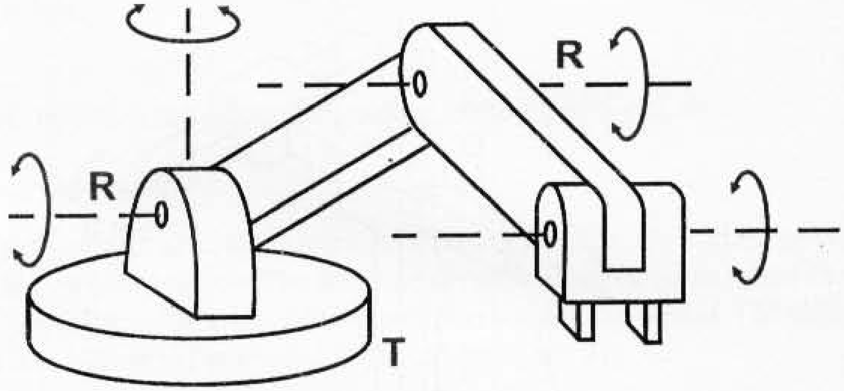
- Limited in their movement to a small and rectangular work space.
- Reduced flexibility.

Applications:

To perform pick and place tasks, material handling, loading/unloading and machining operations

4. **Jointed-arm Configuration Robot:**

This type of Configuration resembles the human arm where the column swivels about a base (the column and the base forms a T-joint), the column top connects to the shoulder through a shoulder joint (which is the R-joint) and the shoulder connecting to the elbow through an elbow joint (which is also an R-joint). Thus, this configuration has the capability to be controlled at any adjustments in the work space. This is shown in *Fig. 5.7*.



Jointed arm Configuration Robot
Fig. 5.7

Example: The Cincinnati Milacron T3 776 Robot *(Courtesy: Cincinnati Milacron)*

Advantages:

- The work volume available is large.
- Operation is quick.
- Flexibility is increased.

Disadvantages:

- Operating procedures are difficult.
- Quite expensive type of configuration.s
- Number of components involved are more.

Applications:

To perform arc welding, spot welding and spray painting operations

5.8 Application of Robots

The practical application of Robots started with the Unimate Robot (developed by Devol and Engelberger in 1961) which was used to unload castings from a die-casting machine at the General Motors plant in the United States. This section deals with the common industrial applications of a Robot. The applications are as detailed below:

I. Material / Part Handling applications

Most of the applications of the Robot falls under this category. Here the Robots are used to

a. *Transfer materials* from one location to another location. Typical applications are as given below:

i. *Pick-and-place application*: The most common and simplest application here is the pick-and-place application where objects are picked from one location and placed to another location.

ii. *Palletizing application*: Another application that is slightly complex is the "Palletizing application" where the robot stacks products or carton boxes onto a pallet at various positions on the pallet to the required height. Example is the KUKA model KR 40 PA that can stack pallets upto 1.6 metre height and that has a payload carrying capacity of 40 kg (*Courtesy of Kuka Robotics Corporation*). The Robot picks from the same location, but is programmed to place at different locations on the pallet in the stacking row and column order. Here we use the teach-and-play method or program to compute the location of carton box by taking into account the center distance between the carton boxes and the box dimensions of length x width x height.

iii. *Depalletizing application*: Here the robot picks parts from an orderly stacked pallet to another location. Example: FANUC Robotics M-410iB/140H can handle 140 kg payload and can palletize and depalletize boxes and bags (*Courtesy: Fanuc Corporation*).

iv. *Stacking application*: Here, the robots are used to stack parts one upon another. After each placement, the vertical position is re-calculated and the new stacking height is determined. Example: FANUC M-2iA robot *(Courtesy: Fanuc Corporation)* was used by an organization to stack stamped parts on conveyors.

v. *Insertion operation*: Here, the robots are used to insert parts into the compartments or spaces provided in a carton.

b. *Machine loading/unloading*: In the machine loading/unloading application, a robot is used to move the work parts to or/and from the production machine.

The following three possibilities can be included for the loading/unloading application:

i. *Machine loading*: In the loading operation, a robot is used to load parts into the production machine, but the unloading of the finished parts after completion of operations of the production machine is done by means other than the use of a robot. Example: This is commonly applied in Press working process.

ii. *Machine unloading*: In the unloading operation, a robot is used to unload the finished parts that comes out of a production machine, but the loading of the parts on to the production machine is done by means other than the use of a robot. Example: Die casting and plastic modelling.

iii. *Machine loading and unloading*: In this operation, a robot is used to both load raw parts into the production machine and unload finished parts from the production machine. Example: Machining operation

Following are the industrial applications of robots used for machine loading/unloading:

1. *Die-casting*: Here the robot is used to safely unload the parts from a die-casting machine with the safety gates closed. Other connected applications are carrying out cooling tasks or parting agent applications.

2. *Forging*: Forging is one of the toughest environments considering the extreme heat, pollution and noise. The use of a robot immensely helps to face the environment of forging. Here the robot loads the red hot billet on to the die of the forging hammer, holds it during the blows and unloads to a safe place away from the hammer.

3. *Plastic injection moulding*: Here a robot unloads parts from the injection moulding machine, cuts the runner and drops runner to scrap area.

4. *Sheet metal press operation (Press working)*: Here a robot loads a blank into the press, then after the press stamping operation is performed the robot unloads the scrap and throws it into the scrap area. The stamped parts from the blank falls in the container placed at the back of the machine.

5. *Machining operations*: Here the robot loads the raw blanks on to the machine tool and unloads the finished parts.

6. *Heat treating*: Here the robot loads/unloads parts to/from a furnace.

II. Processing operations

Robots are used to carry out the processing operations such as spray painting, spot welding, etc by using a tool at its end-effector. The tools can be a spray painting gun for spray painting operation, a spot welding gun for spot welding operation, etc.

In processing operations, the robot manipulates a tool to perform a process on the work part.

Following are few processes that use industrial robots:

a. ***Spot Welding***: Spot Welding is a metal joining process where two metal parts are squeezed together between two electrodes and subjected to a large amount of current to form a joint at particular points or spots. The end-effector of the robot here is the spot welding gun that applies the approximate pressure and current to the sheet parts to be welded. The spot welding robots have enough number of axes of motion to approach points in the work envelope at any angle. This was difficult to realize in a manned environment in the absence of robots. Spot welding is used largely in the automobile industry to weld automobile bodies such as car panels.

b. ***Arc Welding***: Arc welding is a metal joining process where metals are welded by using the heat generated by an electric arc. The welding here is continuous unlike spot welding. When arc welding is manually carried out, the conditions are difficult for the operators since they require Personal Protective Equipment like welding shield with special glass to avoid UV rays, are under the danger of operating at high temperatures involving high amount of heat and moreover they must be accurate in following the welding path. These problems are now overcome with the use of arc welding robots.

The typical components of an arc welding cell includes:

i. *Arc welding robot*: Most popular is the jointed-arm type robot because it allows the welding torch to be manipulated similar to a manual operator. The torch and travel angles can be changed to make welds of good quality. Also welding can be done in areas that are difficult to reach. These robots typically consist of five or six free programmable axes.

ii. *Power Source*: This provides electric power required to do the arc welding operation.

iii. *Welding torch*: This is carried by the robot as its end-effector tool to direct the welding electrode into the arc.

iv. *Wire feeder*: These are used to add the filler material in robotic welding.

v. *Welding fixtures*: These hold the individual parts to be welded in proper alignment during welding.

c. ***Spray Coating***: Spray coating is a process where parts are coated by a spray gun spraying the fluid on to the surface of the part. The fluid passes through the nozzle of the spray gun and is dispersed at high velocity to the surface to be coated. Common examples are powder coating and spray painting.

When human operators carry out the spray coating operations, it results in various health hazards such as the paint or powder fumes / particles entering the operator's body and causing illness, flash fires resulting in burning in the painting booth pit, ear damage due to continued noise of the nozzle, etc. Hence if affordable, robots can be the right substitution to work in such environments.

The robot end gripper is a spray coating gun which sprays the paint or coat on the work surface uniformly. The motion sequence must be smooth with continuous path control.

Spray coating robots are used in coating of the exterior and interior parts of a car, spray staining of wood furniture for carousel presentation, applying stain to textiles (like Jeans material), spraying porcelain coating on bathroom fixtures, etc.

Benefits of spray coating robot includes:

1. Protecting human operators from hazardous coating environments
2. Consistency across coated parts is high
3. Better productivity
4. Uniform coating on the coated surface
5. Reduced paint wastage

d. *Other Processing applications*: These include:

i. *Grinding*: Here the end effector of the robot is the rotating spindle and the grinding wheel is mounted in the spindle chuck. The robot moves its arms relative to the workpiece and grinds the material of the workpiece. Manual grinding has problems like exposure of the operator to fast moving tiny ground particles leading to damage to the eyes and face, requirement of intensive training and grindmark patches. On the other hand, use of robots can give us the perfect grinding finish with saving of time and absence of hazards. As a connected application, robots are used to polish surfaces using a polishing wheel.

ii. *Drilling and other machining processes*: The end-effector is the rotating spindle and the cutting tool is mounted in the spindle chuck.

Drilling a hole manually requires significant time and effort. Using robots in drilling helps to monitor drill speed, torque, countersinking, displacement and breaking of bits. The monitoring is done by sensors on the robots.

Aerospace industry uses robotic drilling due to the precision and productivity benefits. The only challenge of using robots in drilling and other machining operations is that the robot must handle the high cutting forces during machining.

Robots are now used in other machining processes like routing, milling, etc. The end-effector here are spindles on which appropriate tools are mounted according to these machining processes.

iii. *Plasma Cutting*: Plasma cutting is a process that uses high velocity ionized gas called plasma to heat and melt metals. The plasma later blows away the molten material mechanically to cut the workpiece which is usually one inch thick. Use of robots here results in high quality cuts at faster travel speeds. The plasma torch is attached to the robot as its end-effector.

iv. *Laser Cutting*: Laser cutting is a process that uses a high power laser through optics to cut materials. The laser tool as an end-effector is attached to the robot. The result of robotic laser cutting is precision cutting with high repeatability and accuracy.

v. *Waterjet Cutting*: Waterjet cutting is a process used to cut parts using a very high pressure stream of water. The nozzle ensures the high pressure of the water stream. When used with a robot, this nozzle becomes the end-effector and the arm moves in the programmed paths to achieve high quality cutting. Waterjet robots are used to cut various materials like metals, fabrics, board, plastic, etc. Waterjet robots is used in aerospace, automotive, textile, packaging and food industries.

vi. Other applications include wire brushing, deburring, fiberglass cutting, etc.

III. Assembly and Inspection

a. **Assembly**: The combination of two or more parts to form a new object is called as an assembly. The parts that join to form a new entity is securely held together either by fastening or joining processes.

Assembly automation using robots will ensure higher productivity, consistency in quality and cost savings when compared to manual assembly. Robots have saved the assembly workers from the tedious, dull and repetitive jobs which were quite labour-intensive.

There are two strategies that can be adopted to use robots on assembly lines.

i. To produce multiple product styles or models in batches and re-program after end of every batch.

ii. To produce a mixture of various products in the same assembly cell which are of similar configuration but with small variations in terms of features, size, optionals, geometry, etc. This requires each robot in the assembly cell to identify the product model (product style) as it arrives and then execute appropriate tasks programmed for that particular model.

However, the use of robots in mass production is not advisable since they cannot operate at high speeds to meet high productivity and tight production schedules. In these situations, fixed automation is recommended. Fixed automation is an automated production facility where the sequence of production operations is fixed by the configuration of the equipment. The programmed commands are contained in the machine in the form of cams, gears, wiring and hardware that cannot be easily changed from one product style to another. The initial investment of fixed automation lines are high.

The common robot configurations used in assembly line robots are the Cartesian co-ordinate and SCARA (Selective Compliance Assembly Robot Arm), which is similar to the jointed-arm configuration.

Assembly line operations demand better accuracies and thus accurate robots whose repeatability is +/- 0.1 mm or even +/- 0.05 mm are required. Today's robots used in assembly even have dual arms with one arm holding the part while the other performing additional operations. Also, a part from one arm can be transferred to another. This has simplified end-of-the arm tooling.

b. **Inspection**: Inspection is a means to separate poor quality products from the good ones to ensure the required quality. Inspection, when manually carried out is a labour-intensive job that is also time consuming and costly. More inspection means increased manufacturing lead time and increased product cost without adding any real value to the products. So, the use of robots for inspection activities are slowly on the rise in industries.

Following are some of the inspection task cases performed by robots:

i. The robot arm manipulates an inspection probe that moves relative to the product to be inspected. The end-effector here is the inspection probe. Here care must be taken to present the part at the inspection workstation at the right position and the right orientation so that the part is inspected accurately.

ii. Robots can inspect whether the part is present on an assembly or not. Inspection systems for instance look at an engine to find out if it is completely assembled or not. Example: Car manufacturers can use robot to confirm whether an oil filter is put in an engine or not.

iii. The robot picks part at the cell entry point, loads to the inspection machine and after inspection unloads the part and then places to the cell exit point. Few cases may also involve robot taking additional responsibility of segregating parts based on inspection result.

iv. Robots are used to detect flaws by comparing the good part with the bad part. This requires the end users to define what a good part is and what a bad part is.

5.9 Advantages of Industrial Robots

Following are some important advantages of using Industrial Robots:

1. Robots can be substituted for humans to work in hazardous work environments. Example: During arc welding, in foundry environment, in powder coating environment, etc.
2. Robots can produce greater quantity in a short span of time with consistency and accuracy that cannot be matched by humans.
3. Robots can work at constant speeds without any break which is not possible by humans.
4. Robots are capable of lifting heavy loads without getting tired or injured.
5. Robots can work in tight spaces where human reach is not possible.
6. Robots can be re-programmed with changed tooling to take up a different task after the end of a batch or a production run. In such cases, robots are better than fixed automation.
7. Accidents at the workplace is avoided since robots perform the risky jobs which were otherwise done by humans.
8. Since Robots are controlled by computers, they can be integrated to other computer systems to realize Computer Integrated Manufacturing (CIM)
9. The usage of robots produces lesser or no defective parts and hence saves time of rework and money to the organization.

5.10 Disadvantages of Industrial Robots

Following are some disadvantages of using Industrial Robots:

1. Organizations have to make huge investments to introduce robots at their workplaces.
2. Since parts of a robot are made very precisely, their replacement is very difficult and to maintain, it costs huge amount of money.
3. To program and setup the robotic systems and robots, and to avoid unnecessary future problems and mishaps, it requires highly skilled technical engineers and programmers which again is a significant cost for the organization.
4. Unless the level of the artificial intelligence is highly sophisticated, robots may not be able to respond properly during times of emergency, during times of accidents or when an unexpected variance occurs.

EXERCISES 5

1. List few important historical developments of Robotics.
2. Define Robot and Robotics.
3. Why a robot is required in an Industrial Environment?
4. List and explain the elements of a Robotic system.
5. Define the following terms with the help of a simple diagram:
   a. Manipulator
   b. Joint
   c. Link
   d. Degrees of freedom
   e. End-effector
   f. Base
6. Explain the types of end-effectors.
7. With the help of simple diagrams, explain various types of Robot joints.
8. What are the different types of Robots based on the Robot Configuration?
9. Discuss the applications of Robots in
   a. Material handling
   b. Pressing operations
   c. Assembly and inspection
10. What are the advantages and disadvantages of Industrial Robots?

CHAPTER 6

AUTOMATION

6.1 Introduction to Automation

The concept of Automation has evolved from the term mechanization, which had its beginnings during the Industrial Revolution. Mechanization meant the replacement of human power with some form of mechanical power. Mechanization resulted in series of inventions such as Steam Engine by Watt, mechanical loom invented by Jacquard, Power loom by Edmund Cartwright, etc. Another historical development was the analytical engine by Charles Babbage which sowed the seeds for development of the modern computer. Though Mechanization reduced human efforts, it did not replace human with its technologies. Then came the need for automation.

In 1946, the term automation was first coined by Delmar S. Harder of the Ford Motor Company to describe the increased use of automatic devices and controls in mechanized production lines. When initially coined by Harder, the term Automation was used to describe automatic transfer of parts from one metalworking machine to another. But, Automation is now used in both manufacturing and non-manufacturing context to describe a variety of systems where the human effort and intelligence are substantially substituted by mechanical, electrical, or computerized action.

In a general sense, automation is a technology of executing a process by way of programmed commands along with automatic feedback control to ensure proper execution of the instructions thereby resulting in a system that is capable of operating without human intervention.

With constant technological improvements, automated systems have become advanced to a level of capability and performance that far surpasses the human abilities to accomplish similar activities. Automation has given birth to other technologies that are widely popular on their own today. Example: Robotics. Robotics has been explained in detail in the previous chapter.

6.2 Definition of Automation

The word 'Automation' is derived from Greek words "Auto"(self) and "Matos" (moving). Automation can be defined as *the set of technologies of carrying out a process or procedure without human assistance and achieves performance superior to manual operation.*

6.3 Types of Automation

The automation of production systems can be classified into three basic types:

1. Fixed Automation or Hard Automation
2. Programmable Automation or Soft Automation
3. Flexible Automation

1. **Fixed automation:** *Fixed automation or hard automation* is a type of automation which uses special purpose equipment in order to automate a fixed sequence of processing or assembly operations. The programmed commands are contained in the equipment in the form of cams, gears, wiring etc. The equipment is designed to be efficient for the fixed set of operations. Usually each of the operation in the sequence is simple involving a plain linear or rotational motion or both. But integration and co-ordination of one or more operations can introduce complexity in the hard automated system. This type of automation is highly recommended for mass production systems that require high rate of production. Examples are transfer lines found in the automotive industry, paint shops, distillation process, automatic assembly processes, chemical processes, etc.

   Advantages of Fixed Automation:

   1. The production rates realized are high
   2. Since goods are mass produced, the unit cost will be low.
   3. Material handling is automated by the specialized equipment and thus special robot intervention is not required

   Disadvantages of Fixed Automation:

   1. High initial investment for the special purpose equipment
   2. Not flexible to accommodate product variety / product changes.

2. **Programmable automation:** The *Programmable automation or soft automation* is chosen in production systems where the volume of production is relatively low and there are a number of variety of products to be produced. Here, the equipment for production is designed to be adaptable to variations in the product styles/configuration.

The step by step instructions in the form of a program controls the sequence of operations and these programs are read and interpreted by the system.

For every new batch, the production equipment must be re-programmed and changed over to as per the new product configuration.

Advantages of Programmable Automation:

1. Very much suitable for batch production
2. Flexible to adapt to the changes in the product configuration since sequences can be programmed and re-programmed.

Disadvantages of Programmable Automation:

1. The cost of the general purpose equipment is high
2. Production time is lost due to frequent setup changes, loading of fixtures and also due to reprogramming. This reduces production rate compared to fixed automation

Examples of Programmable automation include Numerically Controlled (NC) machine tools, industrial robots, and Programmable Logic Controllers (PLC). In industries programmable automation is found in production of brackets, hinges, locks, door knobs, musical instruments, weaving, etc.

3. **Flexible automation:** This type of automation is used for mid production size and combines the features of both fixed automation and programmable automation. The flexible automated system is built in a way such that it can both produce a variety of products and with almost no time lost for setup changes from one configuration to another. Even reprogramming does not cause lost production time. This is because programming is done off-line at a computer terminal without using the production equipment itself. The system is therefore capable of producing many varieties in the product mix under various schedules without need for batch changes.

Advantages of Flexible Automation:

1. For the variety of product configurations, continuous production is possible
2. Flexible to adapt to the changes in the product configuration in very less time using an off-line computer terminal for programming and re-programming.
3. Improved quality of the product

Disadvantages of Flexible Automation:

1. The cost of investment is huge since the equipment is custom-built
2. Only medium production rates can be achieved unlike fixed automation
3. Compared to fixed automation, unit cost of the product is higher.

Example of a Flexible Automation System is the use of CNC Machine Tools along with Robots and Automated Guided Vehicles (AGV). In industries, flexible automation systems are used in fabrication, assembly and machining processes.

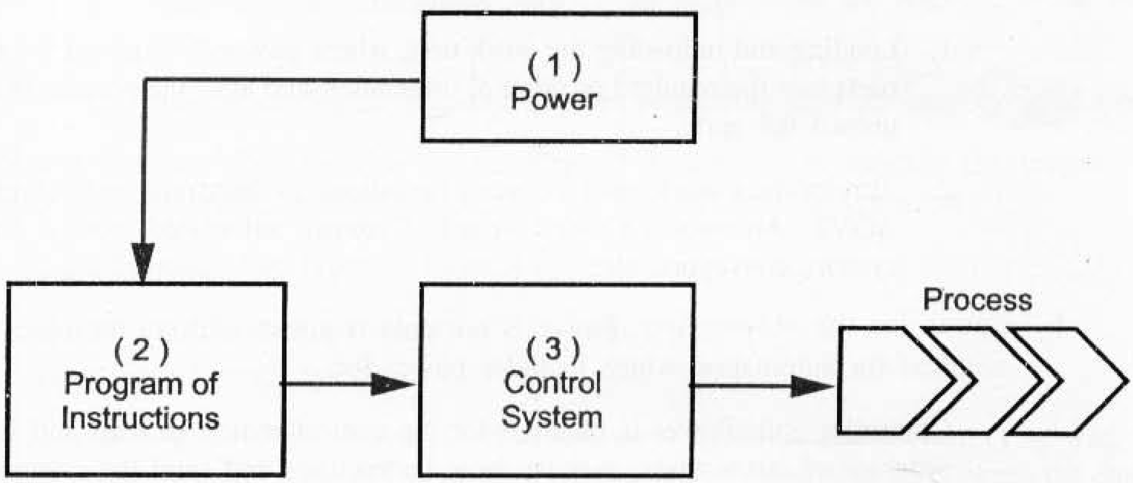
6.4 Basic Elements of an Automated System

An Automated system is the system that is used to realize automation.

As shown in Fig 6.1 there are three basic elements of an automated system. The three basic elements of an automated system are

1. A Power source
2. A program of instructions
3. A control system

Principally in an automated system, the program of instructions are fed to the control system where these instructions are executed and a power source is used to provide power to drive the process as well as operate the control system. The process then becomes an "**automated process**".



Basic elements of an automated system
Fig. 6.1

1. **Power Source**: An automated system is used to automatically complete the tasks in a process. To accomplish this, a power source has to drive both the process and the controls. The commonly used power source in an automated system is electric power.

   Electric power is widely preferred power source for an automated system due to its wide availability at reasonable cost, its ease of conversion into other forms of energy like mechanical, thermal, hydraulic, pneumatic, etc, its easy storage in long life high performance batteries which makes it conveniently available at any place and its usage at lower levels to carryout signal transmission, information processing, data storage and communication.

Other power sources can be conventional sources such as fossil fuels, or non-conventional sources such as solar energy, wind energy, etc. These are generally used in combination with electrical power. Example: Fossil fuels are used to heat the furnace in casting, but electricity is used in the control system to regulate temperature and time cycle.

Even other energy sources can be converted to electrical energy and used to operate the process and its automation. Example: Conversion of Solar energy to electricity to operate an automated system.

As mentioned earlier, a power source is used to drive both process and for the automation.

a) **Power for the process**: Power is required to drive various manufacturing processes such as casting, injection moulding, machining, forging, welding, etc. In a manufacturing process, some form of power is employed to accomplish some action. For example: In sheet metal punching and blanking process, the form of energy used is mechanical and the action accomplished is the mechanical power to shear metal sheets.

   Apart from driving the manufacturing process, power is also used for material handling functions such as

   1. Loading and unloading the work unit, where power is required for moving the parts into the required position & orientation and after the process is completed, unload the parts.

   2. Transporting work units between operations by transport technologies such as AGVS (Automated Guided Vehicle System), automated storage and retrieval system, conveyors, etc.

b) **Power for the automation**: Power is not only required to drive the process but also required for automation which includes power for:

   i. Controller unit: Power is required for the controller unit to read and interpret the program of instructions, execute these instructions and send the commands to the actuator.

   ii. Power to actuate control signals: The controller unit sends the commands in the form of low voltage signals which is amplified to provide the required power for the actuator (which are electromechanical devices such as motors, valves, cylinder, switches, etc) to carry-out the commands.

   iii. Data acquisition and information processing: Power in small amount is needed to collect data from the process to use as input to control algorithm and upkeep of the records of process performance.

2. **Program of Instructions:** The set of actions that is accomplished by an automated system are determined by the program of instructions. Each part produced in a manufacturing operation requires following of sequential processing steps within a work cycle. These processing steps for the work cycle are specified in a *work cycle program*. In NC machines, we call these as *Part Programs*.

   The Work Cycle Programs in an automated system must include the following features:

   a. Distinct number of steps involved in the work cycle. Example: Simple steps of load, process and unload.

   b. Number of Process parameters (which are the inputs to the process), are the process parameters continuous or discrete? How are these parameters actuated? Will the parameters change during the step?

   c. Is the work cycle completely automated or is there any human involvement?

   d. Does the production style remain the same throughout the cycle (as in fixed automation) or does it changes across batches (as in programmable automation) or does it require processing different product styles or models in each cycle (as in flexible automation)?

   e. Does the start dimensions vary? If so adjustments are required in the work cycle.

   f. Does it require the operator to enter processing data for each cycle of work?

3. **Control System:** The function of the Control System is to execute the program of instructions and make the process to carry out a manufacturing operation.

   There are basically two types of Control systems:

   1. Closed loop Control system
   2. Open loop Control system

   1. Closed loop Control System (Feedback Control System): In this control system, the output variable is compared to an input parameter and the difference between the output variable (which is the actual condition) and input parameter (which is the input condition) is sensed and fed back to drive the output according to input requirements.

   The basic elements of a feedback control system shown in Fig. 6.2 above are:

   a. Input parameter: This is the set point which defines what must be the output value.

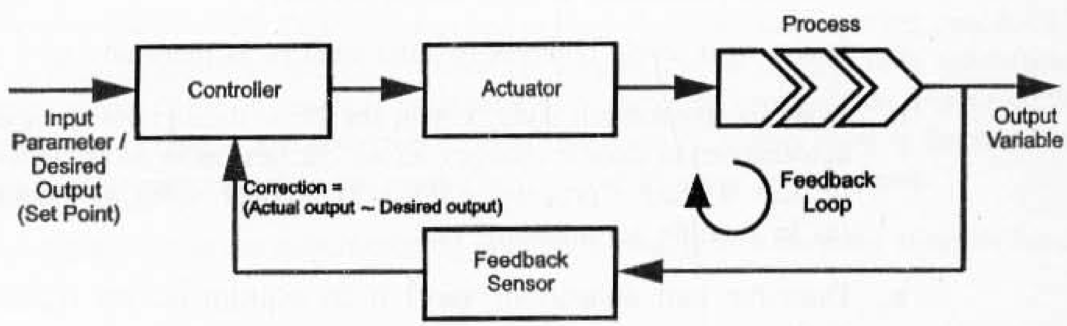
   b. Process: Process is the operation that is being controlled.

   c. Output variable: The output variable is the actual value of the parameter.

d. *Feedback Sensors*: Sensors measure the output variable and feeds it back to the control system. Thus, a feedback loop is created between input and output.

e. *Controller*: The function of the controller is to compare the actual output with the desired input, compute the difference and make suitable process adjustments that reduces the difference between output and input.

f. *Actuators*: The adjustments made in the process are actuated by hardware devices called Actuators that uses hardware devices like motor or valve to physically control the actions.



A feedback control system

Fig. 6.2

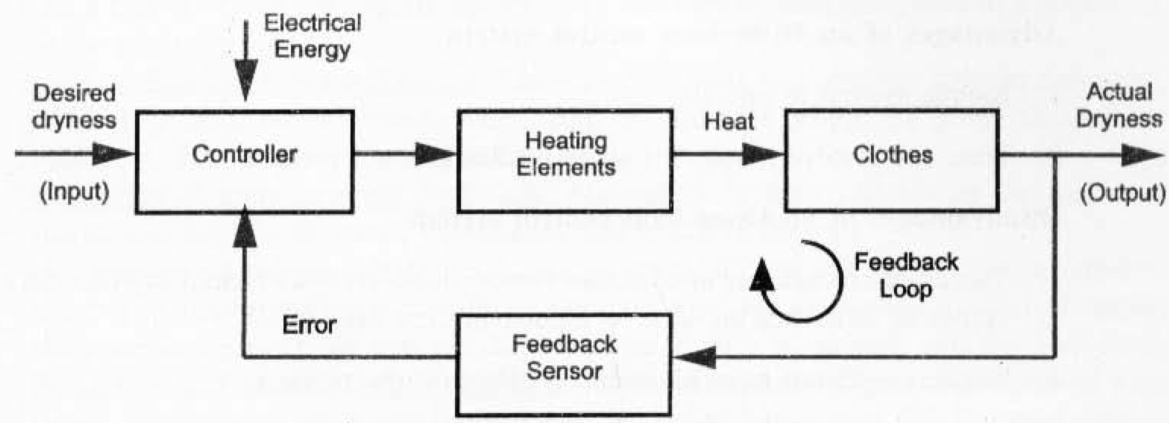
Advantages of Closed loop Control system:

1. The response to an input signal is faster
2. Can be used to stabilize systems that are inherently unstable in the open-loop form.
3. Closed loop systems are more accurate since the feedback ensures that the difference between the actual output and desired input is minimal. Thus errors are also minimal.
4. Closed loop systems are less affected by disturbances.

Disadvantages of Closed loop Control system:

1. The use of sensors for feedback increases the system cost.
2. More complex than open loop system since more number of components are used.
3. Since stability is the main concern in a closed loop control system, more care must be taken to design such a system

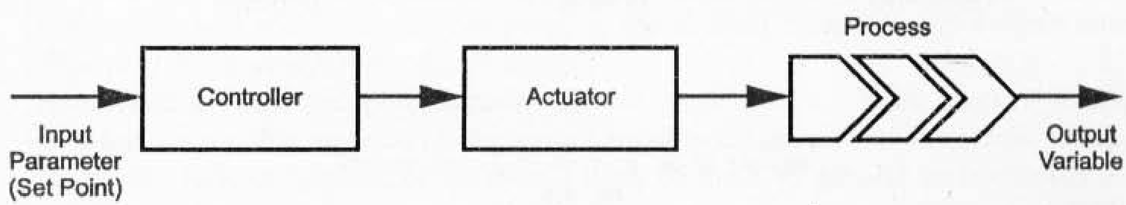
An example of a closed control system is the clothes dryer with a feedback sensor shown below in *Fig. 6.3.*



Example of feedback control system

Fig. 6.3

2. ***Open loop Control System***: In this control system, there is no comparison of the output variable to the input parameter since feedback element is missing here. The Open loop control system is given below in terms of a simple block diagram (Fig. 6.4)



An open loop control system

Fig. 6.4

The open loop control system is chosen when the actions performed by the control system are simple, the reliability of the actuator is very high and the reaction forces counteracting the actuator are so negligible that they do not have any effect on the actuator.

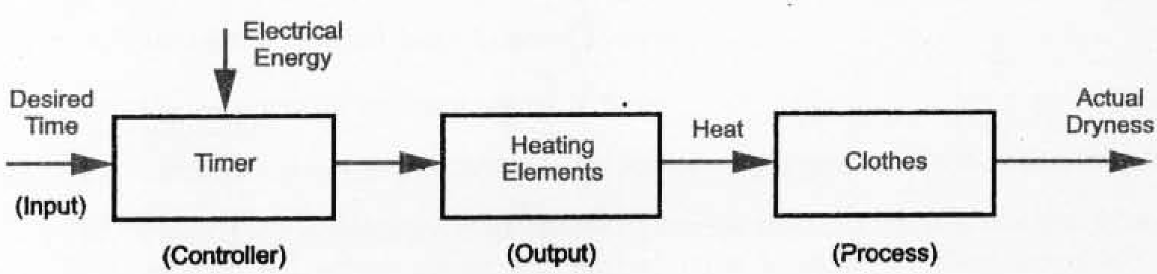
Advantages of an Open loop control system:

1. Simple system to operate
2. Does not involve much cost since feedback is not present

Disadvantages of an Open loop control system:

1. There is no measurement of output versus input. Thus we cannot say that the system output is achieving the desired input requirements.
2. Actuator will not have its intended effect on the process.
3. Open loop systems are more affected by disturbances.

Going by the same example of Electric dryer, we can image it to be an open-loop control system without the sensor as shown in Fig. 6.5.



Example of an open loop control system
Fig. 6.5

6.5 Advantages of Automation

The main advantages of automation are:

1. Automation results in increase of productivity: Use of automated systems can increase the

efficiency in performing tasks which results in higher productivity.

2. Improvement in Product Quality: Automated systems perform the manufacturing process with less variability compared to human workers and hence product quality is improved.
3. Increase in accuracy and repeatability: When an automated system is programmed to carry out a task over and over again, the accuracy and repeatability compared to a human worker is far greater.
4. Improved safety at the workplace: Automated systems can perform tasks in hazardous and unfriendly environment which when done by humans would be prone to injuries and accidents. This improves workplace safety.
5. Reduction in manufacturing lead time: Automated Systems can reduce the lead time for manufacturing due to speed, consistency and less/zero defects.
6. Reduced direct human labour costs and expenses: Using automated systems implies less number of employees are required to get the job done. By having less number of employees, there are numerous costs that are directly reduced such as payroll, benefits, sick days, etc.
7. Mitigation of Potential Labour Shortages: Automation can mitigate the effects of potential labour shortages. It decreases dependency on skilled labour and fills the void created due to a skilled worker retirement.
8. Automated Systems can carry out processes that cannot be done manually. Example, automated systems can carry out certain processes in a nuclear radiation environment which is not possible by human labour.
9. Automation can reduce or eliminate day-to-day manual and clerical jobs.

6.6 Disadvantages of Automation

Though automation has a bright future, it has got its downside. The main disadvantages of automation are:

1. Though automation effectively replaces human labour in performing various tasks, it results in increased unemployment and poverty which counters job creation efforts.
2. High initial cost: The initial investment involved in the automation of a new product or plant is very large. Though the cost of automation may be amortized or spread among many units of products over some time period, the unit cost of the product manufactured using automation will still be higher compared to the product manufactured without automation. This may be at competitive disadvantage.
3. Automated systems can pose Security Threats since with a limited level of intelligence it is more susceptible to committing errors outside of its immediate scope of knowledge (Example, lack of application of simple rules of logic to general propositions).
4. Additional Costs: Other than a high investment cost, automated systems also involve excessive development costs due to research and development, preventive maintenance and cost of training personnel to operate automated systems. These costs offset the costs supposed to have been saved by automation.
5. With excessive automation, humans become slaves of automated machines creating too much dependency on machines rather than human intelligence.

6.7 NC/CNC Machines

6.7.1 Numerical Control

Numerical control or NC is the method of automation of machine tools or other equipment that are operated through precise programmed commands containing coded alphanumeric data which are encoded on a punched paper tape or an alternative storage medium.

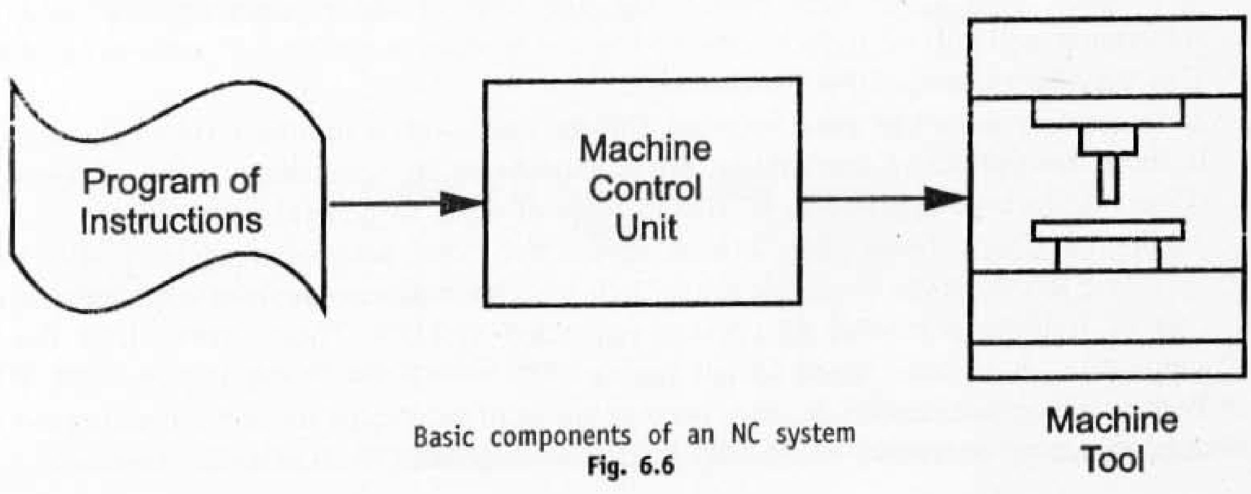
The history of NC Technology dates back to 1940s. It was pioneered by John Parsons of the Parsons Corporation, US. Parsons in 1940 tried to generate a curve automatically by milling cutters by providing coordinate motions. In the late 1940s Parsons came up with the idea of using punched cards containing coordinate position system to control a machine tool. The machine was directed to move in small increments and generate the desired finish. In 1948, Parons demonstrated this concept to the US Air Force. The US Air Force recognized this concept and sponsored the project at the laboratories of Massachusetts Institute of Technology (MIT). Following intensive research efforts, MIT demonstrated the first NC prototype in 1952 and in 1953 MIT proved the potential applications of the NC.

Numerical Control is used in various machine tools such as lathe, boring mill, drill press, milling machine, cylindrical grinder, turning center, etc.

6.7.2 Basic Components of an NC system

An NC system has basically three components: (1) program of instructions, (2) the machine control unit, and (3) machine tool or any other controlled process. The program of instructions becomes an input to the machine control unit, which then commands the machine tool or other process to be controlled.

The following block diagram in Fig. 6.6 shows the basic components of an NC system:



Basic components of an NC system
Fig. 6.6

1. **Program of Instructions**: In NC, the program of instructions is designed for a particular job or a workpiece. When the job changes, the program of instructions also change. This capability to change a program for each new job renders NC flexible in advanced manufacturing. The program of instructions is the detailed step by step instructions which instructs the machine what is to be done. These step by step instructions that are required to perform the required sequence of operations to machine a job is called as the "Part Program". The part program is usually prepared by the *Part Programmer*. The Part program consists of commands that describe the positions of the cutting tool with respect to the workpiece. The instructions also include information such as selection of tools, speed, feed, spindle orientation, etc. The Part Program is coded in either numerical or symbolic form on an input medium which can be interpreted by the machine control unit. The most popular medium is the 1-inch-wide punched tape. Even other forms of input media have been used which includes punched cards, magnetic tape, and even 35mm motion picture film.

2. **Machine Control Unit (MCU)**: The MCU consists of electronics and hardware that read and interpret the program of instructions and convert it to mechanical actions of the machine tool. In earliest form of NC technologies, the MCU included the Tape reader and an information processor. But in the modern technology of NC, the MCU consists of a microcomputer with hardware that stores the part programs and executes them command by command. Each command results in some action by the machine tool. The control hardware includes the components that interface with the machine tool, feedback control elements, reader to enter part programs into memory, control system software, calculation algorithms, and translation software to convert part program into a format that is usable. The earliest NC technology was dependent on hard-wired electronics, but the modern NC technology uses computer and hence we now call this NC technology today as CNC (Computer Numerical Control).

3. **Machine Tool**: As the third basic component of an NC system, the machine tool or other controlled process carries out useful work on the job based on the part program which is directed from the MCU. The Machine Tool is designed to perform machining operations such as drilling, milling, boring, etc and it essentially consists of the worktable on which the job is placed, a rotating spindle, the motors, the controls that are required to drive them, the cutting tools, work fixtures and other auxiliary equipment required in machining operations.

6.7.3 Advantages of NC Machine over Conventional machine

1. **Precision is higher**: An NC system can machine at close tolerances of the order of even 5 microns

2. **Intricate and complex shapes can be machined**: Complex shapes and difficult profiles can be machined through NC system.

3. **Productivity is high**: quick setup and changeover is possible which ensures reduction of non-machining time and therefore boosts productivity. Just the change in the program and loading of new set of tools in the tool turret are enough for changeover or a new setup.

4. **Quality produced is better**: Since NC systems can maintain constant working conditions, consistent quality is ensured.

5. **In process inventory is reduced**: Since changeover happens in least amount of time, work-in-process inventory can be reduced. Thus, space requirements can be reduced.

6. **Lesser production cost per unit**: Since productivity is high, the cost of production per unit is reduced compared to conventional system.

7. **Low profile operators**: Operators need not be highly skilled since his/her job is to load the work and unload the finished part. Inclusion of robots can even eliminate the operator . On the other hand, operators working on conventional machines need to be highly skilled and trained.

6.7.4 Disadvantages of NC Machine over Conventional machine

1. **High investment**: A NC machine costs generally two to five times than a conventional machine. It is therefore a costly proposition

2. **Spares and Maintenance cost**: The maintenance of an NC machine is more than a conventional machine. Spares of NC machine is additional and costs more.

3. **Special tooling**: A NC machine requires special tooling which can add to the expenses.

4. **Programming and operation skills**: NC machines require thorough training and experience of programming and operation.

6.7.5 Computer Numerical Control

Definition: *Computer Numerical Control or CNC is an advanced form of the NC system where the machine control unit is a dedicated microcomputer instead of a hard-wired controller, as in conventional NC.*

Computer Numerical Control has evolved during the rapid improvements of the computer technology. The advent of Microprocessors from the 1970s have helped in quick advancements in the Computer Technology and is in turn adapted in modern CNC Technology. Today's CNC Controller has latest features like high speeds of operation, large memories, bus architectures, improved servos, etc.

CNC Technology has powered the Machine Tool industry today. It is used in majority of machine tools like machining centers, turning centers, grinders, lathes, drilling machines, etc.

6.7.6 Elements of a CNC system

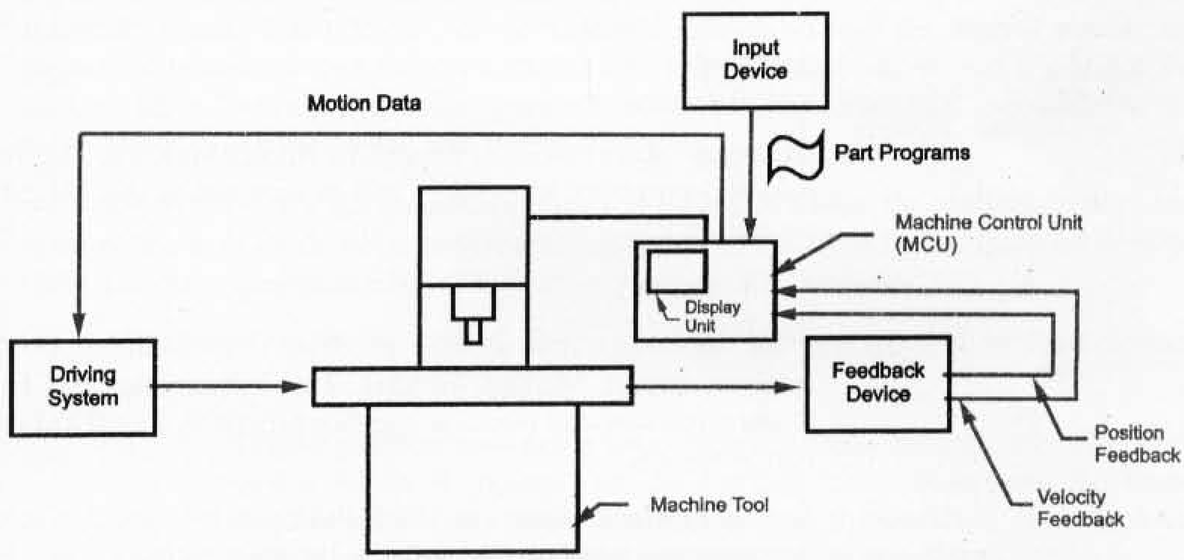
A CNC System consists of the following elements:

1. Input Device

2. MCU or Machine Control Unit

3. Machine Tool
4. Driving System
5. Feedback devices
6. Display Unit

This is shown in Fig 6.7 below:



Elements of a CNC system
Fig. 6.7

1. **Input Device**: The part program is entered into the CNC Control or the MCU through the input device. There are various input devices used on a CNC Machine such as
   a. *USB (Universal Serial Bus) Flash drive*: Here the USB flash drives transfer data to the control. USB is very common nowadays and its use is increased in modern computers.
   b. *Serial Communication*: A serial communication port connects a computer system and a CNC Machine tool through an interface called RS-232. Most machines have RS-232 port and an RS-232 cable connects the computer and the CNC Machine to transfer data from the computer to the CNC Machine.

c. *Ethernet Communication*: The Ethernet communication is a more reliable and efficient means of transferring part programs from Computer to the CNC Control. CNC Machines now provide Ethernet Card support and an Ethernet cable connects the Computer with the Machine to enable data transfer.

d. *Conversational Programming*: This is another way to input part programs to the controller through a keyboard. A built-in intelligent software inside the controller enables the operator to enter step by step data.

2. **MCU or Machine Control Unit**: The Machine Control Unit or the MCU is the heart of the CNC System. It consists of the following components:

   a. *Central Processing Unit*: The CPU is the brain of the MCU and it comprises of

      i. a *control section* that retrieves data from the memory and generates signals which in turn activates all MCU components.

      ii. An *ALU (Arithmetic Logic Unit)* that performs integer arithmetic operations like addition, subtraction, multiplication, counting, etc and logical operations

      iii. *Immediate Access Store or Immediate Access Memory*: This holds the data and programs temporarily that is required at that instant by the control section.

   b. *CNC Memory*: The memory of the CNC is divided into

      i. *Main Memory* which consists of Read Only Memory (ROM) and Random Access Memory (RAM). The ROM stores the Operating System Software and machine interface programs. The RAM stores the Part programs.

      ii. *Secondary Memory* such as Hard disks which is used to store large programs and which can be used by the main memory when required.

   c. *Input/Output Interface*: The Input/Output interface or the I/O interface establishes communication between the machine operator, the components of the CNC system and other connected computers. The Operator control panel is the interface through which the machine operator communicates with the CNC system. A keyboard and a display screen are also included in the panel.

   d. *Machine tool controls*: A Machine Tool consists of various axes such as X, Y, Z, A, B, C and a spindle which rotates at the designed RPM. The position and velocity control of each of the axis and the rotational speed control is accomplished by certain hardware components in the MCU. The MCU generates control signals that is transformed into a form suitable for the specific position control systems that is required to drive the various axes of the machine. Positioning systems here can be an open loop or a closed loop system. For spindle speed control, the MCU houses a drive control circuit and a feedback sensor interface. For majority of the CNC machine tools, spindle speed is a programmed parameter.

e. *Sequence controls for auxiliary functions*: Apart from the general functions like spindle speed, feed rate, etc, certain auxiliary functions like coolant control, emergency stop, tool changing function, etc are carried out under part program controls. A Programmable Logic Controller or PLC is generally used to manage the Input Output interface for such additional functions.

3. **Machine Tool**: This can be any type of machine tool such as a Machining center, a turning center, a lathe, milling machine, etc. The essential parts of the machine tool include the machine table, machine slide, the driving leadscrew, ballscrew, rigid and heavy machine structure, automatic tool changing system, spindle and spindle drive system, chip removal system etc. The machine table is controlled in the X and Y axes, while the spindle runs along the Z axis. In other machine tools, there are additional axes such as A, B or C that allow rotary motions around the X, Y and Z axes.

4. **Driving System**: A drive system essentially is made up of amplifier circuits, drive motors, and ball lead-screws. The control signals (position and speed) of each axis are fed by the Machine Control Unit (MCU) to the amplifier circuits. Then, the control signals are augmented to actuate drive motors which in turn rotate the ball lead-screws to position the machine table. The commonly used types of electrical motors include DC Servo Motor, AC Servo Motor, Stepping Motor and Linear Motor.

5. **Feedback devices:** For the accurate operation of a CNC Machine, the positional values and speed of the axes needs to be continuously updated. This is done by the feedback devices. There are two types of feedback devices:

   a. **Positional feedback devices**: Here again there are two types of feedback devices which are:

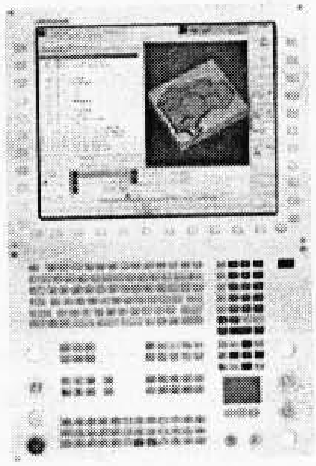
      i. **Linear position measuring transducers**: A linear transducer is a feedback device which is mounted on the machine table to measure the actual displacement of the slide in a manner that the backlash of the screws, motors, etc shall not cause any error in the feedback data.

      ii. **Rotary encoders**: A rotary encoder is a device used to convert rotational position information into an electrical output signal. This is mounted at the end of the motor shaft or screw to measure angular displacement. Rotary encoder cannot measure linear displacement directly.

   b. **Velocity feedback devices**: In a Velocity feedback device, a tachometer or a tachogenerator is mounted at the end of the motor shaft. The tachometer measures the actual speed of the motor in terms of voltage generated. The output voltage from the tachometer is compared with the desired speed and the difference is fed back to monitor the motor speed.

6. **Display Unit:** The display unit is the device that ensures interaction between the machine operator and the machine. Display unit displays the current status of operation such as the spindle RPM, the running part program, the feed rate, position of the machine slide, etc.

Today's display units even show the graphics simulation of the paths taken be the tool so that the operator can verify the part program before actual machining. Any malfunction of the CNC system is also displayed as warnings. Other data such as machine parameters, logic diagram of the programmer controller, error messages and diagnostic data are also displayed. A typical CNC Control (MCU) with display screen is shown below in Fig. 6.8.



Display unit of a CNC machine (Courtesy: Heidenhain)

Fig. 6.8

6.7.7 Salient features of CNC controls

When compared to the hard wired NC technology, the MCU of a CNC offers the following additional standard features:

1. **Part Program Storage**: Today's CNC Controllers provide ample capacity to store multiple programs. Apart from the onboard memory, CNC Control manufacturers now provide memory expansion options such as support to read programs from a USB pen drive.

2. **Varied program input options**: The input medium to enter part programs of the old conventional NC machines was only the punched tape. But modern CNC controllers offer various options for program input such as USB drives, manual data input through the keyboard of the MCU and program input from external PC using RS-232 communication system.

3. **Program editing at the machine tool**: CNC part programs in the MCU memory can be readily edited and tested using the user-friendly technology specific keyboard and the LCD colour display of the CNC control rather than bringing back the program, loading on to a PC, making corrections in the PC and returning back to the MCU. Apart from the editing of programs, the cutting conditions in the machining cycle can also be optimized. A backup of the edited program can be stored on suitable media.

4. **Fixed cycles and programming subroutines**: Machining cycles that are frequently used are stored as "macro" programs and every time there is a need for such machining cycles, the machine operator just "calls" the required macro program cycle through a call statement written in the program rather than typing all the instructions of the particular cycle. Canned cycles and technology cycles are examples for these. Such fixed cycles require certain parameters to be fed by the programmer Example for a bolt hole circle, parameters such as diameter, spacing of the bolt holes, etc must be entered to run the fixed cycle.

5. **Various types of Interpolation**: Interpolation is the function that generates specified points according to which the tool moves during machining. Some of the interpolation types offered by the CNC controls today are Linear interpolation, circular interpolation, helical interpolation, parabolic interpolation, cylindrical interpolation and cubic interpolation

6. **Position Set feature**: To machine a workpiece, a fixture to hold it must be installed and aligned on the machine table. This is done to ensure that the machine axes (X, Y, Z) are established with regard to the workpiece. CNC controls today offer an option to accomplish this task called as the position set where the operator need not scratch his head to locate the fixture accurately on the machine table, but can reference the axes of the machine tool to the fixture's location through a set of target points on the fixture or the workpiece.

7. **Look Ahead function**: Normally the part program for surface machining consists of a sequential linear path with short lengths and fast feed rate. If the blocks in the program are run line by line, then the actual feed rate will become lesser than the programmed feed rate. Also, at the corners, the federate becomes discontinuous. This frequent acceleration/ deceleration results in the workpiece surface becoming degraded and will again require grinding. Instead, the CNC control offers an advanced function called the look-ahead function that looks ahead fifty or hundred blocks and calculates an adequate feed rate for each axis so that the resulting machine surface is smooth.

8. **Cutter length and size compensation**: The earliest type of controls required correct setting of the dimensions of the cutter to ensure that the tool path is according to the part program. The programmer had to know the cutter length and size and had to offset the programmed co-ordinates by the amount of length and radius. In such cases, if a cutter of different size and length was used, then the part would not be correctly machined. But today's CNC controls provide cutter compensation where it becomes easy to use any cutter size and length as long as the offset amounts are entered accurately in the offset register. The control makes the Compensations automatically in the computed tool path. Today's CNC even have a tool length sensor which is inbuilt. This sensor senses and measures the cutter length and this actual measured length is used to correct the path of the tool which varies with the path set as per the program.

9. **Calculations for acceleration and deceleration**: During the running of a work cycle, path changes of the cutter are common. At high feed rates, when there is a sudden change in the cutter path, the cutting tool can leave a mark on the machined component which is undesirable. To avoid this, Modern CNC controls today automatically decelerates the feed

rate well before a path change and once the change of the path is smoothly completed, it then accelerates the feed rate. **Example:** the Siemens Sinumerik 808D CNC Control (Courtesy: Siemens) offers the intelligent jerk limitation function which not only guarantees smooth path but also lowers the stress on the machine mechanical system.

10. **Communications interface**: CNC Controls are today provided with the communication interface such as the RS 232C which can interface with external computers and also with robots in automated environment. This communication interface ensures downloading of a program from an external computer, collecting operational data like workpiece counts, cycle times, and machine utilization and finally interfacing with robots to perform functions such as loading and unloading of parts.

11. **Diagnostics**: Today's CNC systems are equipped with best diagnostics that can identify and rectify faults or malfunctions or signs of impending faults and can even diagnose breakdown of the system.

6.7.8 Advantages of CNC machines

CNC Machines are increasingly used in Industrial Production today due to the following advantages:

1. The accuracy and repeatability obtained is high. It is because of this reason, most of the aircraft parts are produced today on CNC Machines.
2. Complex shaped contours can be machined. Example: turbine blades, blisks, impellers, etc.
3. Can be easily programmed to handle variety of product styles.
4. High volume of production compared to conventional machines
5. Even lesser skilled or trained people can operate CNC Machines unlike the Conventional ones where highly skilled people are required.
6. CNC Machines can be used uninterruptedly without turning them off provided regular maintenance is done.
7. Prototypes can be produced faster and thus results in reduced lead times.
8. Avoids errors that were otherwise committed by humans operating conventional machines.
9. Since CNC machines can be programmed, one person may well take care of a number of CNC Machines. This reduces the employees and hence costs are reduced.
10. Using CNC Machines results in a safer work environment since the operator is not exposed to the machine area during machining.
11. CNC Machines can be upgraded to newer technologies by replacing the existing CNC Control with an advanced one.
12. Many CNC Machines can be linked together to a main computer. Programs from the main computer can be downloaded to any connected CNC Machine. This leads us to another type of NC concept called as the Direct Numerical Control (DNC).

6.7.9 Disadvantages of CNC machines

1. A thorough programming knowledge is required by the operators or programmers. This again requires skilled programmer and hence the cost of labour can be high.
2. Cost of a CNC Machine is high compared to the Conventional Machine Tools.
3. The spares of CNC Machines are relatively costlier than Conventional Machines.
4. CNC Machines require air conditioned environment and/or a chiller unit. Thus extra costs are involved.

EXERCISES 6

1. Define Automation.
2. Explain the following types of automation:
   a. Fixed Automation
   b. Programmable Automation
   c. Flexible Automation
3. With the help of a neat block diagram, explain the basic elements of an automated system.
4. What are the advantages of Automation?
5. What are the disadvantages of Automation?
6. Define Numerical Control.
7. Discuss the basic components of a NC system with a neat and simple block diagram.
8. What are the advantages and disadvantages of a NC machine compared to Conventional machines?
9. Define Computer Numerical Control.
10. Discuss the elements of a CNC system with a neat block diagram.
11. List and explain the salient features of a CNC control.
12. What are the advantages of the CNC Machines?
13. What are the disadvantages of CNC Machines?

CHAPTER 7

ENGINEERING MATERIALS AND COMPOSITES

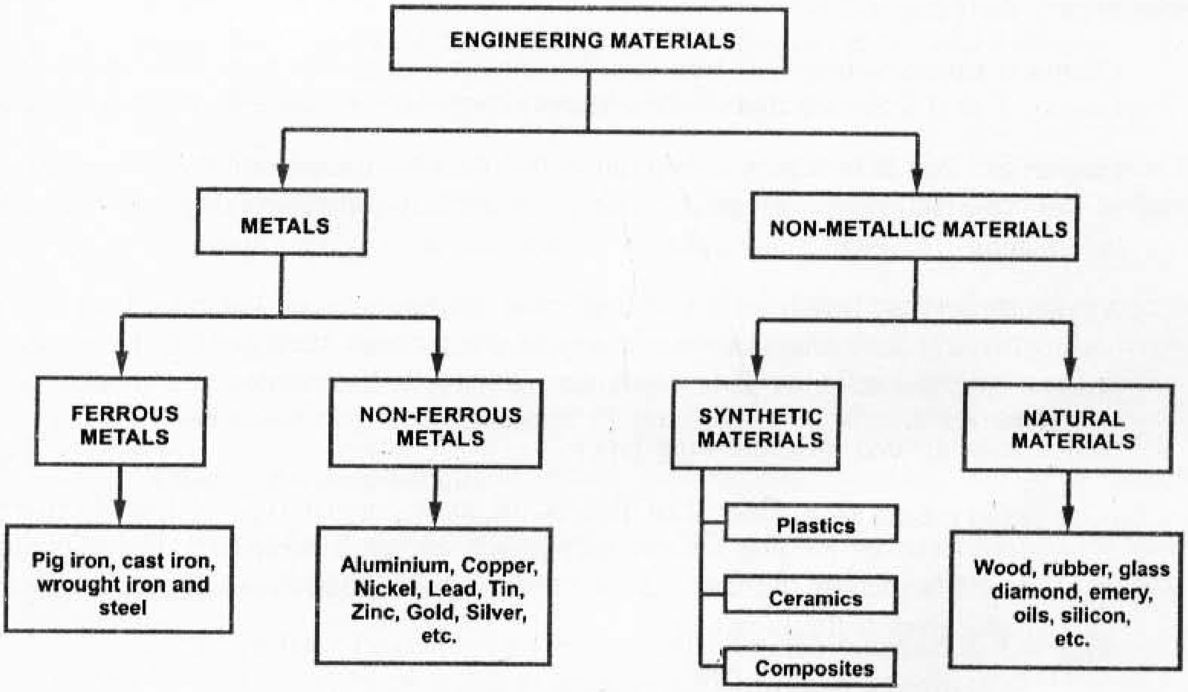
7.1 Introduction to Engineering Materials

From the early ages of Mankind, man has developed useful materials to suit the requirements of his daily life. Ancient people belonging to several civilizations used various materials such as stone, wood and metals to satisfy requirements which include usage of wood for producing fire which was used to heat & prepare food, use of wood for housing, use of stones and metals to make tools, to make jewellery, handicrafts etc. Modern age has seen the development of numerous materials that are used in many applications including domestic use, use in industries, use in weaponry, use in medicine, use in clothing, use in entertainment and fashion, use in spacecrafts, aircrafts, marine applications etc.

Those materials that are used for Engineering applications are termed as *Engineering materials*. The following section shows how the Engineering Materials can be classified.

7.2 Classification of Engineering Materials

Engineering materials are classified as shown in *Fig 7.1*.



Classification of Engineering Materials
Fig. 7.1

7.3 Metals

Metals are classified as Ferrous Metals and Non-ferrous metals based on the presence or absence of iron as its main element.

7.3.1 Ferrous Metals

Ferrous metals are metals that contain iron as its main element. The Ferrous metals possess high strength and are of relatively low cost. They are used in applications where weight is not the primary influencing factor. Examples of Ferrous Metals include Cast iron, Wrought iron and Steel.

1. **Pig Iron**: Pig iron is the intermediate product of smelting iron ore with a high-carbon fuel like coke, normally with limestone as a flux material. Even Charcoal and anthracite could be used as fuel. Typically, pig iron has a very high carbon content of 3.5–4.5%, along with 0.5 to 3% silicon and other constituents of dross (0.04 to 0.2% sulphur, 0.5 to 2.5% manganese and 0.04 to 1% phosphorous), which makes it very brittle and not useful directly

as a material. Pig iron is produced in a blast furnace and poured into pigs or moulds in preparation for conversion into wrought iron, cast iron or steel.

Applications: Though pig iron is not used as a direct material, it is used in making wrought iron, cast iron and steel.

2. **Cast Iron** is a ferrous material that is produced when pig iron is re-melted in a cupola furnace and poured into moulds in order to make castings. Scrap iron or steel is often added to vary the composition.

   Chemical Composition: Cast Iron usually contains iron greater than 90%, about 2 to 4.5% Carbon, 1 to 3% Silicon and small amounts of sulphur, manganese, and phosphorus.

   Properties: Cast Iron is very strong but brittle. Cast Iron has relatively low melting point, is wear resistant, possesses good fluidity, has admirable machinability and is resistant to deformation.

   Applications: Cast Iron is used to manufacture machine frames, columns, beds and plates, housing, flywheels, manhole covers, automotive parts such as engine block, cylinder head, gearbox case and machine parts which are not subjected to tension and shocks.

   Cast Iron is divided into following types:

   a. ***Grey Cast Iron***: Grey Cast Iron is the most popular type of Cast Iron which is produced by melting mixture of pig iron and steel scrap and then allowing it to solidify thereby forming a graphitic structure. Graphite exists in the form of flakes and gives it the grey colour.

   Chemical Composition: It contains 2.5 to 3.5% Carbon and 1 to 2.5% Silicon, 0.5 to 1% Manganese, 0.02 to 0.15% Sulphur and 0.1 to 0.9% Phosphorous. The rest is iron. Grey Cast Iron is hard and brittle.

   Properties: Desirable properties include high fluidity, easy machinability, high strength and ductility under compressive loads. Grey cast Iron is also the least expensive of most of the metallic materials.

   Applications: Base structures of machinery and heavy equipment that are subjected to vibrations are made from Grey Cast Iron. It is also used to make intricate parts, rotor of the disc brake, clutch plates, cylinder block, brake drum, flywheel, in machine tools (frame, bed and guide), gears and housing of gearbox, pump housings, machine frames, decorative castings, etc.

   b. ***White Cast Iron***: White cast iron is manufactured by casting grey cast iron in a mould and rapidly cooling it. By rapid cooling, there is no free graphite or free carbon and instead there is cementite which gives the cast iron its white colour.

   Chemical Composition: White Cast Iron contains 1.7 to 3% Carbon, 0.5 to 1.3% Silicon, 0.5 to 1% manganese, 0.05 to 0.15% sulphur and 0.05 to 0.2% phosphorous. Balance is iron.

Properties: White Cast Iron is very hard, brittle, wear and abrasion resistant, high compressive strength. It is generally not machinable.

Applications: Used in parts that require high abrasion resistance such as rollers of the rolling mills, wear plates, rim of a car wheel, railway wheel brake blocks, hammer mills, shell liners etc.

c. ***Malleable Cast Iron***: Malleable cast iron is produced by heat treatment (annealing) of white cast iron. First the white cast iron is heated slowly to a temperature of about 870°C and kept for about 25 to 60 hours and then cooled slowly.

There are mainly two types of malleable cast iron:

1. *White heart malleable cast iron*: This is produced by packing white cast iron in an oxidizing material to remove carbon. Since the fractured surface is silvery white in appearance, it is called white heart.

2. *Black heart malleable cast iron*: This is produced by packing white cast iron in an inert material like ferrous silicate scale and then annealing. The resultant structure is almost wholly graphite and ferrite. Since the fractured surface is blackish due to the presence of graphite, it is called black heart.

Chemical Composition:

1. White heart malleable cast iron has 3.2 to 3.6% Carbon, 0.4 o 0.9% Silicon, manganese up to 0.4%, sulphur 0.1 to 0.3% and phosphorous 0.1% max.
2. Black heart malleable cast iron contains 2 to 2.6% carbon, 0.9 to 1.6% silicon, 0.04 to 0.17% manganese, 0.08 to 0.5% sulphur, 0.03 to 0.1% phosphorous.

Properties:

(i) White heart malleable cast irons display non-uniform characteristics across varying thicknesses. At lower thicknesses of about 18 mm, it shows good ductility and impact resistance than at higher thicknesses.

(ii) Black heart malleable cast iron have good machinability, higher impact strength and they can be cast to intricate shapes.

Applications:

(i) White heart malleable cast iron is used in making pipe and pipe fittings, automobile parts, hardware items, switch gear equipment, fittings for bicycles and motorcycle frames, and farm implements.

(ii) Black heart malleable cast iron is used in automotive industry in making crank cases, brake shoes, wheel hub, bush bearing, housing of the bearings, axle housing, levers, spanners, gear wheels, etc. It is used in the marine industry in making door keys, hinges, etc. It is also used in making joint fittings for water and gas pipe lines.

d. ***Ductile Cast Iron (Nodular Cast Iron or Spheroidal Graphite Iron)***: Ductile cast iron is called Nodular cast iron because in this metal, free graphite will be in the form of tiny balls or nodules or spheroids in contrast with flakes as observed in grey cast iron. Ductile cast iron is produced by controlling the metal composition as well as addition of magnesium in the form of magnesium-ferro-silicon in the molten metal. This addition changes the surface tension of the graphite and condenses into tiny balls called spheroids.

Chemical Composition: Ductile Cast iron contains 3 to 4% Carbon, 1 to 2.5% Silicon, 0.1 to 0.5% manganese, 0.05 to 0.1% magnesium, 0.03% sulphur and 0.1% phosphorous. Balance is iron.

Properties: Good wear resistance, corrosion resistance, strength, shock resistance, increased ductility, good castability, good machinability, and dimensionally stable at high temperatures. In addition to this, the cost per unit strength is lower than most of the metals.

Applications: Due to wear resistance and strength, used in gears, dies, punches and rolls. Due to excellent machinability, used in pump bodies, pressure castings and shock resisting parts. Due to dimensional stability at high temperature, used in furnace parts. Used in oil and gas industry (especially oil well pumps). It is also used as pipes for water and sewer lines, in petroleum and chemical industries due to its corrosion resistant property. Even Nuclear industry uses ductile iron to make caskets.

e. **Wrought Iron**: Wrought Iron is composed of 99.8% iron. It is produced from pig iron by burning carbon, silicon, manganese, phosphorous and sulphur in a puddling furnace. Since the carbon content is very less, it cannot be hardened by heating and quenching in water.

Chemical Composition: It contains a 0.02% Carbon, 0.12% Silicon, 0.018% Sulphur, 0.02% Phosphorous and slag of 0.07%. The balance is iron.

Properties: Wrought iron is soft, highly ductile and has very high toughness. The machinability is good. Corrosion resistance is superior. Due to low carbon content, the melting point of wrought iron is very high which renders it unsuitable for casting.

Applications: Due to corrosion resistance, it is used in making steam and water pipes, for making bars for stay bolts, engine bolts, rivets, railway couplings, etc. Due to good weldability and high impact strength, it is used in making chain links and crane hooks. It is also used in boiler tubes, horseshoes and ornamental ironworks.

3. **Steel**: *Steel* is an alloy of iron and carbon which is produced either by basic oxygen steelmaking process or by electric arc furnace. In the basic oxygen steelmaking process,

carbon-rich molten pig iron is made into steel by blowing oxygen over molten pig iron which causes oxidation thereby lowers the carbon content of the alloy. The other method Electric arc furnace, is much easier and faster because it only requires scrap steel. Recycled steel is introduced into a furnace and re-melted along with some other additions to produce the end product.

Steels generally have a carbon content ranging from 0.5 to 1.5%. There are other elements in steel such as silicon, sulphur, phosphorous, manganese, etc. By adding alloying elements in required proportions, we can obtain different properties of steel. The role of carbon in steel is important to note because is amount and the resultant microstructure decide various properties of steel such as strength, hardness and response to heat treatment.

Classification of Steels: Steels are broadly classified into

a. Carbon Steels

b. Alloy Steels

c. Tool Steels

a. **Carbon steels**: Carbon steels are types of steel containing primarily iron and carbon. Other elements present in small proportions are sulphur, phosphorous, manganese and magnesium. Carbon steels are classified based on the percentage of carbon contained in it into the following types:

i. **Low Carbon Steel or Mild Steel**: It has a Carbon content of 0.05 to 0.3%. The balance is iron. The most popularly used carbon steel is mild steel.

Properties: Apart from being soft and ductile, Mild steel possess properties such as good weldability, good formability, good machinability, good toughness, good impact resistance at subzero temperature. But Mild steel is generally of low strength (which can be improved by cold working). The surface hardness of Mild Steel can be increased through *carburizing*.

Applications: It finds application

1. in lightly stressed parts, nails, chains, rivets, bolts, keys, plain washers etc.
2. in structural sections such as angles, channels, girders, beams, etc.
3. in small forgings
4. in boiler plates
5. for making shafts, camshafts, gears and axles for low loads

ii. **Medium Carbon Steel:** It has a Carbon content of 0.3 to 0.6%. The remainder is iron content. The tensile strength is higher than mild steel but is less ductile than mild steel. Medium carbon steels can be hardened by calculated additions of manganese, chromium, tungsten, etc.

Properties: Medium Carbon steel has improved toughness, high tensile strength, high hardness, good bending strength, wear resistance, good torsion strength and good machinability.

Applications: It finds application in Transmission shafts, axles, gears, connecting rods, spindles, couplings, springs, spring washers, forging dies, rotor shafts, crane hooks, skip wheels, torque tubes, loco tyres, keys, hand tools, etc.

iii. **High Carbon Steel:** It has a Carbon content of 0.6 to 1.5%. It has an iron content of 96 to 97%.

Properties: It has higher hardness (due to which it has high brittleness), is resistant to wear and tear, is surface abrasion resistant, has large torque capacity, high tensile strength, high yield strength but low impact strength. Ductility is less than medium carbon steel.

Applications: It finds application in Hammers, Chisels, Screws, punches, knives, saws, drills, taps, reamers, lathe tools, ball races and ball bearings, leaf springs, scrapers, bandsaws, circular saws, wrenches, forming dies, blanking dies, shearing dies, shaper tools, planer tools and milling cutters.

b. **Alloy Steels**: Alloy steels are the steels produced by adding elements other than carbon in calculated amounts in order to provide specific properties. The principal alloying elements are nickel, manganese, chromium, tungsten, silicon, copper, cobalt, zirconium, titanium, beryllium, boron, silver, etc.

Alloying elements are added for properties such as:

1. Improved castability, machinability and weldability
2. Improved strength and elastic ratio
3. Improved ductility and improved grain structure
4. Improved fatigue and corrosion resistance.
5. Improved hardenability and case hardenability
6. Maintain strength and shape at elevated temperatures, etc.

The very common types of alloy steels are:

i. **Chromium steel**: In this type of steel *Chromium* is the alloying element. Chromium improves corrosion resistance, hardenability, toughness, provides resistance to abrasion, resistance to heat and causes improvement in cutting ability. It finds its application in balls, rollers and races for bearings, armor plate, safes, and cutting tools. A Chromium addition of 4% to 1% carbon steel can render it useful in making permanent magnets.

ii. **Nickel steel**: In this type of steel *Nickel* is the alloying element. It contains up to 3% Nickel and 0.2 to 0.35% carbon. It finds its application in locomotive forgings, axles, piston rods, parts of a ship and components subjected to shocks and fatigue. An alloy called *Invar* which consists of 36% Nickel and 64% iron has very less co-efficient of expansion and is therefore used in measuring instruments, clock pendulum, etc.

iii. **Manganese steel**: In this type of steel, *Manganese* is the alloying element. Manganese improves strength, hardness, toughness. It is a de-oxidizer and provides high strength at elevated temperatures. It contains usually over 1.5% Manganese and a carbon content of 0.4 to 0.55%. Its applications include axles, gears, shafts, etc. A special alloy steel called *Mangalloy* which consists of 11 to 15% Manganese and 0.8 to 1.25% carbon is a non-magnetic steel with anti-wear properties. Mangalloy is also abrasion resistant and heavy impact resistant. This is why it is used in rock crushers, mining, cement mixtures, crawler treads for tractors, etc.

iv. **Molybdenum steel**: In this type of steel *Molybdenum* is the alloying element. Molybdenum increases tensile strength and creep strength at high temperature, increases wear resistance, heat resistance and corrosion resistance and provides the ability to deep harden. Molybdenum alloys are used in high temperature heating elements, forging dies, extrusions, radiation shields, etc. Sprayed coatings of molybdenum alloys are used in automotive pistons to improve wear and reduce friction.

v. **Tungsten steel**: In this type of steel *Tungsten* is the alloying element. Tungsten increases strength, hardness, toughness, provides shock resistance to softening at high temperature, and wear resistance. The Tungsten alloy (Tungsten carbide) is used in industrial cutting tools. The high melting point of tungsten makes it a good material for rocket nozzles. *Hastelloy* and *Stellite* which are superalloys containing tungsten is used in the blades of a turbine.

vi. **Stainless steel**: *Stainless steel* is a type of steel that do not get stained and is resistant to rusting and corrosion. It mainly consists of 18% Chromium, 8% nickel, 0.03% Carbon. The rest is majorly Iron and in small amounts of Manganese, Silicon, Molybdenum, Phosphorous, Sulphur, Nitrogen, etc. Stainless steel will not readily corrode, rust or stain with water unlike the ordinary steel.

Applications: It finds application in Kitchen equipment, cutlery, springs, circlips, chemical handling equipment, surgical equipment, shaving blades, etc.

c. **Tool Steels**: Tool steels are special steels with Carbon content is in the range of 0.8 to 1.2%. They are very hard and exhibit good wear and abrasion resistance. They withstand hardness at elevated temperatures. The alloying elements added to realize this property are tungsten, vanadium, cobalt, chromium and molybdenum.

A very common example of tool steel is the High Speed Steel or HSS. It contains 0.7 to 0.8% carbon, 12 to 20% tungsten, 3 to 5% chromium, 1 to 2% vanadium and 5 to 10% cobalt. It is used for making drill bits, lathe tools, milling cutters, reamers, etc that is used for high speed cutting operations in machine shop. HSS tools can operate at cutting speeds which are two to three times higher than that of high carbon steel tools and can also retain their red hardness up to a temperature of 620°C.

Applications: Tool steels are used in machining operations that are capable of cutting at high speeds without any loss in the hardness. They are used to make tools and dies for different machining and forming operations.

7.3.2 Non-ferrous Metals

Non-ferrous metals are engineering materials that do not contain iron. There are various reasons as to why non-ferrous materials are preferred. They include good strength to weight ratio, good resistance to corrosion, light weight, high electrical and thermal conductivity, ease of fabrication, etc. Examples of non-ferrous metals include copper, aluminium, zinc, lead, tin, magnesium, nickel, chromium, titanium and cobalt. For many of the above non-ferrous metals, alloys can be obtained by addition of one or more elements to the non-ferrous metal. These alloys are called non-ferrous alloys. The brief description of non-ferrous metals and its alloys are given below:

1. **Aluminium:** Aluminium is a silvery while, soft and ductile material. In its ore form, aluminium is found as hydrated aluminium oxide or ***Bauxite***. Pure aluminium is produced by the *Hall-Heroult process*.

   Properties:

   Important properties of aluminium include the following:

   1. light weight and easy workability
   2. due to the passivation phenomenon, it has the ability to resist corrosion.
   3. Non-magnetic and good reflector of light
   4. Highly ductile
   5. Good electrical and thermal conductivity
   6. Tensile strength of 650 kg/cm^2 which can be nearly doubled by cold working
   7. Recyclable with no deterioration in quality

Applications of Aluminium: Aluminium finds its application in

1. *Metallurgical application*: Aluminium is employed as a de-oxidizer in the production of iron and steels. Due to certain electrical, magnetic and oxidation resistant properties, Aluminium is used for alloying steels.

2. *Electrical industry* use Aluminium to make bus bars, cables, induction motors, conductors, rotors, windings, etc.

3. *Aircraft industry*: Aluminium is used in making aircraft parts due to its light weight and non-corrosion properties.

4. *Automotive applications*: Aluminium due to its light weight is used in automobiles in making cylinder blocks, panels, suspension, chassis and other engine components. The contribution to the light weight of Aluminium in turn contributes to fuel efficiency of the automobile.

5. In the *packaging industry*, it is used to make foils and drinking cans.

6. It is also used to store breweries like beer in containers

7. In *domestic use*, aluminium is used in cooking utensils, ladders, furnishing, shower screens, lighting fixtures, household electrical appliances, etc.

8. It is also used in *construction industry* to make windows, doors, frames, fencing, shutters, curtain walls, insect screens, handrails, gates, prefabricated buildings, metal sheeting for false ceilings, solar panels, roofing, etc.

Alloys of Aluminium:

By addition of other alloying elements like copper, magnesium, manganese, silicon, nickel, zinc, etc to Aluminium, Aluminium alloys are produced to serve much wider applications.

Two of the important alloys of Aluminium are duralumin and Y-alloy.

a. ***Duralumin***: Duralumin has 92% Aluminium, 3.5 to 4.5% Copper, 0.4 to 0.7% Magnesium, 0.4 to 7% Manganese, iron and silicon (max. 0.7%). Duralumin can be highly strengthened by heat treatment. It is as strong as steel but weighs only one third of the weight of steel. Duralumin can be spun, pressed, riveted, machined, etc. Duralumin has low resistance to corrosion and hence it is often coated with pure Aluminium to improve corrosion resistance.

   Applications: The connecting rod of aero engines and automobiles use duralumin. It is also used in aircraft structures. Duralumin sheets coated with pure Aluminium are called Alclad sheets and are used in aircraft industry.

b. ***Y-Alloy***: Y-alloy consists of 93% Aluminium, 4% Copper, 2% Nickel and 1% Magnesium. Y-alloy is a good conductor of heat and is available in both wrought and cast forms.

Applications: Since Y-alloy maintains strength at elevated temperatures, it is used to make pistons, cylinder head of I.C Engine. It is also used to make connecting rods and blades of propeller.

2. **Copper:** Copper is the oldest known metal to the mankind. It is extracted from the ore called *Copper Pyrites*. Extraction is carried out in a reverberatory furnace where ore is refined and then the impure blister copper is further refined by electrolytic process.

Properties: Important properties of Copper include

1. High electrical conductivity
2. High thermal conductivity
3. Good corrosion resistance
4. Light weight
5. High ductility
6. Malleable and soft

Applications: The applications of Copper are as below:

1. Copper in the form of tubes are used in refrigerators, air-conditioners and radiators due to its high thermal conductivity
2. Due to high electrical conductivity, Copper is used in electrical wires, cables, and conductors
3. Used to make popular alloys like brass and bronze
4. Used for roofing, sheathing and flushing drains
5. Due to high corrosion resistance, used in food and brewing plants and chemical plants.
6. Copper is used to make sculptures, statues, etc.
7. Used to make door knobs

Alloys of Copper:

Copper alloys are majorly classified into brass and bronze.

a. **Brass:** Brass is an alloy made of copper and zinc. The grades contain proportions ranging from 51 to 81% (Copper) and 19 to 49% (Zinc) respectively. Apart from zinc, small amounts of aluminium, tin, manganese and lead give special properties to brass. Zinc added to copper helps to improve machinability, strength, hardness and colour.

Properties:

1. Good bearing metal
2. Good machinability

3. Can be cold worked and hot worked
4. Good castability
5. High resistance to corrosion

The common brasses used in the industry are Muntz metal, cartridge brass, naval brass, admiralty brass, delta brass, beta brass, free cutting brass, red brass, precipitation hardening brass, clock brass, silicon brass, etc.

Applications of Brasses:

1. Pump parts, Marine fittings, valves, condenser tubes, fuses, taps, etc.
2. Cartridge cases, tubes, sheets, radiator shells, head lamp reflectors.
3. Ship components such as window anchors
4. making ornaments
5. electrical fittings
6. Brush holders
7. as brazing solder
8. gears, pinions and other moving parts of a clock
9. fire extinguisher shells and parts of a refrigerator
10. used in musical instruments such as horns, trumpets, bugles, etc.

b. **Bronze**: Bronze is an alloy of Copper and Tin. By alloying copper with mainly tin and other elements, the resulting bronze alloy is harder than copper. Generally, tin amounts to 5 to 10% of the bronze. Other elements added include aluminium, silicon, manganese, nickel and phosphorous.

Properties:

1. Very good strength compared to brass and copper.
2. Good bearing property
3. Good corrosion resistance.
4. Improved hardness
5. Easy machinability
6. Good fatigue strength

Few popular types of bronze includes gunmetal or G-metal, bell metal, phosphor bronze, Manganese bronze, etc.

Description and Applications of various types of Bronze:

Gun metal contains 88% Copper, 10% tin and 2% Zinc. Small proportion of lead is also added to improve castability and machinability. It finds applications in marine fittings, pumps, valves, bearings, bushes, fittings of steam pipe, etc.

Bell Metal contains 75 to 80% Copper and the remainder is tin. Due to its good ringing and low damping qualities, it is used in bells and gongs. In eastern parts of India, Bell metal is used to make kitchen utensils.

Phosphor Bronze contains 94% Copper, 5% tin and up to 1% phosphorous. During melting, phosphorous is added as a de-oxidizing agent. Phosphorous improves the castability and other mechanical properties. It has high strength and hardness and finds its use in gears, worm wheels, welding rods, electrical contacts, power screws, in musical instruments (such as saxophone), etc.

Manganese Bronze contains 55 to 60% Copper, 38 to 42% zinc, 1.5% tin, Manganese up to 3.5% and iron up to 2%. This has better hardness, strength and anti-corrosion properties compared to phosphor bronze.

3. **Lead:** Lead is a soft and malleable metal obtained from its ores (mainly the galena ore) and found as oxides or sulphides.

Properties: Lead is a soft metal which is very malleable and ductile. It has poor tensile strength, high co-efficient of thermal expansion, high anti-frictional properties, and can be melted with ease. Lead is also toxic in nature.

Applications: Lead finds its applications in

1. Solders since it has a low melting point
2. The grid or plate of the Lead-acid batteries used in automobiles
3. Sheathing materials for high voltage cables due to its high ductility, good extrusion ability, low temperature and corrosion resistance.
4. Water pipes due to its corrosion resistance
5. paint industry as a colouring pigment although the use is getting reduced due to its toxicity
6. the building industry for flashings or weathering to prevent water penetration, and also in cladding and roofing.
7. The lining of chemical treatment baths (used as lead sheets), acid plants, storage vessels due to its resistance to chemical corrosion.
8. In making bullets and shots for firearms
9. Aviation fuel where tetraethyl lead is used as an anti-knocking additive.

Alloys of Lead: In making of lead based alloys, the common alloying elements are antimony, tin, arsenic, and calcium.

1. *Solder* is an alloy of Lead and tin used for joining less fusible metals. In soft solders, tin and lead in 60/40 proportion is used for electrical soldering.
2. *Babbitt metal* or white bearing metal is a lead alloy obtained by adding antimony, tin and arsenic. Babbitt metal is used as a bearing material for

axles and crankshafts.

3. Lead Alloys made out of lead, antimony (8%) and arsenic (2%) are used to make shots for ammunitions for military and sports purposes.
4. Lead alloys with alloying elements of tin, bismuth and cadmium are used in electrical fuses and boiler plugs.
5. Lead-antimony alloys are used in storage battery grids, castings, pipes and sheets. The addition of antimony provides greater hardness and strength and antimony added will be usually between 2 to 5%.
6. *Lead foil* is made by sandwich of lead between two sheets of tin. Lead foils are used in radiation shielding.

4. Nickel: Nickel is a silvery white lustrous metal. Nickel is the fifth most common element on the earth which occurs in the earth's crust. But since the earth core is inaccessible, nickel is obtained mostly from sulphide ores, serpentine deposits and laterite deposits. It is found that about 65% of the nickel which is produced is used in the manufacture of stainless steels.

Properties: Some of the important properties of Nickel are as below:

1. Good resistance to corrosion and oxidation
2. Very ductile
3. Readily alloys
4. Ferro-magnetic along with high density and strength.
5. Can be easily cast and machinable
6. Can be drawn into wires, forged, welded and brazed
7. Possesses catalytic properties
8. Has high melting point (1453^{o}C)

Applications:

1. Mostly as an alloying element for steel to increase the tensile strength, low co-efficient of thermal expansion, and anti-corrosion property.
2. Used as catalyst for many chemical reactions
3. Articles of iron and steel are nickel plated to protect them from rusting
4. Used in cooking utensils and kitchen sinks
5. Used in vessels for heating and boiling
6. Used in food processing equipment
7. Used in medical equipment
8. Used in chemical plants due to its resistance to alkalies

9. Used to shield against electromagnetic interference for its electrical and magnetic properties
10. Nickel powder is used in rechargeable batteries.

Alloys of Nickel and their applications: The alloying elements added to Nickel to form Nickel alloys are copper, chromium, iron, silicon, aluminium, molybdenum and manganese. Some of the common nickel alloys and their applications are as below:

1. *Monel Metal*: Monel metal is an alloy that contains 60% nickel, 38% copper and small amounts of Manganese, Aluminium and iron. Monel metal has excellent resistance to corrosion and is strong. Monel metal is used in the aircraft industry to make frames and skins of experimental rocket planes. Due to corrosion resistance, it is used in strainer baskets, piping systems, pump shafts, valves, keel bolts, propeller shafts, etc.
2. *German Silver*: German Silver is an alloy containing nickel, copper and zinc and this alloy exhibits high resistance to corrosion. It is used to make resistances in electrical work and utensils.
3. *Nichrome*: Nichrome is an alloy of 80% Nickel and 20% Chromium which is silvery grey in colour, is resistant to corrosion and has high melting point (1400^oC). It is used as a resistance wire for heating due to its stability, in fireworks, in electrical ignition systems as bridgewire, etc.
4. *Hastelloy C*: It is an alloy of Nickel, Molybdenum, Chromium and iron. It has good corrosion resistance and high strength at elevated temperatures.
5. *Inconel*: Inconel is an alloy of Nickel, chromium, iron, molybdenum and other elements. There are various alloys of Inconel where the amount of Nickel ranges between 44 to 72%, Chromium between 14 to 30%, iron from 3 to 10%, molybdenum from 2.8 to 10%. Inconel alloys are resistant to corrosion and oxidation, difficult to machine, can retain strength over a wide temperature range. It is used in gas turbine blades, combustors, pressure vessels, tubes of heat exchangers, etc.
6. *Constantan*: This is an alloy of 45% nickel and 55% copper. It has high specific resistance and not generally affected by temperature variations. It finds application in thermocouples, resistances, wheatstone bridges, etc.

5. **Zinc**: Zinc is a heavy, buish white metal whuch can be extracted from zinc sulphide or *zinc blende* or *sphalerite* by pyrometallurgical or hydrometallurgical treatment.

Properties:

1. It is a fair conductor of electricity
2. It has relatively low melting and boiling points

3. It is resistant to corrosion
4. Good castability
5. Can be recycled indefinitely without degradation

Applications:

1. *Galvanizing*: To protect iron and steel for corrosion, they are immersed in a bath of liquid zinc or is electroplated with zinc. This is called galvanizing, which is a very popular application.
2. *Galvanized Steel* is used to produce automobile parts that are vulnerable to corrosion.
3. Since zinc can be rolled as sheets, is used for roof covering application and for battery containers.
4. Zinc castings produced by pressure die casting process are ductile and have excellent surface finish. They are used in applications ranging from automobiles to zip fasteners.

Alloys of Zinc: Alloying elements added to zinc alloys are Aluminium , Copper and Magnesium which provide strength and dimensional control properties.

Common alloys of zinc are cadmium-zinc alloy, magnesium-zinc alloy, cooper-zinc alloy, lead-zinc alloy and iron-zinc alloy.

6. **Tin**: Tin is a silvery-white metal obtained from an oxide called *tin stone* by refining in a reverberatory furnace.

Properties:

1. Soft, malleable and ductile
2. Tin is corrosion resistant from water but is not resistant for acids and alkalies.
3. It has low melting point (232^{o}C)

Applications:

1. Tin is coated on steel containers for storing food and water
2. Used in cooking utensils
3. Used as an alloying element in soft solder, bell metal, bronze and Babbitt metal
4. Used in perforated lanterns, candle shields, mirror frames.
5. Used as roofing material due to its light weight and corrosion resistance

Alloys of Tin: The alloying elements added to tin to form alloys include copper, antimony, bismuth, lead, etc.

Notable alloys of tin include Babbitt metal, bell metal (already discussed previously), pewter and Britannia metal.

Pewter is an alloy of 85 to 99% tin and remaining made up of elements like copper, antimony, bismuth and lead. Pewter has a low melting point and finds its applications in decorative objects, statues, models, pendants, etc.

Britannia metal is an alloy of 92% tin, 6% antimony and 2% copper. Britannia metal is harder, stronger and easy to work compared to other alloys of tin. A noteworthy application of Britannia metal is in making of statuettes for Oscar awards which is plated with gold. Other applications include making teapots, candlesticks, jugs, utensils, etc.

7. **Silver**: Silver is a naturally occurring metal which is soft, white and a lustrous transition metal. It is little harder than gold and is very ductile and malleable. It has the highest electrical and heat conductivity of all metals and the lowest contact resistance. It is classified under precious metals. Silver is stable only in pure air and water.

Applications:

Silver finds its application in the following:

1. making jewellery and ornaments
2. currency coins
3. tableware and utensils
4. in brazing and soldering
5. in mirrors
6. in High capacity silver-zinc and silver-cadmium batteries
7. in dental alloys
8. used in printed circuit boards as paints
9. used in photography

8. **Gold:** Gold is a bright yellow, dense, soft, malleable and ductile metal. It is chemically non-reactive. The metal occurs in nature in the form of nuggets, grains in rocks, in veins and in alluvial deposits. Its melting point 1,064 degrees C. Gold is resistant to corrosion and tarnishing. Gold reflects heat and is a good conductor of electricity. Gold is an expensive metal.

Applications:

1. making of bars used for monetary exchange,
2. making of ornaments and jewellery,
3. in the treatment of rheumatoid arthritis,

4. in_dentistry to make crowns, bridges, dentures, etc,
5. used in space to protect spaceships from x-rays and solar radiation,
6. as a heat shield in electronic circuits, gold plating is done on contacts, switches, relays and connectors,
7. Formula one cars use gold foils in the engine as a heat shield,
8. Used in making trophies, cups, medals in the sports industry.
9. In India, many of the statues of worshipped Gods and/or parts of temples are made from Gold.

7.4 Non-metallic Materials

Non-metallic Materials are classified into:

1. Natural Materials 2. Synthetic Materials

7.4.1 Natural Materials

These include non-metallic materials that occur in nature. There is a long list of these materials and only a few can be listed as below:

1. **Wood**: Wood is a naturally occurring material that is hard, has a fibrous structure which is found in the stems and roots of trees and other woody plants. Wood has been used for thousands of years as a construction material and as a solid fuel. Apart from this wood is used in shipbuilding, art, utensils, sport equipment, toys, etc. One of the industrial use of wood is in the making of casting patterns.

2. **Rubber**: Rubber in its natural form occurs as an elastic material that is obtained from the latex sap of trees (mainly trees of the genera Hevea and Ficus) which can be vulcanized and finished into various products. Uncured rubber is used for adhesive, insulation and friction tapes, etc. Vulcanized Rubber is used widely in the manufacture of vehicle tyres, hoses, tubes, rollers, etc.

3. **Glass**: Glass is an amorphous solid material which is non-crystalline in nature. It is smooth with non-porous surface and is abrasion resistant, a good insulator, hardwearing, good resistant to chemical attacks, etc. Glasses are usually brittle and can be optically transparent. Glass is used in food containers, laboratory apparatus, doors, furniture, utensils, vehicle windows, mirrors, as lenses for spectacles, telescopes or magnifying glasses.

4. **Emery**: Emery is a fine grained abrasive powder largely used as abrasive and is naturally occurring aluminium oxide. Emery paper and emery cloth are used in smoothing rough metal or wood surfaces. Emery boards are usually used for filing fingernails. Grinding wheels contains emery which is used to grind and polish various substances, including metals, stones, gems, and optical glass.

5. **Diamond**: Diamond is the hardest naturally occurring substance which is a precious stone consisting of a clear and typically colourless crystalline form of pure carbon. Diamonds are used in cutting tools for operation at high speeds for metal finishing where surface finish

is very importance (Such as internal combustion engine pistons and bearings). Diamond is also used for dressing grinding wheels. Commonly, diamonds are vastly used in making Jewellery.

6. **Oils**: An oil is a neutral, nonpolar chemical substance which is a viscous liquid at ambient temperature. Oils have a high carbon and hydrogen content and are normally flammable and slippery. Oils are used in cooking, paints, to light lamps, lubrication, cosmetics, as a fuel, etc. In industries, oils are used to lubricate bearings and machine tools, used as jet fuel.

7. **Silicon**: Pure silicon is found in the shiny dark gray crystalline form and as an amorphous powder. Silicon is used in transistors, rectifiers, solar cells, and alloys. The compounds of silicon are largely used in glass manufacturing and in the building industry.

7.4.2 Synthetic Materials

Synthetic materials are those materials that are man-made and that do not occur in nature.

Examples are Plastics, Ceramics and Composites.

1. **Plastics**: The name of Plastic originated from the Greek word called 'Plasticos' meaning to be able to be shaped or moulded by heat. Plastics are organic polymers of high molecular mass which are derived from breaking down carbon based materials, normally crude oil, coal or gas, so that their molecular structure changes. This is actually done in petrochemical refineries under application of heat and pressure, and is used to produce majority of our present day plastics.

   Plastics are categorized as

   a. **Thermoplastics:** These are plastics that can be soften and get formed by the application of heat, and when cooled, takes up the shape of the form. In case heat is applied again, they will soften again. Examples of thermoplastics are acrylic and styrene.

   b. **Thermosetting plastics**: These are plastics that soften by the application of heat, and upon cooling gets moulded into the mould shape. But in case heat is applied again, softening deos not happen and gets permanently moulded in the mould shape. Examples of thermosetting plastics are polyester resins that are used in glass reinforced plastics work, and melamine formaldehyde used in the manufacture of Formica for kitchen work surfaces.

2. **Ceramics**: Ceramic is an inorganic, non-metallic solid manufactured by baking naturally occurring clays at high temperatures after moulding to shape. Ceramics are used in the manufacture of knives, as high–voltage insulators, high–temperature–resistant cutting tool tips, dies, engine parts, pottery, tiles, structural and refractory bricks, etc.

   The third popular example of Synthetic Material is a Composite. The following section deals in detail about Composites.

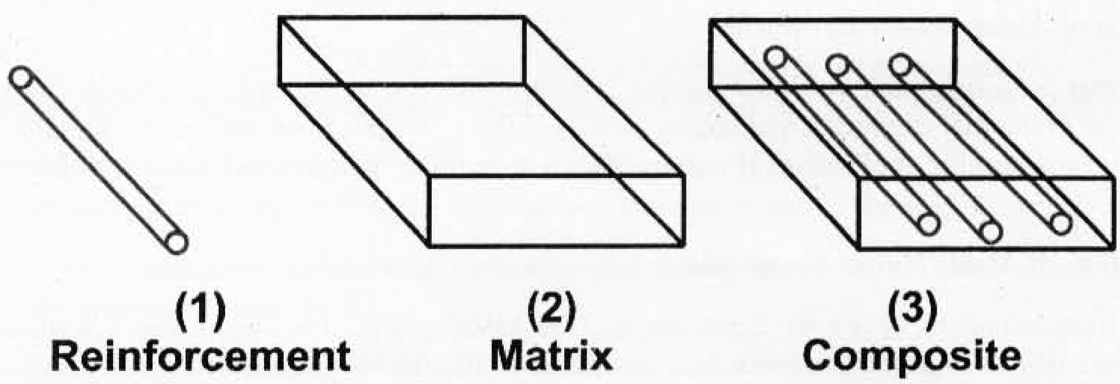
7.5 Introduction to Composites

Definition of Composite: A *Composite* is defined as a material which is a combination of two or more dissimilar materials which have different interfaces between them and the resulting material properties are enhanced compared to the individual constituent materials.

Composite has existed from the times of Egyptians who used straw bricks (1400 BC), a composite material and Mongols invented the composite bow. Today we find the use of composites in automobile parts, aircraft parts, in sports equipment, office furniture, in laptops, loudspeakers, in healthcare etc.

7.5.1 Constituents of a Composite

The main constituents of composites (as in *Fig 7.2*) are the reinforcements and the matrix. In a composite material one material forms a matrix to bond together the other material called *reinforcement material.* The matrix and reinforcement are chosen in such a way that their mechanical properties complement each other, at the same time their deficiencies are neutralised. Example: in Glass Reinforced Plastic moulding, the matric is the polyester resin and this binds together the glass fiber reinforcement.



Components of a Composite
Fig. 7.2

The reinforcement material in a composite is in the form of rods, strands, fibers or particles which is bonded together with the other matrix materials.

The functions of a Reinforcement includes

1. Contributing the desired properties,
2. Carrying the load and
3. Transferring the strength to the matrix.

The functions of the matrix includes

1. Holding the fibres together
2. Protecting the fibres from abrasion amongst themselves
3. Protecting the fibres from environment
4. Distributing fibres properly
5. Distributing the loads evenly between fibres
6. Apart from the fibre, the matrix also enhances few properties of the resulting material and structural component. These properties are the transverse strength of the lamina and the impact resistance.
7. Providing good finish to the product

7.5.2 Classification of Composites

Classification method I

Based on the type of matrix material, Composites are classified as below:

a. **Metal Matrix Composites (MMC)**

Metal Matrix Composites are composites that contain at least two component parts one of which is metal. The other material may be a metal or ceramic or an organic compound. MMC is made by dispersing a ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase into a metal matrix (aluminium, magnesium, iron, cobalt, copper).

Properties of Metal Matrix Composites

MMCs offer properties such as higher specific strength, stiffness, higher operating temperature, low co-efficient of thermal expansion and greater wear resistance; and also the opportunity to tailor these properties for a specific application. However, MMCs have lower ductility and the cost of fabricating is high.

Applications of Metal Matrix Composites

1. Used in making piston for diesel engine. The MMC piston offers good wear resistance and strength at high temperatures than compared to the traditional cast iron piston.

2. Metal matrix composites possessing high strength and specific stiffness can be used in applications where weight saving is a vital factor. .Examples are robots, high-speed machinery, and high-speed rotating shafts for ships or land vehicles.

3. MMCs are used in automotive engine and brake parts due to its good wear resistance and high specific strength.

4. They are also used in lasers, precision machinery, and electronic packaging due to the tailorable coefficient of thermal expansion and thermal conductivity of the MMC.

5. They also find applications in spacecraft structures, missile structures, fighter aircraft engines and structures.

b. Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites consists of ceramic fibres embedded in a matrix made from ceramic materials such as carbon (C), silicon carbide (SiC), alumina (Al_2O_3), mullite (Al_2O_3-SiO_2) or zirconia (ZrO_2). The fibres can also be of the same materials as mentioned for matrix. CMC is usually represented as "Fibre type/Matrix type". Example: C/SiC (Carbon fiber/Silicon Carbide Matrix), etc.

Properties of Ceramic Matrix Composites

The CMCs offer useful properties such as good corrosion resistance, high compressive strength, high thermal shock resistance, high mechanical strength at high temperatures, high thermal stability, etc. The downside of Ceramic Matrix Composites is its low crack resistance resembling glass. This is now overcome to a large extent by integration of long strand fibres.

Applications of Ceramic Matrix Composites

1. *Automotive applications*: C/C type CMCs are used in Disc Brakes of airplanes and racing cars due to lesser wearing, no effect of humidity, corrosion resistance and lesser disk mass.
2. *Space Applications*: Since CMCs can withstand very high temperatures, they are used in space applications such as nose, leading edges, lower surface of the wing and steering flaps.
3. *Gas Turbine applications*: Gas turbine engine components such as combustor liners, vanes, shrouds, blades, flaps, seals, etc made from CMCs are being researched and tested by GE Aircraft engines (*Courtesy: GE*)
4. *Pump applications*: SiC/SiC Ceramic Matrix Composite is used in shaft sleeve of Slide bearings of pumps (particularly boiler feedwater pumps of power stations)
5. *Cutting tool applications*: CMCs such as SiC whisker reinforced aluminium oxide are used in Cutting tools for machining of materials that are generally hard to machine.
6. Other applications include heat exchanger and radiant burner tubes, flame tubes, and high temperature furnace parts.

c. Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composites that comprises of a variety of short or continuous fibres that are bound together in an organic polymer matrix. They contain a matrix from thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polysterene) and embedded fibres are of glass, carbon, steel or Kevlar (dispersed phase). The reinforcement supports the mechanical loads to which the structure is subjected to. The function of the matrix is to bond the fibres together as well as to transfer loads between them.

Properties of Polymer Matrix Composites

1. The reinforcement in a Polymer Matrix Composite provides high strength and stiffness along the direction of reinforcement.

2. PMCs weigh less and hence are ideally suited in aerospace and automotive industry.
3. Superior corrosion and fatigue resistance when compared to metals.

Applications of Polymer Matrix Composites

1. *Aerospace Applications*: Due to the low weight of PMCs, it is used in the Aerospace in parts such as rotor blades & hubs, fuselage, thrust reversers, satellite structure, bulkhead & floor, cargo liner, wings, landing gear and doors.
2. *Marine Applications*: Due to anti-rusting properties, PMCs are used in boat parts such as propeller shafts, floorboards, rudders, boat hulls, masts, booms, submersibles pressure hull, and bulkheads.
3. *Automotive Applications*: PMCs are of low weight and its usage in automotive parts can reduce overall vehicle weight and hence can contribute to more fuel efficiency. PMCs are therefore used in automotive parts like car exterior body panel, battery trays, engine components, bumper fascia, protective shields, grills of the radiator, instrument panels and fuel lines.
4. *Construction Applications*: Due to Corrosion resistance and the speed & ease of erection, PMCs are used in construction applications such as Bridge decks, bridges, column wraps, cladding, etc.
5. *General engineering Applications*: PMCs find its use in storage tanks, pressure vessels, pipe systems, air ductwork, power transmission drive shafts, etc.
6. *Electrical & Electronics Applications*: PMCs are used in equipment housings, cable trays, transformer spacers, etc.
7. *Sports Industry Applications*: PMCs are used in bike frames, canoes, fishing rods, racquets, archery bows, golf clubs, ski poles & skis, surf boards, etc.
8. *Domestic consumer Applications*: PMCs are used in sanitary ware, bath unit, shower enclosures, sinks and furniture.

<u>**Classification method II**</u>

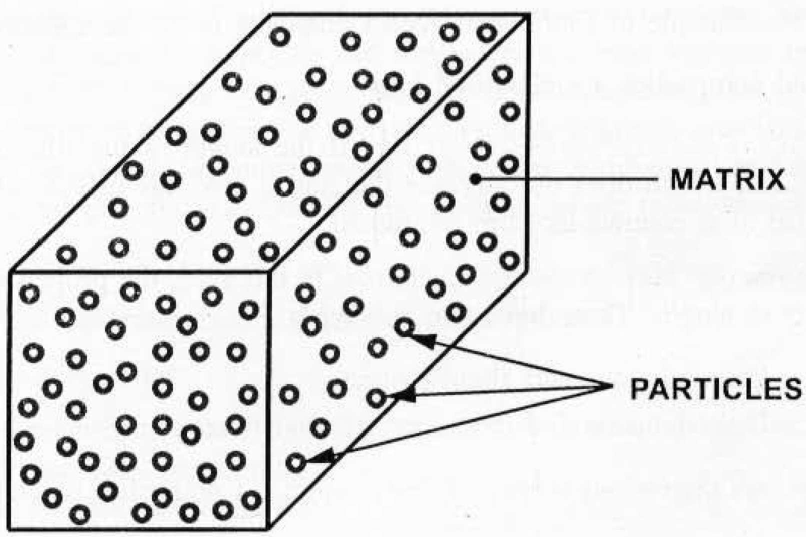
Composites can also be classified based on reinforcing material structure as

A. Particulate Composites
B. Fibre reinforced Composites
C. Laminate Composites

A. Particulate Composites

Particulate Composites consists of particles embedded in a body of matrix. The particles can be in the form of flakes, powders, chopped fibres, platelets, hollow spheres, buckyballs or carbon nanotubes form. These embedded particles are very fine particles, sometimes even less than 0.25 microns. The embedded particles provides reinforcement to the matrix material, strengths it, and provides specific properties for various applications.

Example of particulate composite is binging course rock and gravel in a matrix of cement for providing strength and stiffness. The advantages of using particulate composites include high tensile (or pulling) strength at high temperatures, high toughness and oxidation resistance. They also possess a high strength to weight ratio, hence are less dense, and lighter, than other materials which can withstand the same amount of force.



Particulate Composite
Fig. 7.3

1. Because of its inherent strength and cheap construction, particulate composites find applications in small appliances such as cell phone casings and even in helmets.
2. Aluminium alloy-corundum particulate composite is used in automobile piston and cylinder sleeve applications. The reinforcement used is corundum (Al_2O_3) due to its properties such as high wear resistance and less thermal conductivity.
3. Ceramic-metal particulate composites or cermets are used as a tool material for high speed cutting of materials such as hardened steels which are difficult to machine. Cermets also finds its applications in wheels of the turbine, mechanical seals, valve and valve seats, etc.
4. Carbon black particles with reinforced rubber is a particulate composite used in automobile tyres. Carbon black particles are of nanometer sizes and provides resistance to wear & tear and increase the stiffness and tensile strength of the tyres.

B. Fibre reinforced Composites (FRC)

Fibre Reinforced Composites or FRC are composed of axial particles in the form of fibres embedded in a matrix material. The aim of developing a fibre-reinforced composite material is to obtain a material which has high strength and high elastic modulus for its weight. Reinforcing fibres are usually of metals, ceramics, glasses, or polymers that are turned into graphite (and called carbon fibres). Fibres help by increasing the modulus of the matrix material. The strong covalent bonds that exist along the length of the fibres provides them with a very high modulus in the particular direction since to break or extend the fibre, the bonds should also be broken or moved. When Carbon fibres are embedded in the matrix, they are called Carbon Fibre Reinforced Composite (CFRC). The FRC is relatively costly since the fibres are not easy to process into composites.

One classic example of Fibre reinforced Composite is the fibreglass in a thermoset plastic.

Fibre reinforced composites are classified into

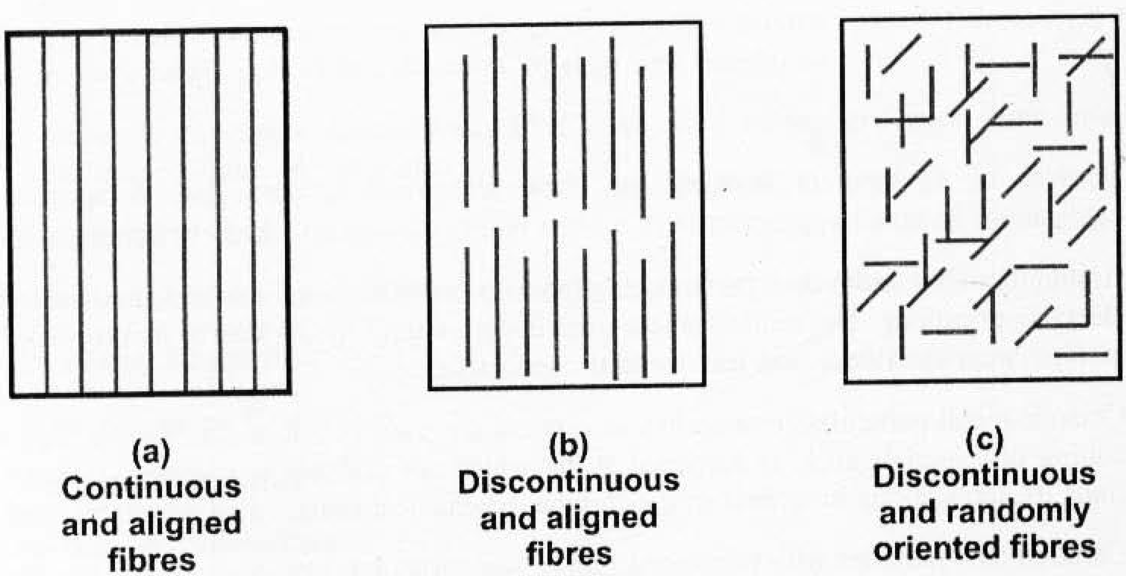
a) *Continuous fibre reinforced composite*: If the length of the fibre is such that any further increase in length does not increase the elastic modulus of the composite, then composite is called as a continuous fibre reinforced.

b) *Discontinuous fibre reinforced composite*: In this type, the properties of the composite vary with fibre length. These have two sub types:

   i. Discontinuous and aligned fibres

   ii. Discontinuous and randomly oriented fibres

Fig. 7.4 shows the various types of Fibre reinforced Composites based on the fibre orientations.



Various types of Fibre Reinforced Composites

Fig. 7.4

***Applications of Fibre Reinforced Composites*:**

1. Fibre-reinforced composites are used in advanced sports equipment like a time-trial racing bicycle frame that consists of carbon fibres in a thermoset polymer matrix.
2. The body parts of racing cars and few other automobiles are of composite material that is made of fiberglass in a thermoset matrix.
3. A hybrid mixture of Carbon fibres and Kevlar 49 fibres are used as primary materials to make wings, fuselage and tail assembly components of an aircraft.

C. Laminate Composites

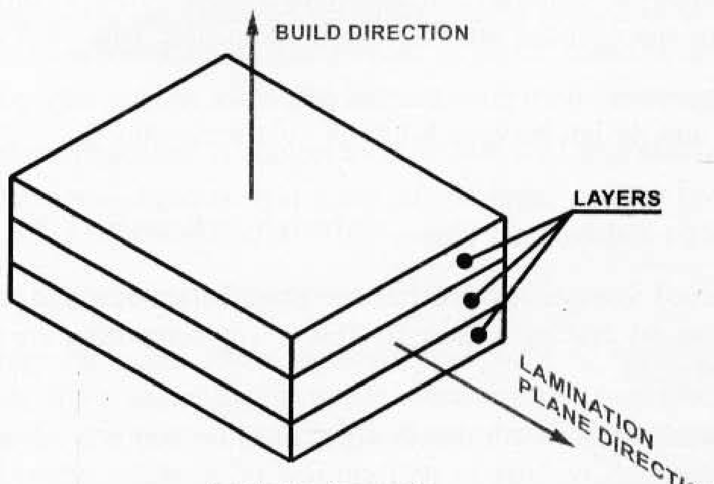
This type of composite consists of various layers of materials held together to give stiffness, strength and co-efficient of thermal expansion and the layers are held together in a polymeric, metallic or ceramic material. The fibres used in laminate composites can be glass, graphite, silicon carbide and boron. The matrix materials can be epoxies, alumina, titanium, aluminium, polyimides etc. Laminate composites involve two or more layers of the same or different materials. The layers can be arranged in different directions to provide the strength where required. Example: carbon sandwich composite.

Examples of laminate materials include Formica and plywood.

***Applications of laminate composites*:**

1. Aramid aluminium laminate (Arall) and Glass Aluminium laminate is finding its application as possible skin materials for aircraft.
2. Plywood is used in making furniture

A typical Laminate Composite is as shown in *Fig. 7.5* below:



Laminate Composite

Fig. 7.5

7.5.3 Properties of Composites

Composite materials have the following useful properties:

1. Light in weight.
2. Excellent specific strength and stiffness. High strength to weight ratio.
3. Excellent spring-back property with resilience.
4. Non-corrosive and resistant to chemicals. Good weathering properties.
5. Fire retardant and fire-resistant.
6. Low thermal conductivity.

7.5.4 Advantages of Composite Materials

When compared to metal parts, composite materials have the following advantages:

1. Composite materials are non-corrosive and resistant to chemical agents that includes acid rain and salt spray, whereas metal parts would suffer under action of these agents. Thus the maintenance and repair costs are reduced.

2. Composite materials have lower weight than their metal counterparts. Usage of Composites can lead to substantial savings in weight compared to similar metal parts (25% the weight of steel, 30% lighter than aluminium). This reduction of weight amounts to significant cost savings especially in fuel consumption.

3. Outstanding strength-to-weight and stiffness-to-weight ratios can be achieved by using Composite Materials.

4. Composite materials exhibit good Resilience. That is, the ability to deform and spring back to its original shape without resulting in any major damage. In the transport industry, composites show good Shape memory and impact tolerance.

5. Both the composite materials and adhesives/coatings share a comparable polymeric make-up, Adhesive and coatings are very much compatible with each other.

6. Composite structures have good thermal properties and are very good insulators. They retain their shape and do not become brittle at cold temperatures.

7. Particularly in military applications, using high strength composites can give good protection from blast and ballistic threats.

8. Fibre-reinforced composites are low in electrical conductivity and are very good fire retardants, thereby making it fire safe. This is why composites are selected to make covering for electrical parts.

9. Innovative designs that were previously difficult to achieve can now be achieved with use of composites with no loss in performance or strength. Example: complex aerodynamic profiles.

10. Expensive finishing on the surface is not required in composites as it gives post-mould paint-finish type surface.
11. The part and fastener count is reduced in composites.
12. Almost any colour shade of the composite part is possible through pigmentation of the gelcoat.

7.5.5 Disadvantages of Composite Materials

Although composites have distinct merits over metals, they do have few disadvantages as mentioned below:

1. The cost involved in the fabrication of composites is high. For example, a part made of graphite/epoxy composite may cost up to 10 to 15 times the material costs. However, improvements in processing and manufacturing techniques may lower these costs in the future.
2. Composites are more brittle than the wrought metals. Therefore composites are more easily damaged than the wrought metals.
3. The repair of composites is not a simple process unlike that in metals.
   a. Repair at the original cure temperature requires the right pressure and tooling.
   b. In few cases, the critical flaws and cracks in composite structures may go undetected which may lead to structure breakdown.
   c. Hot curing is required in many cases and this require special tooling
4. Composite materials must be cleaned thoroughly before repair. This consumes time.
5. The Cost of raw materials used for manufacturing composites are high.
6. Composite materials are not isotropic (exhibiting same properties in all directions). Thus the mechanical characterization of composites is much complex than compared to the metals.
7. The Matrix in the composites is subject to environmental degradation.

7.5.6 Applications of Composite Materials

Following are the various applications of Composite Materials:

1. **Aircraft Industry**: From the 1960s, Aircraft parts such as fairings, spoilers, and flight controls are made from composite materials since use of composites saves weight over aluminium parts. In the present generation large aircraft composite usage is found in fuselage and wing structures.

2. **Automobile Industry**: Modern automobile industry uses composites to make the vehicle lighter, safer and more fuel-efficient. Car parts such as front ends, tail doors, cross-car beam, side doors, seating, hoods, bonnets, fuse boxes, moulded headlamps, engine valve cover, car leaf springs, etc are made of composites by many Car manufacturers today.

3. **Sports equipment**: Composites finds its application in sports equipment such as Badminton racket, tennis racket, golf stick, hockey stick, softball bat, table tennis bat, light boat structure, helmets, climbing ropes, high jump pole, skis, snowboards, inline skates, ski boots, etc.

4. **Construction industry**: Polymer composite materials have been used by the construction industry in non-load bearing applications like trimmings, kitchenware, vanities and cladding.

5. **Biomedical industry**: Composite materials are widely used in orthopaedic applications such as bone fixation plates, hip joint replacement, bone cement, and bone grafts. Composites finds in dental applications such as in the preparation of crowns, repair of cavities, or entire tooth replacement.

6. **Wind Energy Applications**: Composites are used in the manufacture of blades of a Wind turbine.

7. **Marine Applications**: Composite materials are used nowadays extensively in the construction of ships and marine structures since composites have a higher stiffness and strength by weight than compared to most other materials like steel and aluminium. Composites are used in marine applications in Boat Hulls, Minesweepers, Ship Superstructures, etc

8. **Military applications**: Composites are used in submarines, armoured vehicles, bullet-proof vests and military aircraft.

7.5.7 Advanced Composites

Advanced Composite Materials or ACMs as they are called are composite materials that consists of high strength fibres with high stiffness or modulus of elasticity while bound together in a weaker matrix. The high strength fibres provide higher strength along the direction of the reinforcing fibre. Apart from high stiffness or elasticity, the high strength fibres also exhibit properties such as chemical resistance, temperature resistance, dimensional stability, flexibility and ease of processing. The aircraft / aerospace industry is today slowly replacing metal parts with advanced composite parts.

7.5.8 Applications of Composites in Aerospace / Aircraft

Composite materials are widely used in the Aircraft Industry. The use of light weight, structurally strong and temperature resistant composite materials have reduced fuel consumption, improve efficiency, improve performance and reduce direct operating costs of aircrafts.

The usage of Composite materials date back to 1950s when Boeing used Fibreglass in their 707 passenger jet. Fibreglass is a common composite material that consists of glass fibres embedded in a resin matrix. In the Boeing 707 passenger jet developed in the 1950s, about 2% of the total material used for the aircraft was of composite materials. Boeing increased the usage of composite materials in every new advanced aircraft that they built. Boeing 747, 767 and 777 had increased usage of advanced composites on the exterior and few interiors. But now Boeing 787 dreamliner is designed with about 50% composite materials.

Composites are used in the following parts of an aircraft:

1. Carbon fibres embedded in toughened resins are used to make the vertical and horizontal tails.
2. The floor beams of the passenger cabins use advanced composite materials.
3. Secondary structures such as aerodynamic fairings (Tail skid fairings) also use composites.
4. The nose landing gear doors are made from graphite fibreglass or carbon fibre.
5. Fixed trailing edge of lower panels are made of Graphite-aramid-fibreglass.
6. The aft is made of Graphite fibreglass.
7. The fuselage panels, frames, window frames, clips, and door are made from carbon fibre reinforced plastic (CFRP).
8. The shock strut door at the middle front is made of graphite composite.
9. The main landing gear doors are made of Graphite-aramid composite material.
10. The tail cone is made of carbon fibre.
11. The central torsion box is made of carbon fibre composite.
12. The radome at the pilot end tip of the aircraft is made from glass fibre. In light combat aircrafts, even Kevlar polyester material is used today.
13. The interior honeycomb panels of an aircraft now use composites.

Apart from fibreglass, today's aircraft also include more advanced composite materials such as the Carbon laminate composite and carbon sandwich composite. Carbon laminate composites consists of assemblies of layers of fibrous composite materials that are joined to provide strength, co-efficient of thermal expansion, bending strength and stiffness. The individual layers consist of high-modulus, high-strength fibres in a polymeric, metallic, or ceramic matrix material. Commonly used fibres include graphite, glass, boron, and silicon carbide, and some matrix materials are epoxies, polyimides, aluminium, titanium, and alumina. When layers of different materials are used, it becomes a hybrid laminate.

7.5.9 Advantages of Composite usage in Aircraft

Composite usage has benefitted the aircraft in many of the following ways:

1. Fuel efficiency due to reduced weight: By usage of composite materials, the weight of the aircraft components are reduced by nearly 20% and the fuel efficiency has increased by 20% which means huge savings of money as well as fuel.
2. Since composites do not corrode and are not susceptible to fatigue, usage of composite fuselages provide few additional passenger comfort amenities that are not available in conventional metal aircrafts. Example: less ear popping on landing can be experienced by the passenger since for a composite fuselage, the pressurization differences between the inside cabin and the outside air can be higher.
3. The disaster due to fatigue (as observed in the Aloha Airlines disaster of 1980s) is reduced due to the superior cyclic load capability of the composites.
4. Due to the corrosion resistance of composites, the humidity levels in the cabin may be higher which results in fewer headaches and dry mouths after a long flight.
5. Due to the very stiff material properties of composites, windows can be larger, which is a passenger benefit.
6. *Formability*: Since the composites can be shaped to any contour, aircraft does not need rivets sticking out which would cause drag. (Drag is the aerodynamic force that opposes an aircraft's motion through the air).
7. *Longer life*: Composites possess a longer life expectancy compared to steel or aluminium.

7.5.10 Limitations of Composites in Aircraft

1. The layers that form the laminate composite structure can de-laminate between layers where they are weaker due to out-of-plane loads perpendicular to the layers or compression load on the layers. The delamination can make the structure weak if not taken care in design.
2. Usage of composite material results in higher costs and hence higher air travel costs.
3. When composite materials are joined to metals, then composite are more stressed as they carry more load. To compensate this, additional material may be required to build up the joint, which adds more cost and also adds weight, which is not desirable in aircraft. Also, the metal may expand more than the composite leading to joint failures. Better simulation techniques are required to analyse and solve this issue.

7.5.11 Applications of Composites in Automobiles

Today's automobile industry is up to many challenges, which includes a competitive global environment and to beat the competition the new generation automobiles need to deliver high performance, reduce costs, and satisfy stringent safety requirements. Thus a relook at the materials used in automotive engineering is required to face the challenges. Materials used in automobiles are vital. Eventually, lighter materials mean lighter vehicles and lower emission levels. Composite properties such as strength, quality and light weight justify its increased usage in the automobile industry.

The history of usage of composites in automobiles started in 1930 with Henry Ford attempting to use soya oil to produce phenolic resin used in manufacturing a wood filled composite material for car bodies. The 1950s saw the usage of Glass fibre reinforced material and cold setting polyester resins in the bonnets and side valences of a car (The 1954 Singer Hunter Model Car). In the 1980s, the Pontiac Fiero Car used composites for making space frame chassis and the body making the car more composite inclusive than before. The advent of Formula One (F1) racing cars saw the usage of Composites in its construction. Carbon fibre composite is used today that accounts for 75% of its construction.

Composite materials usage is found mostly in today's luxury cars and Formula One Racing cars. Japan and European car manufacturers are using composites even in the entry level segment and mid-range segment.

Composites are used in the following parts of an automobile:

1. The seat structure of the car is made in composites which can reduce a weight of 23% compared to a steel structure. Example: Mercedes uses polymer composites and has achieved 3 kg weight reduction in the seat structure.
2. The standard steel suspension springs are being replaced by glass fibre reinforced polymer composite materials. Example: Audi uses these composite springs in its upper mid-sized models.
3. The front end of few cars are made from thermoplastic composites. This enables front end to be a single piece and replaces a number of steel panels and also reduces weight. Example: the Audi A4 and the Volkswagen Golf and Polo use composite front end made of thermoplastic composites.
4. The tail doors of a few cars are made of composites. Example: Citroen AX, BX, Fiat Regata, Renault Espace, etc.
5. Few luxury class cars now use composite wheels where an electroplated composite cover is bonded to a weight optimized forged aluminium wheel with foam filling in the voids. Thus, the weight of the wheel is reduced. These are also more aerodynamic and reduces fuel consumption. Example: Audi A8 luxury sedan uses such wheels.
6. The interiors of the car such as seat bases, door trim panels, rear package shelves, headliners and load floors are made of glass mat thermoplastic (GMT) composite.
7. The weight of the fascia in the front bumper of a car are reduced by using sheet moulding composite (SMC) for cross-car beam and/or integrating the beam with the air duct and the fascia armature. Example: the cross-car beam in Ford Ranger is made of SMC and the weight saving is upto 2.3 kg.
8. The bumpers of automobiles are made with glass mat thermoplastic composite. This reduces weight to a good extent.

9. It is not only that composites are used in cars. In the case of trucks, the combination of carbon and glass fibres in vinyl ester resin is bonded to the aluminium end caps to form a single piece of drive shaft which has good corrosion resistance and additional vibration dampening. Example: Such drive shafts are used in General Motors manufactured Pickup trucks.

The future of composites in automobile industry:

There are various developments and research happening to replace conventional metal parts with composites. Some of these developments are:

1. The hood at the front of the car is being made of carbon fibre which weighs less than the conventional steel hoods. Example Ford Motor plans for introducing a carbon fibre hood that can reduce the weight by 50% compared to the steel hood.

2. Due to useful properties such as stiffness, strength, low density, damage resistance, fatigue strength and high dampening capacity with respect to mechanical vibrations, the Kevlar 49 composite are currently being evaluated for use in leaf springs, transmission supports, drive shafts, bumper beams, etc.

EXERCISES 7

1. How do you classify Engineering Materials?
2. Classify and explain the various types of ferrous metals.
3. Classify and explain very briefly the various types of non-ferrous materials.
4. What are the main types of Non-metallic Materials? Explain very briefly each type and subtypes.
5. Define Composite.
6. What are the constituents of a Composite? Explain.
7. How do you classify composites based on matrix material? Explain very briefly each type.
8. How do you classify composites based on reinforcement material? Explain very briefly each type.
9. List the important properties of a Composite.
10. What are the advantages and disadvantages of Composites?
11. State the various applications of Composite Materials.
12. What are advanced composite materials?
13. State the applications of Composite Materials in Aircraft.
14. State the applications of Composite Materials in Automobiles.

CHAPTER 8

WELDING, BRAZING AND SOLDERING

8.1 Introduction

Metal fabrication involves joining of two metals together. Various processes are used to join the metals together depending the material and thickness of the parts to be joined and degree of permanency required etc. Here some of the important features and methods of joining by welding, soldering and brazing are discussed.

8.2 Welding

Welding may be defined as the metallurgical joining of two metal pieces together to produce essentially a single piece of metal. Welding is extensively used in the fabrication work in which metal plates, rolled steel sections, castings of ferrous materials are joined together. It is also used for repairing broken, worn-out, or defective metal parts.

1. Principle of Welding

A *welding* is a metallurgical process in which the junction of the two parts to be joined are heated and then fused together with or without the application of pressure to produce a continuity of the homogenous material of the same composition and the characteristics of the parts which are being joined .

2. Types of Welding

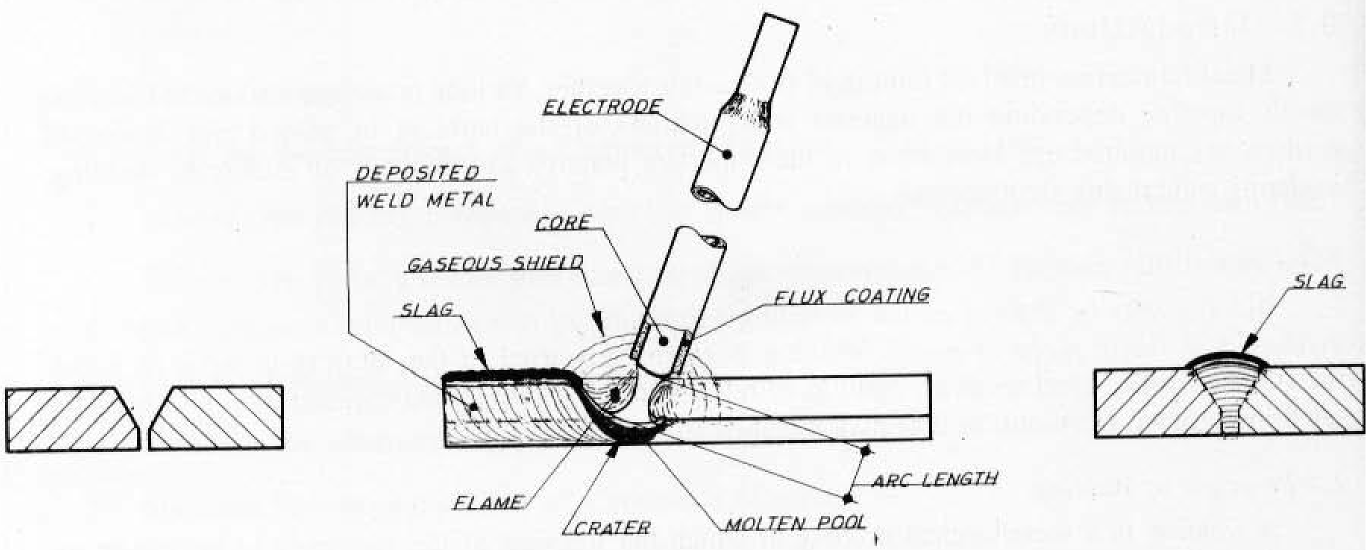
Welding processes may be classified based on the basic principles employed as ; *(i) pressure welding* and *(ii) fusion welding.*

In *pressure welding,* the parts to be joined are heated only up to the *plastic state* and then fused together by applying the external pressure. The different types of pressure welding are ; *forge welding* and *resistance welding.*

In *fusion welding* which is also known as *non-pressure welding,* the joint of the two parts is heated to the molten state and allowed to solidify. The different types of fusion welding are ; *arc welding* and *gas welding.*

8.3 Arc Welding

The principle of arc welding is as follows. When two conductors of an electric circuit are touched together momentarily and then instantaneously separated slightly, assuming that there is sufficient voltage in the circuit to maintain the flow of current, an èlectric arc is formed. Concentrated heat is produced throughout the length of the arc at a temperature of about 5000 to 6000°C. In arc welding, usually the parts to be welded are wired as one pole of the circuit, and the electrode held by the operator forms the other pole. When the arc is produced, the intense heat quickly melts the workpiece metal which is directly under the arc, forming a small molten metal pool. At the same time the tip of the electrode at the arc also melts, and this molten metal of the electrode is carried over by the arc to the molten metal pool of the workpiece. The molten metal in the pool is agitated by the action of the arc, thoroughly mixing the base and the filler metal. A solid joint will be formed when the molten metal cools and solidifies. The flux coating over the electrode produces an inert gaseous shield surrounding the arc and protects the molten metal from oxidizing by coming in contact with the atmosphere. *Fig. 8.1* illustrates the arc welding process.



Plates Before Welding
A

Welding Process
B

Welded Joint
C

Arc Welding
Fig. 8.1

1. Arc Welding Machine

Both alternating current (A.C) and direct current (D.C) are used for arc welding. Whenever A.C. supply is not available, *D.C generators* are used for D.C arc welding. For A.C arc welding a *step down transformer* is used. The transformer receives the A.C. supply between 200 and 440 volts and transforms it to the required low voltage in the range of 80 to 100 volts. A high current of 100A to 400 A will be suitable for general arc welding work.

In D.C welding, the workpiece is connected to the *positive pole* of a D.C generator and the electrode to the *negative pole* in order to melt greater mass of metal in the base material. This kind of setup is said to have " *straight polarity*". When the less heat is required at the base material, the polarity is reversed. Because of this option of selection of polarity depending upon the type of the job, in D.C. welding it is possible to melt many metals which require more heat to melt.

In A.C. arc welding, there is no choice of polarity since they change in every cycle. As the A.C. current acquires zero values twice in every cycle, at these moments the potential difference is also zero and hence higher voltage is required to maintain the arc.

2. Arc Welding Electrodes

The two types of electrodes used in arc welding are *(i) consumable electrodes* and *(ii) non-consumable electrodes.*

Consumable electrodes also melt along with the workpieces and fill the joint. They are made of various metals depending upon their purpose and the chemical composition of the workpieces. The consumable electrodes either will be *bare or coated.* When the bare electrodes are used, the globules of the molten metal while passing from the electrodes absorb oxygen and nitrogen from the atmospheric air to form non-metallic constituents which gets trapped in the solidifying weld metal and thereby, decreasing the strength of the joint. The coated electrodes facilitate ; (i) the protection of molten metal from oxygen and nitrogen of the air by providing a gas shield around the arc and the molten pool of metal; (ii) to establish and maintain the arc throughout welding ; (iii) the formation of slag over the joint thus protects from rapid cooling ; and (iv) the addition of alloying element. The electrodes are made of either soft steel wire or alloy steel. The coating is usually composed of chalk, ferro manganese, starch, kaolin, alloying and binding materials.

When *non-consumable electrodes* are used, an additional filler material is also required. The advantages of using this type of electrode is that the amount of the metal deposited by the filler rod can be controlled which is not possible in the other types of electrodes.

3. Electric Arc Cutting

In electric arc cutting, a very high current is passed so as to melt the workpiece. The insulating cover of the coated electrodes permits the introduction of the electrode into the cut without causing a short circuit. The electrode is also used up during cutting. All metals which can be readily melted can be cut. Generally arc cutting is employed to cut cast iron, alloy steels, non-ferrous metals and scrap metal.

8.4 Resistance Welding

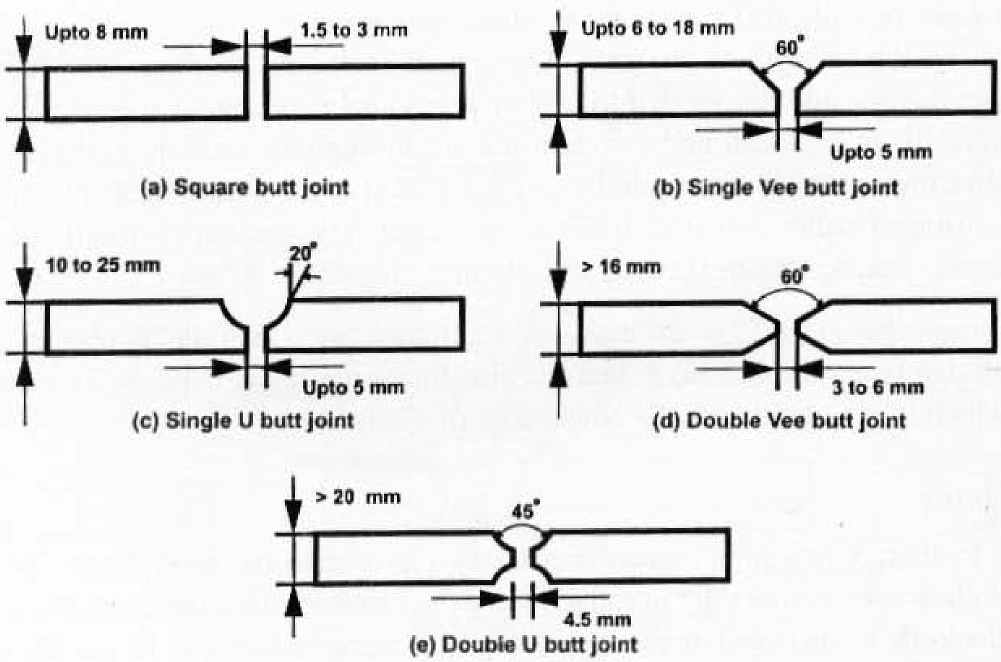
This type of welding employs the principles of both the pressure and fusion welding methods. It consists of heating of the parts to be welded to the plastic state and joined together by applying the mechanical pressure. The heating is accomplished by the passage of a heavy localized electric current discharged at a low voltage across the contact area of the metal parts to be joined. The current flowing from one part to the other at the joint encounters a very high resistance and the temperature at the joint increases. When the temperature attained is slightly greater than the melting temperature of the parts external mechanical pressure is applied at the joint which will result in a forge weld fastening the parts together. The parts to be welded by resistance welding are relatively thin in comparison with the parts which are normally gas or arc welded. Generally the resistance welding is employed for fastening thin metal sheets and wires.

General Welding Procedure

A step-by-step general procedure for welding is as described below:

Step 1: Cleaning: The surfaces of the parts to be welded need to be thoroughly cleaned for removal of dirt, oil, grease, etc.

Step 2: Edge Preparation: The process of preparing a contour at the edges of the pieces to be joined is called as *edge preparation*. This involves beveling or grooving. The idea behind this is to get fusion or penetration through the entire thickness of the member. The edge preparation is necessary mainly for butt welds of thickness greater than 3 mm. The various types of edge preparations required for different butt joints are shown in *Fig. 8.2* below:



Edge Preparation for butt joints
Fig. 8.2

Step 3: Clamping: Next, the parts to be welded are clamped suitably through jigs and fixtures so that there are no undesirable movements during welding.

Step 4: Check for safety equipment: Safety personal protective equipment like goggles and shields to protect the eyes, protective clothing to prevent the sparks and flying globules of molten metal, safety shoes, gloves, aprons and other safety equipment must be ensured.

Step 5: The initial weld: Initial tack welds are done at the opposite corners of the joint to secure the pieces together. Any cracks at this stage must be chipped off as the presence of these cracks causes residual stresses. The length and spacing of the tack weld varies with the thickness of the metal and length of the joint.

Step 6: Intermediate and final welding: The weld joint is formed through various weaving movements (of various shapes called weld beads). During the process, filler metal and a suitable flux are used. After the intermediate run of welding, final run is taken.

Step 7: Excess material removal: Extra material on the weld surface can be removed using tongs and chipper. The final weld is now allowed to cool and finally cleaned.

8.5 Gas Welding

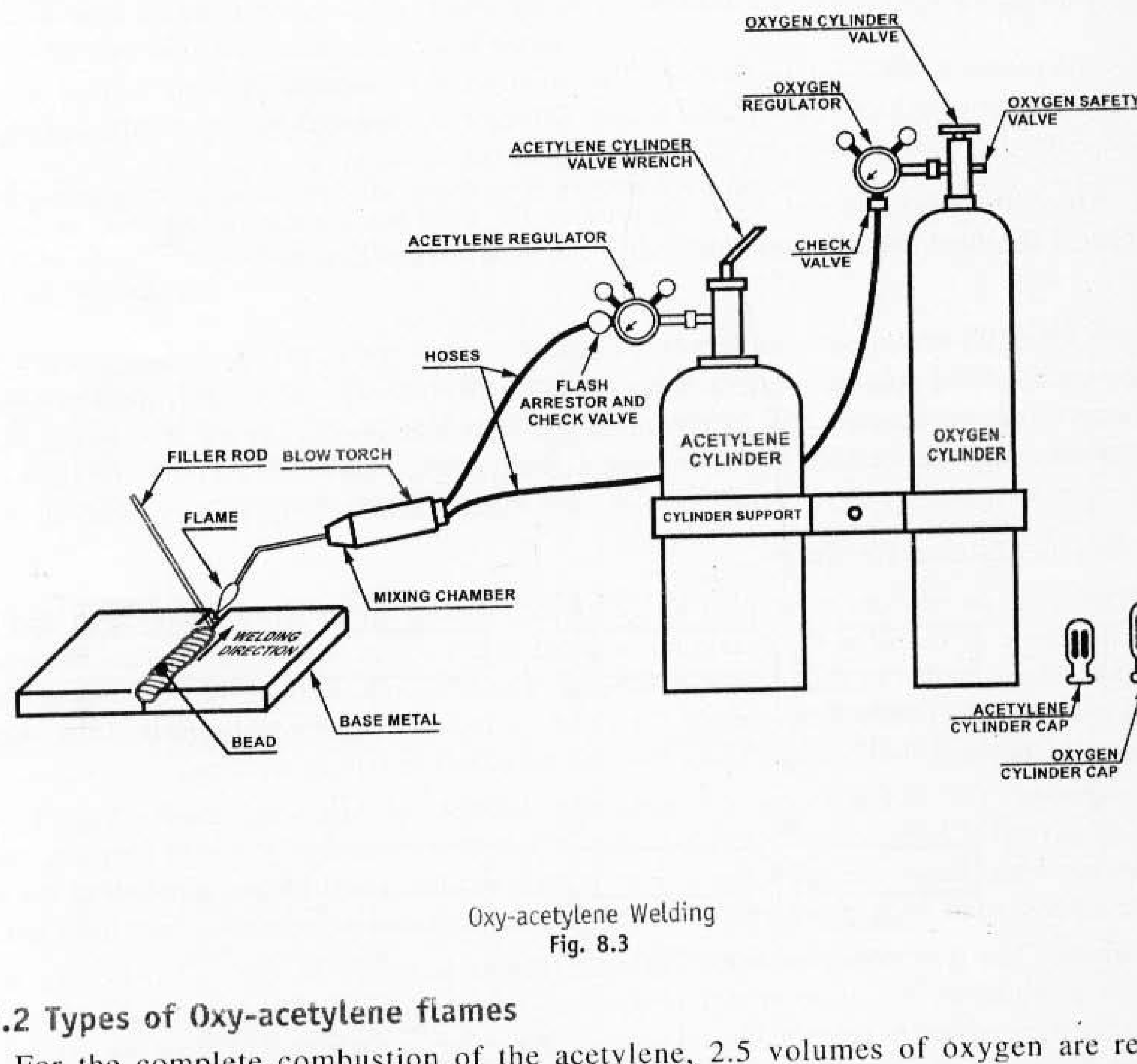
Gas welding is a *fusion method* of welding, in which a strong gas flame is used to raise the temperature of the workpieces so as to melt them. As in arc welding, a filler metal is used to fill the joint. The gases that can be used for heating are ; (i) oxygen and acetylene mixture and (ii) oxygen and hydrogen mixture. The oxy-acetylene gas mixture is most commonly used in gas welding.

8.5.1 Oxy-Acetylene Welding

When right proportions of oxygen and acetylene are mixed in the welding torch and then ignited, the flame produced at the nozzle tip is called as the *oxy-acetylene flame*. This flame when used in welding is known as ***Oxy-acetylene welding***. The temperature attained by the oxy-acetylene flame is around 3200^{0}C and therefore has the ability to melt all commercial metals. Thus, there is a complete bonding of the joining metals that can be achieved during welding.

Equipment: The oxy-acetylene gas equipment consists of *two large steel cylinders ;* one containing oxygen at high pressure, and the other dissolved acetylene also at high pressure, *rubber tubes, pressure regulators* and *blow torch*. The oxygen and the acetylene are supplied to the blow torch separately, where both of them get mixed and come out through the nozzle of the blow torch.

Working: The typical oxy-acetylene welding process is shown in *Fig. 8.3.* After the initial equipment preparation, the to-be-welded component setup and safety checks are completed, the pressure regulators fitted to the oxygen and acetylene cylinders are adjusted to draw the oxygen and acetylene gas in the required proportions from the cylinders respectively. The pressure regulator in each of the cylinders is fitted with two gauges. One gauge indicates the gas pressure inside the cylinder and the other gauge indicates the reduced pressure at which the gas goes out. The respective gases from cylinders are carried from the pressure regulator to the welding torch using the rubber hose pipes. Upon reaching the welding torch, these gases are allowed to mix in a mixing chamber and then are led out of the torch through the orifice of the blow pipe. The resultant flame at 3200 degrees Celsius is used melt the work pieces. To fill up the gap between work pieces and to add strength to the joint, filler rods (mostly of metal similar to the work pieces) are added to the molten metal pool. A Flux such as borax is used to dissolve and remove metal oxides formed during welding. The technique used to weld can be leftward or rightward welding technique. In the left ward welding technique, the flame from the torch preheats the material yet to be welded, while in the right ward welding, the flame post-heats the weld-bead. The molten metal pool that contains molten metal of the filler rod and the work piece solidifies to form a welded joint.

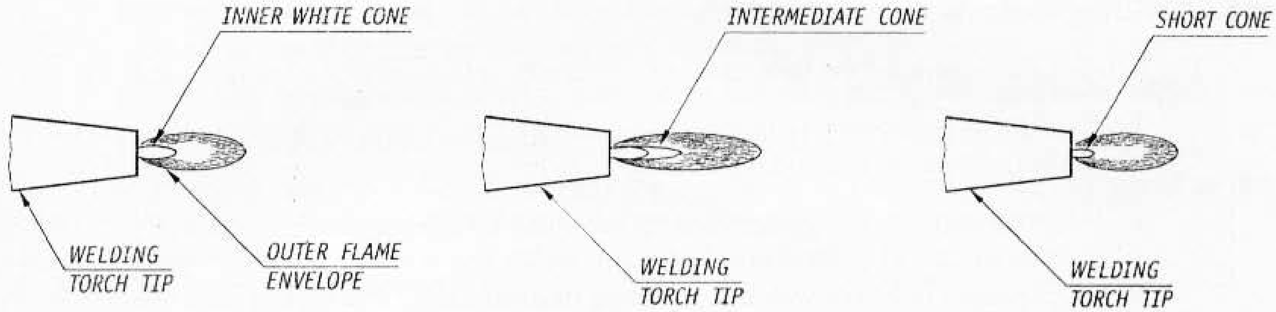


Oxy-acetylene Welding
Fig. 8.3

8.5.2 Types of Oxy-acetylene flames

For the complete combustion of the acetylene, 2.5 volumes of oxygen are required for 1 volume of acetylene. In practice, however, ratio of the parts of oxygen to the parts of the acetylene, referred as *gas ratio* varies from 0.95 to 1.5. Depending on the gas ratio, *neutral, oxidizing and carburising or reducing flames* as shown in *Fig. 8.4* can be obtained.

A *natural flame* shown in *Fig. 8.4A* is obtained by supplying equal volumes of oxygen and acetylene. The neutral flame consists of an inner small *whitish cone* surrounded by a sharply defined *blue flame.* Most of the oxy-acetylene welding is done with the use of the neutral flame.



Neutral Flame
A

Carburising
B

Oxidizing Flame
C

Gas Flames
Fig. 8.4

A *carburising* or a *reducing flame* shown in *Fig. 8.4B* is obtained by supplying excess acetylene in the gas ratio between 0.95 to 1. It has *three cones* ; an *inner white cone*, surrounded by an *intermediate whitish cone* known as *"intermediate flame feather"* and a *bluish envelope flame.* This flame is generally used due to its reducing nature, for welding alloy steels, cast iron and aluminium to protect from the oxidizable elements.

The *oxidizing flame* shown in *Fig. 8.4C* is obtained when there is excess oxygen. having gas ratio in the high range from 1.15 to 1.5. In appearance it resembles a neutral flame with the exception that the inner white cone flame is some what shorter. This is used for oxy-acetylene cutting and is not suitable for welding, since the weld metal will be oxidized.

Advantages of Oxy-acetylene welding

1. Most versatile process of welding with wide use in various manufacturing activities.
2. Low cost of the equipment and low cost of maintenance of the equipment.
3. Here, the heat source and the filler metal are separated, and hence control can be exercised on the rate at which the filler metal deposits.
4. The rate of heating and cooling is slow. This helps in retaining the structural homogeneity.
5. The equipment is portable and multi-functional because, apart from gas welding, it can also be used in torch brazing, braze welding, preheating and post-heating.

Disadvantages of Oxy-acetylene welding

1. Difficult to attain low cost target while joining heavy sections.
2. Handling and storage of gases not an easy job
3. It takes a long time for the flame to heat up the metal piece than compared to arc welding
4. Possible hazards due to explosion of gases.

8.6 Welding Defects

The following are some of the defects which reduce the efficiency of a welded joint.

1. *Cracking* – It occurs due to incorrect electrodes or wrong working procedures. Cracked welds must be cut out and re–welded.
2. *Incorrect edge preparation* – Too narrow an angle of the edges of the workpieces result in poor fusion, slag inclusion and weak weld. Too wide an angle between the inclined edges results in heavy welding, resulting in overheating and locked up stresses.
3. *Craters* – These are concave depressions in the external surface of the welded joints which reduces the volume of the weld and thus the strength of the joint.
4. *Under-cutting* – It is the excess melting of the parent metal which reduces its strength.
5. *Unequal legs* – In fillet welding, the unequal length of the legs of the weld reduces the strength of the joint.
6. *Porous weld* – Insufficient gap between the electrode and the workpiece results in poor penetration which may cause slag inclusion and porous welds.
7. *Over welding* – When welding is carried over an already welded layer, it may overheat the earlier layer of weld and there may not be proper fusion between the two layers.

8.7 Merits and Demerits of Welding

Merits:

1. The welding process gives metallic continuity in the workpiece, thus imparting properties in the joint that are equivalent to those of the metal being joined (mechanical, thermal, chemical, electrical, leak-tightness, durability, etc).
2. Welded joints are capable of withstanding elevated stresses.
3. Welded joints are durable. This means it is unaltered by variations in temperature, changing climatic conditions, etc
4. Welding ensures the leak-tightness of the welded piece.
5. Welding is a cheap and economical process.
6. It is possible to weld similar and dissimilar metals.
7. The use of portable welding equipment renders the process convenient to use.
8. Less noisy operation when compared to a process like riveting which requires noisy blows while fastening.

Demerits:

1. Welding causes residual stresses and distortion of the workpiece.
2. The eyes of the welder get strained due to light radiations emitted during the welding process. The eyes will be heavily strained when the welding process is continuous even though the welder uses goggles or protective shield.

3. The fumes that come out can be suffocating while welders are operating in areas that are less ventilated or air circulation is minimal.
4. Welding usually requires edge preparation before welding two pieces of metal.
5. Welded joints should necessarily be stress-relieved.
6. Welding requires a skilled operator for producing a neat job. Thus, compared to nut-and-bolt fastening or rivet-fastening processes, skill level required is more.

8.8 Applications of Welding

Welding is used widely in various types of industries like automobile, aircraft, construction equipment manufacturers, etc for mainly two purposes:

1. *Fabrication*: Welding is used extensively in the fabrication of body parts in automobile, aircraft and air-conditioning & refrigeration industries.
2. *Repair and Maintenance work*: Welding is used to join structural parts that are worn out..

The welding applications can be briefly listed as follows:

1. Aircraft building industry uses welding process to join its various constituent parts.
2. Cylinders, boilers and vessels manufacturing: Here, welding is used to join rolled cylindrical sheet along the height of the cylinder and join the dish end plates to the cylindrical part.
3. Welding process is extensively used in the construction of various types of structures like bridges, buildings and ships.
4. Used in machine tool industry in building various mechanical, food processing, farming, earth moving and textile machineries.
5. Used in building of bus, truck and car bodies and parts.
6. Used in the manufacturing of furnaces and tanks.
7. Used in the manufacture of steel furniture.
8. Used in the manufacturing of cranes and hoists.
9. Used in the manufacturing of railway equipment.

8.9 Soldering

Soldering is a method of uniting two thin metal pieces using a dissimilar metal or an alloy by the application of heat. The alloy of lead and tin, called *soft solder*, is used in varying proportions for sheet metal work, plumbing work and electrical junctions. The melting temperature of the soft solder will be between 150 to 350°C. To clean the joint surfaces and to prevent the oxidation, a suitable flux is used while soldering. Zinc chloride is the flux that is commonly used in soft soldering. A soldering iron is used to apply the heat produced from the electrical source.

An alloy of copper, tin and silver known as *hard solder* is used for stronger joints. The soldering temperatures of hard solders ranges from 600 to 900°C.

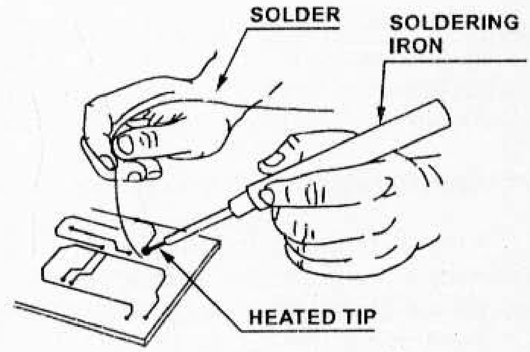
8.10 Method of Soldering (The Soldering Iron Method)

The method of soldering is illustrated step by step procedure below:

1. Cleaning of joining surfaces: Firstly, the joining surfaces are cleaned mechanically to make them free from dust, oil, scales, etc and ensure that the molten filler metal wets the surfaces.

2. Application of flux: Then, the joining surfaces are coated with a flux, usually rosin or borax. This cleans the surfaces chemically and helps the solder in making a bond.

3. Tinning of the surfaces to be soldered: Before carrying out the soldering operation, the soldering iron must be "tinned". This is to remove a thin film of oxide that forms on the copper bit, which in turn does not allow the job to be heated and thus it becomes difficult to solder. In tinning, the copper bit is heated and then rubbed with a file to clean it properly and then rotating with solder using resin. This causes the formation of a thin film of solder over the copper bit. This whole process is called "tinning".



Soldering Iron method
Fig. 8.5

4. Heating: The soldering iron is then heated and the flowing molten filler metal fills the joint interface. Allow the soldered area to cool and then solidify thus making the joint.

5. Final Clean-up: After completing the soldering, and the joints are formed, clean it with steel wool or solvent to remove left-over flux. After this clean the soldering iron using a damp sponge.

Fig. 8.5 shows the Soldering Iron method.

8.11 Other types of Soldering

The above method discussed is the Soldering iron method. There are however other methods of soldering such as:

1. *Torch soldering*: In this type of soldering, the required heat in order to heat the joint is supplied by the flame of an oxy-acetylene gas torch. The blow torch consists of a mixing chamber where acetylene and oxygen are mixed in the required proportions and the flame is directed toward the work pieces (whose surfaces are applied with a flux). The work pieces are then heated to the required temperature and the solder is fed into the joint area where due to heat it melts and flows into the gap in-between the two work pieces. Upon cooling, the joint is formed. Torch soldering is used mostly in the plumbing field for soldering copper tubing to copper fitting.

2. *Wave soldering*: Wave soldering is a large-scale soldering process by which electronic components are soldered to a printed circuit board to form an electronic assembly. The wave soldering process gains its name from the fact that the process passes the printed circuit boards to be soldered over a wave of solder. The molten solder is pumped out of a narrow slot thus creating waves. The Printed Circuit Board is moved over these waves and the bottom of the board comes into contact with the waves and the solder sticks to the component and solder pads by surface tension.

There are even other methods of soldering such as dip soldering, resistance soldering and induction soldering, which is not presently in the scope.

8.12 Advantages of Soldering

1. Low cost and easy to use.
2. Soldered joints are easy to repair or do rework.
3. The soldered joint can last for many many years.
4. Low energy is required to solder.
5. An experienced person can exercise a high degree of control over the soldering process.
6. Soldering does not change the microstructure or composition of base materials.

8.13 Disadvantages of Soldering

The disadvantages of Soldering are as below:

1. Very limited strength since low melting alloys are inherently of low strength.
2. Since the same heat is applied for the whole assembly, it can be detrimental to components in the assembly that are heat sensitive.
3. It is not easy to disconnect soldered connections. Removal of the solder may cause physical and electrical damage which cannot be repaired.
4. The heat of the soldering iron or the flame of the torch can cause damage to adjacent components.
5. Solder contains lead which is toxic in nature. The fumes can cause negative effects on health and environment.

8.14 Brazing

Brazing is a method of joining two similar or dissimilar metals using a special fusible alloy. It produces joints stronger than soldering. During brazing, the base metal of the two pieces to be joined is not melted. The filler metal must have the ability to wet the surfaces of the base metal to which it is applied. Some diffusion or alloying of the filler metal with the base metal takes place even though the base metal does not reach its melting temperature. The materials used in brazing are ; *copper base* and *silver base alloys*.

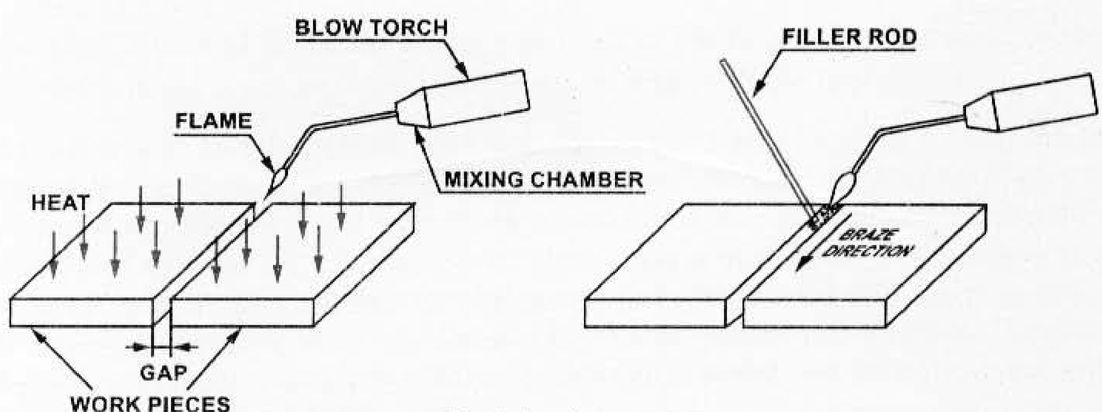
8.15 Types of Brazing

There are various techniques of brazing based on application of heat. The various techniques include:

1. Torch brazing
2. Furnace brazing
3. Dip brazing
4. Vacuum brazing
5. Infrared brazing
6. Resistance brazing
7. Braze welding
8. Induction brazing
9. Electron beam and laser brazing, etc.

Only important techniques are discussed here.

1. ***Torch brazing***: Torch brazing shown in *Fig. 8.6* is one of the popular types of brazing. Before brazing, the work pieces are cleaned with an emery cloth to remove dirt and grease. Torch brazing uses the heat of the flame from a blow torch which is directed toward the work pieces whose surfaces are painted with a slurry of flux. The flame used is a carburizing type oxy-acetylene flame. When the work pieces are heated to a temperature (greater than 450 degrees Celsius), the filler material is fed into the flame. The filler material melts and flows into the gap between the work pieces. The result is the brazed joint.



Torch brazing

(a) Heat applied to work pieces Fig. 8.6 **(b) Actual brazing**

Torch brazing technique is used to join parts that are made from materials which do not oxidize at the brazing temperature or that can be protected from oxidation using a suitable flux. The popular filler metals used are aluminum-silicon alloys, silver-base alloys, and copper-zinc alloys. A flux is necessary to prevent the surface from oxidation. Examples of fluxes used include borax, boric acid, fluorides and chlorides. Self-fluxing copper-phosphorus alloys are also used. Torch brazing is done in air and is the most common brazing process. Residual flux is removed to avoid corrosion.

It is important to note that majority of metals can be torched brazed except titanium and zirconium. Torch brazing is best suited for small production volumes or in specialized operations. Drawback is the high labour cost and the requirement of a highly skilled operator to produce quality brazed joints. The new development is usage of automated equipment for torch brazing which increases productivity, gives good braze quality and reduces the cost of brazing.

2. ***Furnace brazing***: Furnace brazing is another type of brazing used for its suitability in mass production. It is a semi-automated process by which metal parts are joined using a dissimilar lower filler metal. It does not require skilled labour unlike in Torch brazing. In furnace brazing, the work pieces to be joined are cleaned, then the brazing filler metal is applied to the surfaces to be joined, and later placed into a furnace. Next, the furnace has to be evacuated of air in order to eliminate any oxidation or contamination taking place. Then, whole assembly in the furnace is brought to the brazing temperature of about 450 degrees Celsius (but below the melting point of the metals being joined), after which the braze filler metal melts and flows into the joints. The brazing filler material can take various forms such as wire, foil, fillings, slugs, powder, paste, tape, etc.

   The furnace used is normally an electrical resistance type of furnace. Other furnaces that can be used include vacuum furnace, controlled atmosphere type furnace, mesh belt type furnace or reducing atmosphere type furnace. Example of Furnace brazing in a vacuum furnace is during the fabrication of aerospace and nuclear components. Furnace brazing can be used to join a wide variety of metals like nickel based alloys, stainless steels, carbon and alloy steels. Non-ferrous materials like including aluminium, titanium and copper can also be brazed.

3. ***Dip brazing***: Dip brazing is a type of brazing that is particularly suited for brazing aluminium. The parts to be joined are chemically cleaned, are assembled with the filler metal preplaced very near to the joints. The filler metal is basically 88% aluminium and 12% silicon. The assembly is then preheated in an air furnace to 550°C to ensure uniform temperature of all the dissimilar masses present in the assembly. Subsequently the assemblies are dipped for about two minutes into a molten salt bath (usually NaCl, KCl and other compounds) which serves as heat transfer medium as well as the flux. The temperature maintained in the bath is about 590°C. Once the assembly is dipped in the bath, the molten flux comes in contact with all internal and external surfaces at the same time. As the bath itself is a flux, complete bonding on oxide-free surfaces takes place and results in high quality joints.

4. ***Induction brazing***: Induction brazing is a brazing technique that utilizes a high frequency induction power source in order to create the heat required to melt the braze filler metal. The two or more materials are joined together by a filler metal that has a lower melting point than the base materials using induction heating. In induction heating, normally ferrous materials are rapidly heated from the electromagnetic field that is created by the alternating current from an induction coil.

5. ***Resistance brazing***: In Resistance Brazing, the joint to be brazed is connected to an electric circuit. When the electric current passes, the joint offers resistance to the passage of electric current which develops heat. This heat melts the brazing filler metal and joins the work pieces. Resistance-brazing is used for low volume production applications in which rapid and localized heating is necessary. Advantages of resistance brazing are clean operation without flames without affecting the surroundings and high quality joints with semi-skilled workforce.

8.16 Advantages of Brazing

The following are the advantages of brazing:

1. It is easy to learn.
2. It is possible to join virtually any dissimilar metals.
3. The bond line is very neat aesthetically.
4. Joint strength is strong enough for most non-heavy-duty type of applications.
5. The distribution of stress is evenly spread over a large area.
6. Allows bonding over a larger area.
7. No effect or negligible effect on the composition and microstructure of the base materials.
8. It is cost effective to braze complex and multi-part assemblies.

8.17 Disadvantages of Brazing

The following are the disadvantages of brazing:

1. Since the filler metals are used, the joint strength is less compared to a welded joint.
2. Joints may be damaged while operating at very high temperatures.
3. Requires extensively cleaned joint and use of proper fluxing agents. Otherwise, the colour of the joint may look aesthetically bad.
4. The flux residues must be removed to avoid corrosion.
5. It is difficult to join large sections with brazing.
6. The filler materials are expensive and hence will add up to the brazing process cost.

8.18 Differences between Soldering and Brazing

Sl.No.	Soldering	Brazing
1	In case of soldering, the metals are joined with the help of a filler metal with a low melting point, below 450 degrees Celsius, and below the melting point of the metals to be joined.	In case of brazing, the filler metal has a melting temperature between 450 and 1000 degrees Celsius.
2	Weaker joints compared to Brazing	Stronger joints compared to Soldering
3	The typical solder filler metals are alloys of tin	The typical filler metals for brazing are Aluminium, Silver, Copper, Nickel and Gold
4	The flux used is usually Rosin	The flux used is usually Borax
5	Economical Process	Not as economical as Soldering
6	Usually suitable process to join metals with small thicknesses	Suitable process even for joining metals of larger thicknesses

8.19 Differences between Brazing and Welding

Sl.No.	Brazing	Welding
1	In case of brazing, the metals to be joined are not melted and the joint is produced through the solidification and adhesion of a thin layer of molten filler metal.	In case of Welding, the surfaces to be joined are melted.
2	There is no penetration into the base metal	There is penetration into the base metal
3	The molten Brazing filler alloy spreads along the joint	The molten filler alloy does not spread along the joint and solidifies where it melts.
4	Relatively weaker joints are produced	Relatively stronger joints are produced
5	Average operator skill level is required	High operator skill and experience
6	Not as economical as welding	Economical compared to brazing

EXERCISES 8

1. Define welding.
2. Explain the principle of welding.
3. What are the differences between pressure welding and fusion welding ?
4. Differentiate between arc welding and gas welding. *(VTU, September 2000)*
5. Differentiate between consumable and non-consumable electrodes.
6. State the advantages of coated electrodes.
7. With a neat sketch, explain the oxy-acetylene welding process.
8. State the advantages and disadvantages of oxy-acetylene welding.
9. What is electric arc cutting ? Explain.
10. Name the three types of oxy-acetylene flame. Explain the application of each one of them.
11. With sketches, indicate different flame formations in gas welding. *(VTU, September 2000)*
12. What are the common defects found in welding ?
13. What are the merits and demerits of welding ?
14. What are the applications of welding?
15. Differentiate between soldering and brazing.
16. With the help of a neat sketch explain the gas welding. *(VTU, March 2001)*
17. Explain soldering. What fluxes are commonly used in soldering ? Why the flux is necessary ? *(VTU, March 2001)*
18. Explain the soldering iron method of soldering with a neat sketch.
19. Explain the common types of soldering.
20. What are the advantages and disadvantages of Soldering?
21. Explain torch brazing with a neat sketch.
22. Explain briefly furnace brazing, dip brazing, induction brazing and resistance brazing.
23. What are the advantages and disadvantages of Brazing?

CHAPTER 9

REFRIGERATION AND AIR CONDITIONING

9.1 Introduction

From earlier times, the art of *artificial cooling* is employed in ice making, preservation of the perishables such as, milk, food, drinks, medicines, etc. and indoor air cooling to provide human comfort and cool environment required in electronic, precision manufacturing and process industries, and also in numerous other applications like cryogenics, etc. The two methods employed for artificial cooling are ; (i) *refrigeration* and (ii) *air-conditioning*. Refrigerators are used in ice making, preservation of perishables, cryogenics, etc. and air-conditioners are used in indoor air cooling.

9.2 Refrigeration Defined

Refrigeration is defined as a method of reducing the temperature of a system below that of the surroundings and maintains it at the lower temperature by continuously abstracting the heat from it.

9.3 Principle of Refrigeration

In refrigeration, the heat is to be removed continuously from a system at a *lower temperature* and transfer it to the surroundings at a *higher temperature*. This operation according to the Second Law of Thermodynamics can only be performed by the aid of the external work. Therefore in a refrigerator, power is to be supplied to remove the heat continuously from the refrigerator cabinet to keep it cool at a temperature less than the atmospheric temperature.

9.4 Refrigerant

In a refrigerator, a medium called *refrigerant* continuously extracts the heat from the space within the refrigerator which is to be kept cool at temperatures less than the atmosphere and finally rejects to it. Some of the fluids like, Ammonia, Freon, Methyl Chloride, Carbon dioxide are the commonly used refrigerants.

9.5 Refrigeration Concepts

The principle of refrigeration is based on the following basic concepts.

1. Heat flows from a system at higher temperature to another at lower temperature.
2. Fluids by absorbing the heat, change from liquid phase to vapour phase and subsequently condense by giving off the heat.
3. The boiling and freezing temperatures of a fluid depend on its pressure. When a certain fluid at a very low pressure and temperature is compressed, even though its pressure increases it may still be in the condensed state itself if its temperature is not increased to the saturation temperature corresponding to the increased pressure.
4. Heat can flow from a system at low temperature to a system at higher temperature by the aid of external work as per the Second law of Thermodynamics.

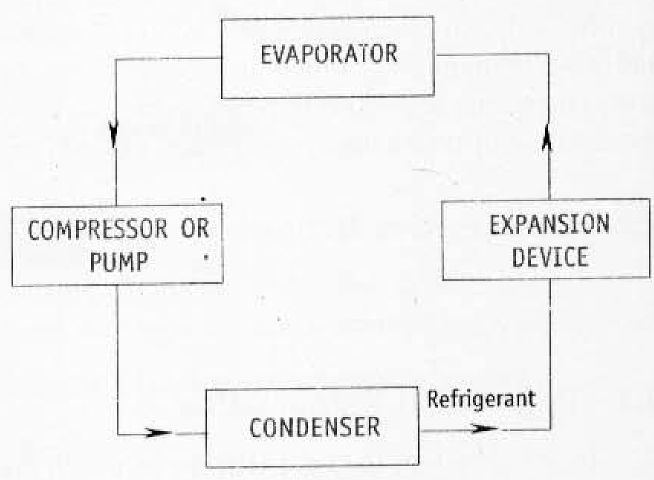
9.6 Parts of a Refrigerator

To accomplish the task of producing the cooling effect, a refrigerator must consist of the following main parts as shown in *Fig. 9.1*.

1. Evaporator
2. Condenser
3. Circulating System
4. Expansion Device

1. Evaporator

As the name itself implies, the evaporator is the heart of the refrigerator where the liquid refrigerant is evaporated by the absorption of heat from the refrigerator cabinet in which the substances which have to be cooled are kept. The evaporator consists of simply metal tubing which surrounds around the freezing and cooling compartments to produce the cooling effect required for freezing ice or lowering the temperature of perishables placed in the cooling compartment. Since it produces the cooling effect it is also sometimes called as cooling coil or freezer coil.



Parts of a Refrigerator
Fig. 9.1

2. Circulating System

The circulating system comprises of the mechanical devices such as compressors or pumps necessary to circulate the refrigerant to undergo the refrigeration cycle. They increase the pressure and therefore the temperature of the refrigerant. Generally these devices are driven by the electric motors. The electrical energy input to the motor is the energy input to the refrigerators.

3. Condenser

A condenser is an appliance in which the heat from the refrigerant is rejected at higher temperature to another medium, usually the atmospheric air. In a condenser the refrigerant vapour gives off its latent heat to the air and consequently condenses into liquid so that it can be recirculated in the refrigeration cycle. The latent heat of the refrigerant that is given off in the condenser mainly comprises of the heat absorbed in the refrigerator cabinet and the heat developed due to compression.

4. Expansion Device

An expansion valve serves as a device to reduce the pressure and temperature of the liquid refrigerant before it passes to the evaporator. The liquid refrigerant from the condenser is passed through an expansion valve where it reduces its pressure and temperature.

9.7 Refrigeration Effect Unit of Refrigeration and Ice Making Capacity

In a refrigeration system, the rate at which the heat is absorbed in a cycle from the interior space to be cooled is called *refrigerating effect.*

The capacity of a refrigeration system is expressed in *tons of refrigeration* which is the unit of refrigeration. A ton of refrigeration is defined as the quantity of heat absorbed in order to form one ton of ice in 24 hours when the initial temperature of the water is 0°C. Here it should be noted that *one American ton (2000 pounds)* is taken as the standard in the refrigeration practice.

In S.I. System,

$$1 \text{ Ton of Refrigeration} = 210 \text{ kJ/min} = 3.5 \text{ kW}$$

Ice Making Capacity: An Ice Making Machine is normally specified by its Ice Making Capacity. Ice Making Capacity is defined as the capacity of the Refrigerating System to make ice beginning from water (at room temperature) to solid ice. It is usually specified by kg/hr.

9.8 Coefficient of Performance and Relative Co-efficient of Performance

The performance of a refrigeration system is expressed by a factor known as the *coefficient of performance (COP). The COP of a refrigeration system is defined as the ratio of heat absorbed in a system to the work supplied.*

If Q = Heat Absorbed or Removed, kW

W = Work supplied, kW

$$COP = \frac{Q}{W}$$

Relative Co-efficient of Performance (Relative COP): The ratio of the Actual COP to the Theoretical COP is known as Relative Co-efficient of Performance.

$$Relative\ COP = \frac{Actual\ COP}{Theoretical\ COP}.$$

9.9 Refrigerator and Refrigeration

A *refrigerator* is a machine by means of which cold can be produced and the *refrigeration* is a process of removal of heat from a substance at a temperature lower than the surroundings with the aid of external work.

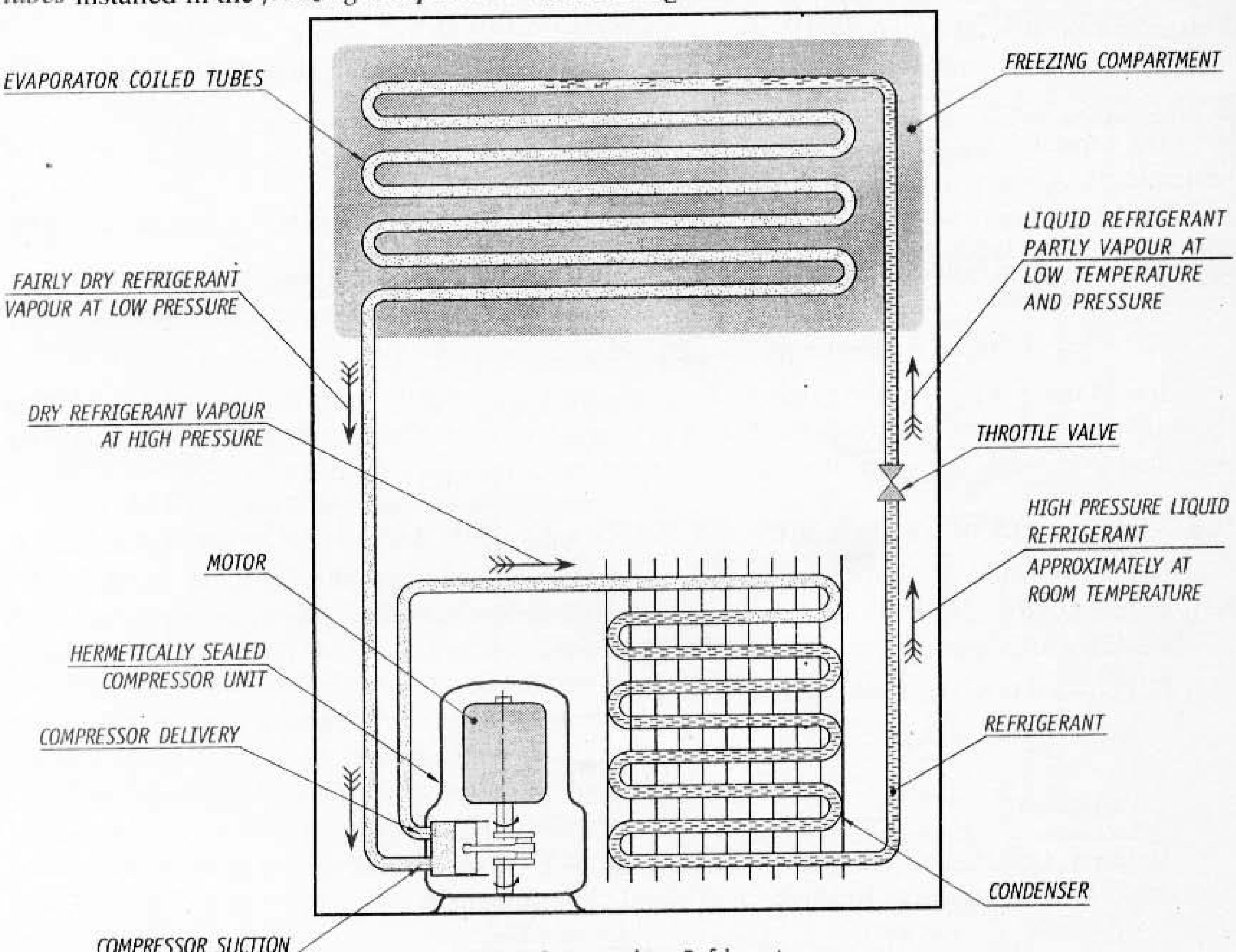
9.10 Types of Refrigeration Systems

The mechanical refrigerator systems are classified as : 1. Air Refrigerator, 2. Vapour Compression Refrigerator, 3. Vapour Absorption Refrigerator. The air refrigerator is out of the scope of this book, hence only the later two types of refrigerators are discussed here.

9.11 Vapour Compression Refrigerator

In a vapour compression refrigerator, vapour is used as the refrigerant. It is circulated through the system in which it alternately evaporates and condenses thus undergoing a change of phase from vapour to liquid and again liquid to vapour. During evaporation it absorbs the latent heat from the refrigerated space and subsequently gives off heat while condensing. A vapour compression system makes use of *mechanical energy supplied to the compressor to run the refrigerator.*

Fig. 9.2 shows a vapour compression refrigerator. It consists of an *evaporator made of coiled tubes* installed in the *freezing compartment* of the refrigerator and connected to the suction side of the



Vapour Compression Refrigerator

Fig. 9.2

compressor and a *throttle valve* as shown. The delivery side of the compressor is connected to a *condenser* which in turn is connected to a throttle valve.

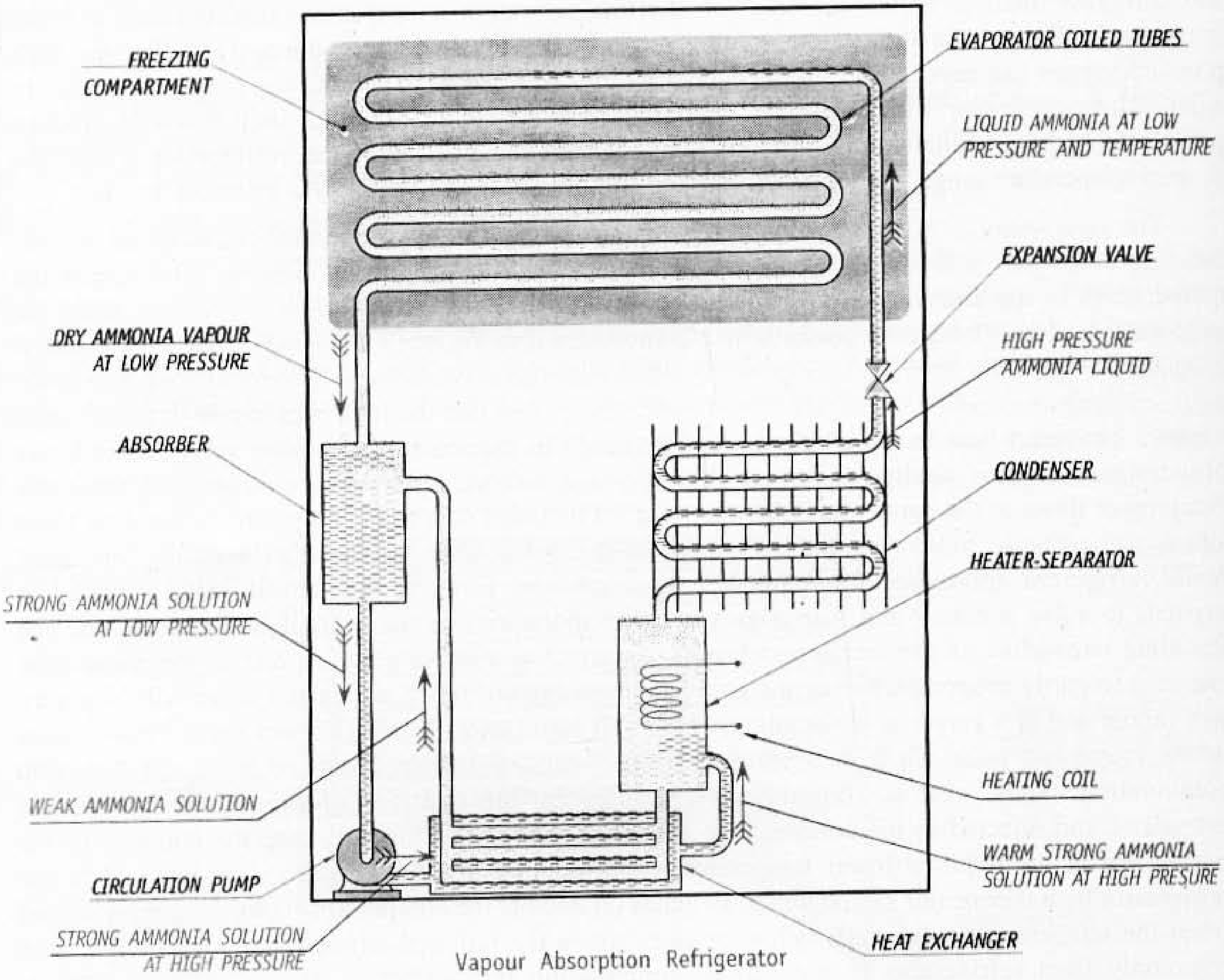
The object of including a compressor in this system is to draw the vapours from the evaporator and compress them to higher pressures so that the saturation temperature corresponding to these pressures is higher than that of the cooling medium flowing into the condenser, so that the high pressure vapour can reject heat into the condenser and be ready to expand to the evaporator pressure again. The compressor will be usually oversized so that if it runs continuously it would produce progressively lower temperatures. In order to maintain the interior of the refrigerator within the desired temperature range, the motor driving the compressor it controlled by a thermostat switch.

The *refrigerant at low pressure and temperature* passing in the evaporator coiled tubes absorbs the heat from the contents in the freezing compartment and evaporates. This in turn lowers the temperature in the freezing compartment. The evaporated refrigerant *at low pressure* from the evaporator is drawn by a compressor which compresses it to *higher pressures* so that the *saturation temperature of the refrigerant corresponding to the increased pressure is higher than the temperature of the cooling medium (atmospheric air) in the condenser,* so that the high pressure-high temperature vapours can reject heat in the condenser and be ready to expand in the throttle valve to the lower evaporator pressures again. *The high pressure-high-temperature refrigerant vapour* from the compressor flows to the condenser where it gives off its latent heat to the atmospheric air. As a result of the loss of latent heat in the condenser, the refrigerant condenses. The ***high pressure condensed liquid refrigerant*** approximately at room temperature now flows to the throttle valve in which it expands to a *low pressure* and then passes to the evaporator coils for recirculation once again. The throttling expansion of the refrigerant lowers its pressure and temperature and at the same time causes it to partly evaporate. Hence the refrigerant coming out of the expansion valve will be a very wet vapour and at a very low temperature which will be around –10°C. This wet vapour now passes to the evaporator coils where it absorbs its latent heat and then recirculated to repeat the cycle continuously. Thus, heat is continuously extracted by the contents of the refrigerator in the evaporator and rejected in the condenser to the atmospheric air. This will keep the contents of the refrigerator at the required lower temperature. The required low temperature is maintained in the refrigerator by a *thermostat switch* which switches on and off the compressor motor by a relay as and when the temperature either falls below or rises above the required temperature. One of the most commonly used refrigerants in the vapour compression refrigerator is dichlorodifluoromethane, popularly known as Freon 12, or R12. This refrigerant vapourises at – 6.7°C in the evaporator under a pressure of 246.2 kPa and after compression to 909.2 kPa would condense at 37.8° C in the condenser.

9.12 Vapour Absorption Refrigerator

A vapour absorption system makes use of the ability of a substance, called *absorbent to absorb large volumes of the vapour of a refrigerant even when cold and reduce it to a liquid, and subsequently give off its vapours when heated.* Water which has this ability is the mostly used absorbent, and since ammonia readily dissolves in water and vapourises when its solution is heated is the commonly used refrigerant in the vapour absorption refrigerator. In this refrigerator, the ammonia liquid vapourises in the evaporator coils absorbing the latent heat from the freezing compartment thus keeping it cool and subsequently gives off heat when it condenses in a condenser. Then ammonia liquid from the condenser is heated in a heater to vapourise it. Thus *the absorption system makes use of heat energy to change the state of the refrigerant required in the cycle.* A pump is used to circulate the refrigerant in the cycle.

This type of refrigerator is shown in *Fig. 9.3.* It consists of an *absorber, a circulation pump, heat exchanger, heater cum separator, condenser, expansion valve* and *evaporating coiled tubes.*



Vapour Absorption Refrigerator

Fig. 9.3

Dry ammonia vapour is dissolved in the cold water contained in the absorber, which will produce a strong ammonia solution. **A circulation pump, draws the *strong ammonia solution* from the absorber and pumps it to the heat exchanger, where** it is warmed by the *warm weak ammonia solution* **which is flowing back from the *heater-separator.* From the heat exchanger, the *warm high pressure strong ammonia solution* is passed to the heater-cum-separator provided with the heating coils. The heating coils in the heater-separator heats the strong ammonia solution.** Heating of the high pressure strong ammonia solution will drive out the ammonia vapour from it **and consequently the solution in the heater–separator becomes weak which in turn flows back to the heat exchanger where it warms up the strong ammonia solution passing through it.** The *high pressure ammonia vapour* from the heater-separator now passes to a condenser, where it is condensed. *The high pressure ammonia liquid* is now expanded to a *low pressure and low temperature* in the throttle valve. The *low pressure condensed ammonia liquid* at *low temperature* is passed onto the evaporator coils provided in the freezing compartment, where it absorbs the heat and evaporates. **The *low pressure ammonia vapour* from the freezing compartment is passed again to the absorber where it is reabsorbed by dissolving in** water. The *strong low pressure ammonia solution* from the absorber is again recirculated to repeat the cycle continuously.

9.13 Comparison between Vapour Compression and Absorption Systems

Sl. No.	Principle	Vapour Compression System	Vapour Absorption System
1.	Working Method	Refrigerant vapour is compressed.	Refrigerant vapour is absorbed and heated.
2.	Type of the Energy Supplied	Works solely on Mechanical Energy.	Works solely on Heat Energy.
3.	Work or Mechanical Energy Supplied	Mechanical energy required is more because refrigerant vapours are compressed to higher pressures.	Mechanical energy required to run the pump is less since the pump is required only to circulate the refrigerant.
4.	COP	Although the coefficient performance is relatively higher, it reduces at part loads.	Although the coefficient of performance is relatively lower, it will be more or less same at part and full loads.
5.	Capacity	The design capacity is limited since a single compressor unit can produce upto 1000 tons of refrigeration.	The absorption systems can be designed to capacities well above 1000 tons.
6.	Noise	Noise is more due to the presence of the compressor.	Almost quiet in operation as there is no compressor.
7.	Refrigerant	Freon –12.	Ammonia.
8.	Leakage of Refrigerant	Due to high pressures, the chances of leakage of the refrigerant is more and is a major problem.	Almost there is no leakage of the refrigerant.
9.	Maintenance	The maintenance is high because of the compressor.	The maintenance is less.
10.	Operating Cost	The operating cost is high since the electrical energy is expensive.	The operating cost is less because the thermal energy can be supplied from sources other than the electrical energy and also the electrical energy required to run the pump is relatively less.

9.14 Refrigerants Commonly Used in Practice

The most commonly used refrigerants are :

1. *Ammonia* – in vapour absorption refrigerator.
2. *Carbon dioxide* – in marine refrigerators.
3. *Sulphur dioxide* – in household refrigerators.
4. *Methyl chloride* – in small scale refrigeration and domestic refrigerators.
5. *Freon - 12* – in domestic vapour compression refrigerators.
6. *Freon-22* – in Air Conditioners.

1. Ammonia

Ammonia as a refrigerant is employed in refrigerators operating on the absorption principles. Because of its high latent heat (1300 kJ/kg at –15°C) and low specific volume (0.509m^3/kg at –15°C) it produces high refrigeration effects even in small refrigerators. Since ammonia will not harm the ozone, it is environmental friendly. It is widely used in cold storage, ice making plants, etc. Its toxic, flammable, irritating and food destroying properties makes it unsuitable for domestic refrigerators.

2. Carbon dioxide

The efficiency of the refrigerators using carbon dioxide refrigerant is low. Therefore it is seldom used in domestic refrigerators, but is used in dry ice making plants. It is colourless, odourless, non-toxic, non-inflammable and non-corrosive.

3. Sulphur dioxide

Earlier sulphur dioxide was one of the most commonly used refrigerants in domestic refrigerators. Although it has better thermodynamic properties, it has low refrigerating effect and high specific volume, therefore large capacity high speed compressors are required. Since it combines with water and forms sulfurous and sulfuric acids which are corrosive to metals, the refrigerators using sulphur dioxide as refrigerant are seldom used.

4. Methyl Chloride

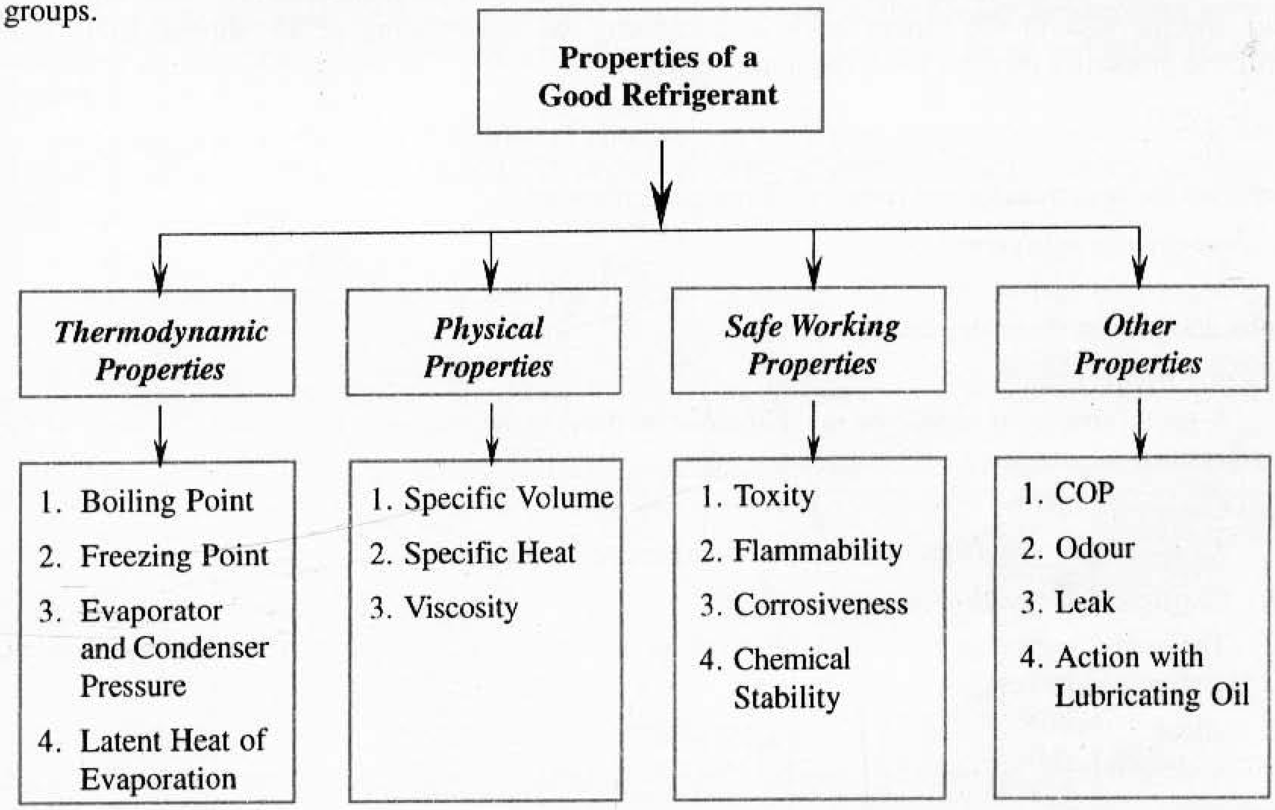
Methyl chloride was used earlier in domestic and small scale industrial refrigerators. Since it will burn under some conditions and slightly toxic, is not generally used.

5. Freon

Freon group of refrigerants is used almost universally in domestic refrigerators. These refrigerants are colourless, almost odourless, non-toxic, non-inflammable, non-explosive and non-corrosive, Freon-12 and Freon-22 are the two freon refrigerants commonly used in domestic refrigerators and air conditioners. Although these refrigerants are now being used extensively in the refrigerators and the air conditioners, it has been found that these refrigerants are posing a major threat to the global environment through their role in the destruction of the ozone layer.

9.15 Properties of a Good Refrigerant

The desirable properties of an ideal refrigerant are classified into the following four main groups.



1. Boiling Point

An ideal refrigerant must have *low boiling temperature* at atmospheric pressure.

2. Freezing Point

An ideal refrigerant must have a *very low freezing point* because the refrigerant should *not* freeze at low evaporator temperatures.

3. Evaporator and Condenser Pressure

In order to avoid the leakage of the atmospheric air and also to enable the detection of the leakage of the refrigerant, *both the evaporator and condenser pressures should be slightly above the atmospheric pressure.*

4. Latent Heat of Evaporation

The *latent heat of evaporation must be very high* so that a minimum amount of refrigerant will accomplish the desired result; in other words, it increases the refrigeration effect.

5. Specific Volume

The *specific volume of the refrigerant must be very low.* The lower specific volume of the refrigerant at the suction of the compressor reduces the size of the compressor.

6. Specific heat of liquid and vapour

A good refrigerant must have *low specific heat when it is in liquid state* and *high specific heat when it is vapourised.* The low specific heat of the refrigerant helps in sub-cooling of the liquid and high specific heat of the vapour helps in decreasing the superheating of the vapour. Both these desirable properties increase the refrigerating effect.

7. Viscosity

The *viscosity of a refrigerant at both the liquid and vapour states must be very low* as it improves the heat transfer and reduces the pumping pressure.

8. Non-toxicity refrigerant

A *good refrigerant should be non-toxic,* because any leakage of the toxic refrigerant increases suffocation and poisons the atmosphere.

9. Corrosiveness

A *good refrigerant should be non-corrosive* to prevent the corrosion of the metallic parts of the refrigerators.

10. Chemical Stability

An *ideal refrigerant must not decompose* under operating conditions.

11. Coefficient of Performance

The *coefficient of performance of a refrigerant must be high* so that the energy spent in refrigeration will be less.

12: Odour

A *good refrigerant must be odourless,* otherwise some foodstuff such as meat, butter, etc. loses their taste.

13. Leakage Tests

The refrigerant must be such that *any leakage can be detected by simple tests.*

14. Action with Lubricating Oil

A *good refrigerant must not react with the lubricating oil* used in lubricating the parts of the compressor.

9.16 Air Conditioning

Providing a cool congenial indoor atmosphere at all times regardless of weather conditions needed either for human comfort or industrial purposes by artificially cooling, humidifying or dehumidifying, cleaning and recirculating the surrounding air is called *air conditioning.* The artificial cooling of air and conditioning it to provide maximum comfort to human beings is called *comfort air conditioning.* Similarly, providing a controlled atmosphere required in some engineering manufacturing and processing is called *industrial air conditioning.*

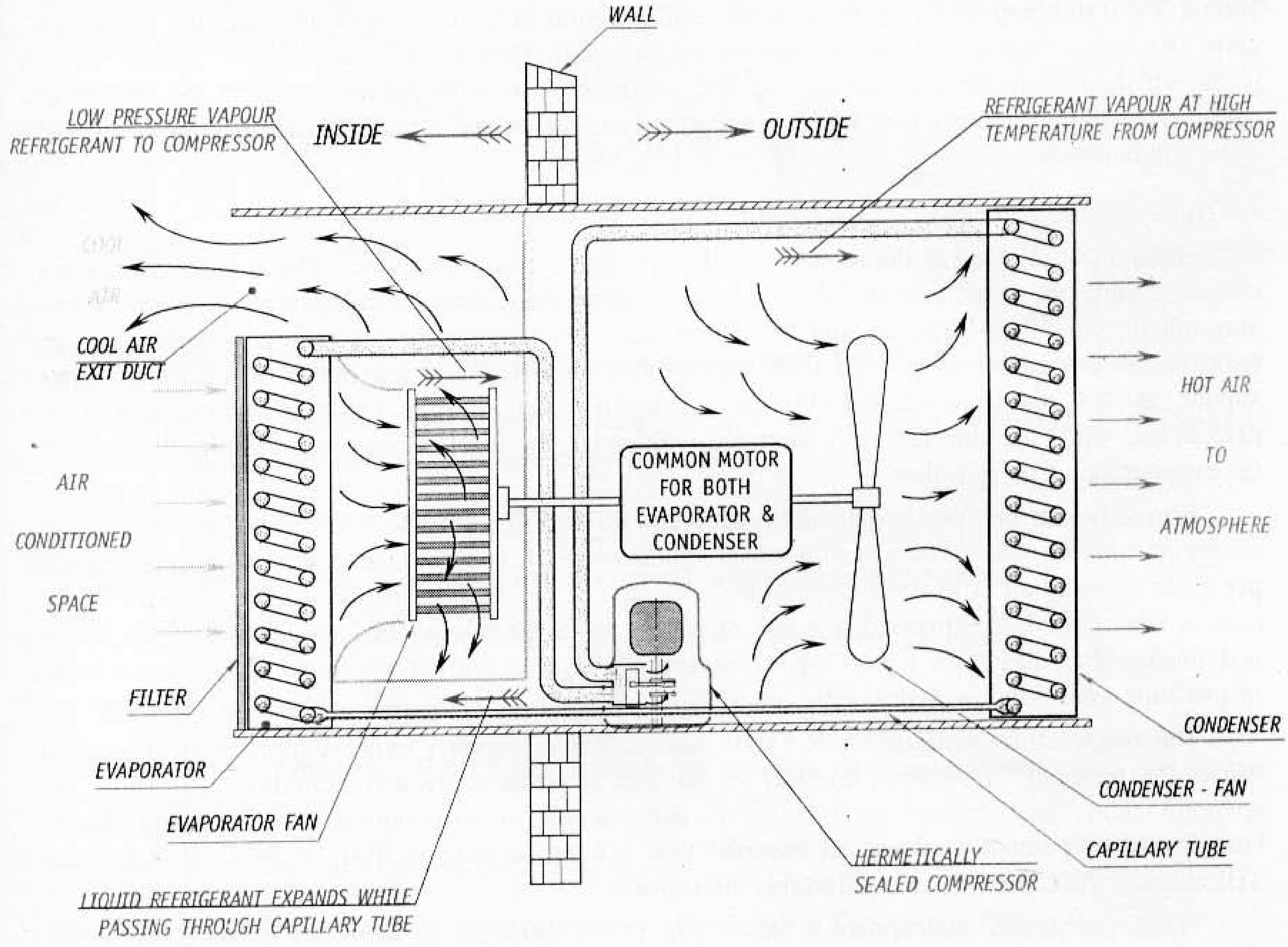
Although the cooling and conditioning of the air required for comfort air conditioning is more or less same in any part of the globe, the industrial air conditioning needs to be designed to suit the specific individual application.

Many a times the term *air conditioning* is used improperly to air cooling. Sometimes the air conditioning units consists merely of a blower equipped with refrigerating units that provide only a flow of cool filtered air.

9.17 Room Air Conditioner and Principles of Air Conditioning

An air conditioner continuously draws the air from an indoor space to be cooled, cools it by the refrigeration principles and discharges back into the same indoor space that needs to be cooled. This continuous cyclic processes of drawing, cooling and recirculation of the cooled air keeps the indoor space cool at the required lower temperature needed for comfort cooling or industrial cooling purposes.

Since both the comfort and industrial air conditioners work almost on the same basic principle, the working principle of an air conditioner is explained taking a comfort room air conditioner shown in *Fig. 9.4* as an example.



Air Conditioner
Fig. 9.4

It mainly consists of an *evaporator, condenser, compressor, two fans* one each for the evaporator and *condenser* units usually driven by the single motor, *capillary*, etc. It is generally mounted on a window sill such that the *evaporator unit is inside the room and the condenser part projecting outside the building.*

The *high-pressure, low-temperature liquid refrigerant* from the condenser is passed to the evaporator coils through the *capillary tube* where it undergoes expansion. The ***low-pressure, low-temperature liquid refrigerant*** passes through the evaporator coils. The evaporator-fan continuously draws the air from the interior space with in the room through an air filter by forcing it to pass over the evaporator coils. The air from the interior passing over the evaporator coils is cooled by the refrigerant which consequently evaporates by absorbing the heat from the air. ***The high-temperature evaporated refrigerant*** from the evaporator is drawn by the suction of the compressor which compresses it and delivers it to the condenser. *The high-pressure, high-temperature refrigerant vapour* now flows through the condenser coils. The condenser-fan draws the atmospheric air from the exposed side-portions of the air conditioner which is projecting outside the building into the space behind it and discharges to pass through the centre section of the condenser unit over the condenser coils. *The high-pressure, high-temperature refrigerant* passing inside the condenser coils condenses by giving off the heat to the atmospheric air. The *cooled high-pressure refrigerant* from the condenser passes through the capillary tube where it undergoes expansion and is again re circulated to repeat the cycle continuously.

1. Humidity and its control in Air Conditioning

Humidity is defined as the moisture content present in the atmosphere. The atmosphere always contains some moisture in the form of water vapour ; the maximum amount depends on the atmospheric conditions. The amount of vapour that will saturate the air increases with a rise in temperature. For example, at 4°C, 1000 kg of moist air contains a maximum of 4.4 kg of water vapour ; at 38°C, the same amount of moist air contains a maximum of 18 kg of water vapour. As is evident that when the atmosphere is saturated with water, the level of discomfort is high because of the evaporation of perspiration.

Humidity can be specified in three different ways. The *absolute humidity is defined as the weight of water vapour contained in a given volume of air.* It is expressed in grams of water vapour per cubic metre of air. The *specific humidity is defined as the ratio of weight of water vapour to the total weight of air.* It is expressed in grams of water vapour per kilogram of air. The *relative humidity* is defined as the *ratio of the actual vapour content of the air to the vapour content of air at the same temperature when saturated with water vapour.*

The *temperature-humidity index* (THI), also called *discomfort index,* expresses in numerical values the relationship between comfort or discomfort temperature and humidity. It *provides an apparent temperature, or how hot the air feels*. For example, an air temperature of 38°C and relative humidity of 60 percent produces an apparent very hot temperature or THI, or 54°C. It is felt that THI index of 20°C provides a comfortable atmosphere.

When a controlled atmosphere is required in air conditioning, the humidity of the air is varied. When dry air is required, it is usually dehumidified by cooling or by dehydration. In the latter process the air is passed through adsorptive chemicals such as silica gel. Air is humidified by circulation through water baths or sprays.

2. Air cleaning in Air Conditioning

When the air must be free of dust, as it is necessary in the manufacture of drugs and medical devices and instruments, the air conditioning system is designed to include some type of filter. The air is passed through water sprays or in some filters through labyrinth of oil-covered plates, in others, dust is removed electrostatically by means of precipitators. In the ordinary room air conditioners, the filter provided in front of the evaporator as shown in *Fig. 9.4,* cleans up the air by filtering.

9.18 Central Air Conditioning

Centralised air conditioning systems, widely employed in theatres, offices, stores, restaurants, public buildings, etc, provide the controlled atmosphere by heating, cooling and ventilation. The centralised air conditioning systems include refrigerating units, blowers, air ducts and a plenum chamber in which the air from the interior of the building is mixed with outside air. In such installations, cooling and dehumidifying are done during summer months and regular heating systems are used during winter.

EXERCISES 9

1. Explain the basic concepts of refrigeration. *(VTU, September 2000)*
2. Explain the principle of refrigeration.
3. Show the main parts of a refrigerator using a simple sketch and explain their functions.
4. Define refrigeration effect, unit of Refrigeration, Ice making capacity, co-efficient of performance and relative coefficient of performance.
5. What is the difference between refrigerator and refrigeration ?
6. Sketch and name the important parts of a vapour compression refrigerator.
6. Explain with a neat sketch the working of a vapour compression refrigerator. *(VTU, September 2000)*
7. Describe with a neat sketch the working of a vapour absorption refrigerator.
8. What is the difference in the basic principle of working of vapour compression and vapour absorption refrigerators ?
9. Name the refrigerants that are commonly used.
10. What are the properties of a good refrigerant ? Explain.
11. Explain the principle of air conditioning.
12. What is the difference between comfort air conditioning and industrial air conditioning ?
13. Draw a neat sketch of a room air-conditioner and explain its working principle.
14. Define humidity, absolute humidity, relative humidity and temperature-humidity index.
15. Write a short note on Centralised Air Conditioning. *(VTU, March 2000)*

NEW V.T.U SYLLABUS 2014

ELEMENTS OF MECHANICAL ENGINEERING

Subject Code: 14EME14/14 EME 24 I.A. Marks: 25

Hours/week: 04 Exam Hours: 03

Total Hours: 50 Exam Marks: 100

Course Objectives:

Students belonging to all branches of Engineering are made to learn certain fundamental topics related to mechanical engineering so that they will have a minimum understanding of mechanical systems, equipment and process.

Module – 1: Energy Resources: (10 Hours)

1. **Non-renewable and renewable energy resources**
2. **Fuels**: Petroleum based solid, liquid and gaseous fuels, calorific values of fuels, combustion and combustion products of fuels
3. **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
4. **Wind Power**: principle of operation of a typical windmill
5. **Hydro Power**: Principles of electric power generation from hydro power plants
6. **Nuclear Power**: Principles of Nuclear Power Plants
7. **Bio Fuels**: Introduction to bio fuels, examples of various bio fuels used in engineering applications, comparison of bio fuels with petroleum fuels in terms of calorific value and emission.
8. **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: Turbines, IC Engines and Pumps: (10 Hours)

1. **Steam turbines**: Classification. Principle of operation of Impulse and reaction turbines. Delaval's turbine, Parson's turbine (No compounding of turbines).
2. **Gas turbines**: Classification, working principles and operations of open cycle and closed cycle gas turbines.
3. **Water turbines**: Classification, principles and operations of Pelton wheel, Francis turbine and Kaplan turbine.
4. **Internal Combustion Engines**: Classification, I.C. Engine parts, two stroke and four stroke petrol

engines, four 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 I.C Engines)

Module – 3: Machine Tools and Automation: (10 Hours)

1. **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)

2. **Robotics and Automation**:

    a. **Robotics**: Introduction, classification based on Robot configuration; Polar, cylindrical, Cartesian coordinate and spherical. Application, advantages and disadvantages

    b. **Automation**: Definition, types – Fixed, programmable & Flexible automation, NC/CNC Machines: Basic elements with simple block diagrams, advantages and disadvantages.

Module – 4: Engineering Materials and joining processes: (10 Hours)

1. **Engineering Materials**: Types and applications of ferrous & non-ferrous metals and alloys.

2. **Composites**: Introduction: Definition, classification and applications (aircraft and automobiles)

3. **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: Refrigeration and Air-conditioning: (10 Hours)

1. **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

2. Principles and applications of Air conditioners, room air conditioner.

Scheme of Examination:

* Two full Questions (with a maximum of four sub questions) of twenty marks each to be set from each module. Each question should cover all the contents of the respective module.

* Students have to answer five full questions choosing one full question from each module.

Multiple Choice Questions

Energy Resources and Steam

1. The energy related to bodies in motion is called
   a. Internal energy
   b. Kinetic energy
   c. Potential energy
   d. Capital energy
2. Which of the following is not a non-conventional energy resource?
   a. Tidal energy
   b. Solar energy
   c. Wind energy
   d. Fossil fuels
3. Flat plate collector is an example of
   a. Heliochemical process
   b. Heliothermal process
   c. Helioelectrical process
   d. None of the above
4. Which of the following is not an artificial fuel ?
   a. Blast furnace gas
   b. Lignite
   c. Producer gas
   d. Coal gas
5. The partially carbonized decomposed material found in the boggy land is called
   a. Wood
   b. Coal
   c. Peat
   d. Charcoal
6. With regard to Wind energy, for maximum power output, the exit velocity must be equal to _______ of the entrance velocity
   a. One thirds
   b. Two thirds
   c. Half
   d. Three fourths
7. If E is the kinetic energy and V is the velocity, then wind power (P) can be calculated using the formula P equal to
   a. E/V
   b. V/E
   c. EV
   d. E/(2V)
8. Which of the following is not a petroleum based liquid fuel?
   a. Kerosene
   b. Biodiesel
   c. Diesel oil
   d. petrol
9. Which of the following gaseous fuel is obtained by passing steam over the incandescent coke?
   a. Coke oven gas
   b. Producer gas
   c. Water gas
   d. Blast furnace gas
10. Of the following only one is not a product of combustion. Which is that?
    a. Sulphur dioxide
    b. Manganese dioxide
    c. Nitrogen oxide
    d. Carbon dioxide
11. A nuclear reactor based on deuterium-tritium fusion would release _________ percentage of its energy in the very fast moving neutrons
    a. 90
    b. 45
    c. 80
    d. 69
12. From which of the following, biofuels cannot be produced?
    a. Corn
    b. Soybean
    c. Animal fat
    d. Rubber
13. In a solar pond, maximum heat is trapped in which of the following zones?
    a. LCZ
    b. NCZ
    c. UCZ
    d. Both LCZ and UCZ
14. The dryness fraction of wet steam will be
    a. Equal to one
    b. More than one
    c. Less than one
    d. Can be any number
15. The enthalpy of dry saturated steam is given by the expression
    a. $h_g = h_f + xh_{fg}$
    b. $h_g = h_{fg} + xh_f$
    c. $h_g = h_f - h_{fg}$
    d. $h_g = h_f + h_{fg}$
16. The energy required to change the phase is called
    a. True latent heat
    b. Internal energy
    c. External work of evaporation
    d. None of the above
17. The periodically collected sediments at the bottom of the boiler in operation is removed by

a. Check valve
b. Junction valve
c. Blowoff valve
d. Economizer

18. The helioelectrical process works on the principle of
a. Photosynthesis
b. Flemings's rule
c. Photovoltaic effect
d. None of the above

19. Which of the following is not a fire tube boiler?
a. Cornish boiler
b. Cochran boiler
c. Stirling boiler
d. Lancashire boiler

20. The boiler accessory used to regulate the flow of steam from the boiler is
a. Safety valve
b. Steam separator
c. Feed check valve
d. Steam stop valve

21. The first estimate of the solar constant was made by
a. Percival Lowell
b. Claude Pouillet
c. John Herschel
d. Galileo Galilei

Turbines

22. In impulse turbine, the velocity of steam ____________ as it glides over the blades
a. Remains constant
b. Continuously decreases
c. Continuously increases
d. Gets doubled

23. Which of the following is not an impulse steam turbine?
a. De Laval turbine
b. Curtis turbine
c. Parsons turbine
d. Zoelly and Rateau

24. The Kaplan turbine is also called
a. High pressure turbine
b. High capacity turbine
c. Propeller turbine
d. Medium head reaction turbine

25. The rapidly moving particles of steam entering the rotating part of the turbine undergoes a change in
a. Direction of motion
b. Momentum
c. Both a and b
d. None of the above

26. Which of the following does not apply to an open cycle gas turbine?
a. Exhaust gases from the turbine exit the atmosphere
b. Fresh air is drawn in every cycle
c. Working substance is continuously replaced
d. Large amount of cooling water is required in the cooler

27. The Kaplan turbine is a ________ head reaction turbine
a. Low
b. Medium
c. High
d. Very high

28. In the nozzle of the steam turbine, the loss in the enthalpy of the steam must be __________ the increase in the kinetic energy of the steam
a. Greater than
b. Less than
c. Equal to
d. Triple

29. In an impulse water turbine, ________% of pressure energy is converted into the kinetic energy in one or more number of nozzles before passing to the turbine wheel.
a. 100
b. 0
c. 75
d. 50

30. Which of the following is not true for a reaction steam turbine?
a. Occupies less space for the unit power
b. Suited for medium and high power generation prime movers
c. Speeds are relatively less than impulse turbine
d. Compounding is not required

31. Which one of the following is not a component of a closed cycle gas turbine?
a. Compressor
b. Heater
c. Cooler
d. Strainer

32. In a Francis turbine, the __________ is keyed to the turbine shaft
a. Guide wheel

b. Draft tube
c. Runner
d. None of the above

I.C. Engines

33. During the compression stroke of a four stroke petrol engine
 a. Both the inlet and exhaust are closed
 b. Both the inlet and exhaust are open
 c. The inlet is open and the exhaust is closed
 d. The inlet is closed and the exhaust is open
34. In an I.C Engine the ratio of brake power to the indicated power is called
 a. Overall efficiency
 b. Thermal efficiency
 c. Mechanical efficiency
 d. Relative efficiency
35. Which of the following is correct?
 a. Friction power = Indicated power + Brake power
 b. Brake Power = Indicated power + Friction power
 c. Indicated power = Friction power - Brake power
 d. Indicated power = Friction power + Brake power
36. The theoretical diesel cycle is also known as
 a. Constant volume heat addition cycle.
 b. Constant pressure heat addition cycle.
 c. Increase volume heat addition cycle.
 d. Increased pressure heat addition cycle.
37. The extreme position of the piston near to the cylinder head of the I.C engine is called
 a. Cover end
 b. Extreme dead centre
 c. Crank end
 d. Bottom end
38. The S.I engine has compression ratio between
 a. 3:1 to 12:1
 b. 2:1 to 14:1
 c. 7:1 to 12:1
 d. 16:1 to 20:1
39. In a two-stroke engine, power is developed in ________________ of the crankshaft
 a. Every half revolution
 b. Every one-fourth revolution
 c. Every revolution
 d. Every three-fourths revolution
40. The engine speed of petrol engine is of the order of
 a. 1000 rpm
 b. 1500 rpm
 c. 3000 rpm
 d. 2000 rpm
41. Which of the following is not true for a two stroke engine?
 a. Frictional losses are more
 b. A lighter foundation is enough
 c. Can be easily started than a four stroke engine
 d. Has less maintenance cost
42. Which of the following is not an example of a C.I. engine?
 a. Bulldozer
 b. Scooter
 c. Truck
 d. Bus
43. One of the following statements are wrong with respect to Petrol engines
 a. Air and petrol mixture is drawn during the suction stroke
 b. Governing method is quantitative
 c. Low compression ratio
 d. Cannot be started easily in cold conditions

Machine Tools Operations

44. The angle that is ground on a single point lathe tool to provide a smooth flow of chip over the tool bit so as to move it away from the workpiece is called
 a. Side relief angle
 b. End relief angle
 c. Rake angle
 d. Side cutting edge angle
45. ___________Operation on a lathe is performed to generate shoulders at the end of the workpiece
 a. Turning
 b. Knurling
 c. Facing
 d. Taper turning
46. The process of smoothing the surface of the drilled holes is called
 a. Honing
 b. Reaming
 c. Boring
 d. Lapping
47. ___________ is the process of making the end of a hole into a conical shape

a. Countersinking
b. Counterboring
c. Spot facing
d. Tapping

48. Which of the following is not a method of taper turning in a lathe
a. Swivelling the compound tool rest
b. Taper turning attachment
c. Tailstock setover
d. None

49. ____________operation performed on a lathe generates serrated surfaces
a. Knurling
b. Turning
c. Facing
d. Thread cutting

50. The process of increasing the size of an already drilled hole is called
a. Countersinking
b. Reaming
c. Counterboring
d. Boring

51. ____________ is the moveable part of the lathe that carries the dead centre in it
a. Compound tool rest
b. Tailstock
c. Headstock
d. Saddle

52. An example of a light duty drilling machine is
a. Multiple drilling machine
b. Gang drilling machine
c. Radial drilling machine
d. Bench drilling machine

53. The milling process in which the workpiece is fed in the same direction of the cutter tooth is called
a. Up milling
b. Plain milling
c. Down milling
d. End milling

54. ____________ is a milling operation used to machine two or more parallel vertical surfaces at a single time
a. Form milling
b. Slot milling
c. Gang milling
d. Straddle milling

55. ____________ is the milling operation that is used to produce keyways
a. Form milling
b. Angular milling
c. End milling
d. Straddle milling

56. ____________ is the milling operation used to mill flat surfaces that are neither parallel nor perpendicular to the milling cutter axis
a. Plain milling
b. Form milling
c. Straddle milling
d. Angular milling

57. Which of the following is not true for a horizontal milling machine?
a. The milling cutter can rotate about its own axis
b. Cutter is mounted on an arbor
c. Spindle can be tilted to the left
d. Spindle is horizontal

Robotics and Automation

58. The word "Robot" was first coined by
a. George Devol
b. Karel Capek
c. Joseph Engelberger
d. Takeo Kanade

59. Which of the following grippers are commonly used to hold flat surfaces?
a. Mechanical gripper
b. Magnetic gripper
c. Adhesion gripper
d. Vacuum gripper

60. The robot joint that allows only rotary relative motion is
a. R-joint
b. L-joint
c. T-joint
d. V-joint

61. The polar configuration of robot is made up of
a. L and R joints
b. L and T joints
c. L, R and T joints
d. L, R and O joints

62. The IBM 7565 robot is a classic example of
a. Cartesian coordinate robot
b. Jointed arm robot
c. Polar configuration robot
d. SCARA robot

63. Which of the following is not true for a robot?
a. A robot can work at constant speeds
b. A robot can work in tight spaces
c. A robot can think by itself
d. A Robot produces less defectives

64. In which of the following robot configurations, the vertical reach is low?

a. Jointed arm configuration
b. Spherical configuration
c. Cartesian configuration
d. Cylindrical configuration

65. Which of the following automation is the best suited for mass production?
a. Flexible automation
b. Programmable automation
c. Fixed automation
d. Both a and c

66. Automated guided vehicle is an example of
a. Flexible automation
b. Programmable automation
c. Fixed automation
d. Artificial intelligence

67. One of the statements below are not true for a closed loop system. Which one is that?
a. The response to an input signal is faster
b. Can be used to stabilize systems that are inherently unstable in the open-loop form.
c. Closed loop systems are accurate
d. Closed loop is simpler than open loop

68. The RS 232 is an example of
a. Conversational programming
b. Ethernet communication
c. Serial communication
d. Wireless communication

69. Which of the following is not contained in the CPU of the MCU of a CNC machine?
a. Control section
b. Main memory
c. ALU
d. Immediate access memory

70. The look ahead function ensures
a. rapid acceleration
b. Smooth machined surface
c. Faster machining
d. Safe stop

71. The program of instructions in an NC system is edited on which of the following input mediums?
a. Punched card
b. Magnetic disc
c. Punched tape
d. a, b and c

Engineering Materials and Composites

72. Pig iron is produced in a
a. Reverberatory furnace
b. Cupola furnace
c. Blast furnace
d. Electric arc furnace

73. Graphite exists in the form of flakes in
a. Wrought iron
b. Nodular cast iron
c. Pig iron
d. Grey cast iron

74. Nuclear industry uses ___________ to make caskets.
a. Ductile iron
b. Whiteheart malleable iron
c. Grey cast iron
d. White cast iron

75. Which of the following is used to make lightly stressed parts?
a. Chromium steel
b. Mild steel
c. Medium carbon steel
d. Nickel steel

76. Invar is an alloy of
a. Nickel and copper
b. Nickel and iron
c. Nickel and chromium
d. Nickel and molybdenum

77. Sprayed coatings of _____________ alloys are used in automotive pistons to improve wear and reduce friction
a. Nickel
b. Tungsten
c. Manganese
d. Molybdenum

78. HSS is a good example of
a. High carbon steel
b. Tool steel
c. Stainless steel
d. Alloy steel

79. The non-ferrous metal commonly chosen in automobiles due to its light weight is
a. Copper
b. Zinc
c. Nickel
d. Aluminium

80. Which of the following is not true for copper?
a. High electrical conductivity
b. High thermal conductivity
c. Low ductility
d. Light weight

81. Gun metal is an alloy mainly containing
a. Copper and zinc
b. Copper, tin and zinc
c. Copper and tin
d. Copper, Manganese and zinc

82. Solder is an alloy of

a. Lead and silver
b. Lead and chromium
c. Lead and tin
d. Lead and zinc

83. Which of the following alloy is used in Wheatstone bridge?
a. Constantan
b. Inconel
c. Hastelloy C
d. Nichrome

84. Oscar award statuettes are made from
a. Pewter
b. Britannia metal
c. Muntz metal
d. German silver

85. Which of the following is not a synthetic material?
a. Composite
b. Thermosetting plastic
c. Ceramic
d. All of the above

86. The disc brakes of racing cars use ______________ composite
a. PMC
b. CMC
c. MMC
d. Both b and c

87. Which of the following is not an application of cermet?
a. Valve seat
b. Turbine wheel
c. Mechanical seal
d. Telephone casing

88. Identify one among the following statements that is not true for a composite
a. Composite materials exhibit good Resilience
b. Composite materials are non-corrosive
c. Composites are cheap and economical to use
d. Composites have good stiffness-to-weight ratios

Soldering, brazing and welding

89. ____________ flame is obtained by supplying excess acetylene in the gas ratio between 0.95 to 1
a. Neutral
b. Oxidizing
c. Carburizing
d. None

90. The melting temperature of soft solder is between
a. 150 to 350°C
b. 250 to 450 °C
c. 350 to 550 °C
d. 0 to 50 °C

91. The flux normally used in brazing is
a. Rosin
b. Boric acid
c. Borax
d. Both b and c

92. In arc welding, the temperature of the arc can go up to
a. 1000 °C
b. 3000 °C
c. 6000 °C
d. 9000 °C

93. The temperature attained by oxy-acetylene flame is around
a. 1800 °C
b. 3200 °C
c. 4600 °C
d. 2100 °C

94. Which of the following is not true for welding?
a. Welding ensures leak tightness
b. Welding does not cause residual stresses
c. Welding is economical process
d. Welded joints are durable

95. The flux commonly used in soldering is
a. Zinc chloride
b. Borax
c. Boric acid
d. Both b and c

96. Before carrying out the soldering operation,
a. The surface has to be cleaned
b. Flux has to be applied
c. Tinning of the surfaces is to be soldered
d. All of the above

97. The intermediate cone is observed in
a. Reducing flame
b. Neutral flame
c. Oxidizing flame
d. All the above

Refrigeration and air-conditioning

98. The commonly used marine refrigerant is

a. Sulphur dioxide
b. Carbon dioxide
c. Freon-12
d. Freon-22

99. 1 ton of refrigeration is equal to
a. 210 kJ/sec
b. 210 MJ/min
c. 210 kJ/min
d. 210kJ/hour

100. Which of the following is NOT a refrigerant?
a. Sulphur dioxide
b. Ammonia
c. Methyl chloride
d. Benzene

101. Which of the following is not a desired property of a refrigerant?
a. High boiling temperature
b. Odourless
c. Non-corrosive
d. None of the above

102. The ______________ refrigerator uses mechanical energy supplied to run the refrigerator
a. Vapour compression
b. Vapour absorption
c. Both a and b
d. Neither a nor b

103. Which of the following is the refrigerant most commonly used in air conditioner?
a. Ammonia
b. Freon-22
c. Methyl chloride
d. Sulphur dioxide

104. In a good refrigerant, the latent heat of evaporation must be
a. High
b. Very low
c. Low
d. Very high

105. The __________________ is defined as the weight of the water vapour contained in a given volume of air
a. Absolute humidity
b. Specific humidity
c. Total humidity
d. Net humidity

106. Ice making capacity is expressed in
a. kJ/hr
b. kg/hr
c. kg
d. kW/hr

107. The ________________ of a refrigerant at both the liquid and vapour states must be very low
a. Specific heat
b. Viscosity
c. Freezing point
d. Condenser pressure

108. In air conditioning, ________________ provides an apparent temperature or how the air feels
a. Absolute humidity
b. Specific humidity
c. Non-pollution index
d. Temperature-humidity index

Answers to Multiple choice questions

Energy Resources and Steam

1(b)	2(d)	3(b)	4(b)	5(c)	6(a)
7(c)	8(b)	9(c)	10(b)	11(c)	12(d)
13(a)	14(c)	15(d)	16(a)	17(c)	18(c)
19(c)	20(d)	21(b)			

Turbines

22(b)	23(c)	24(c)	25(c)	26(d)	27(a)
28(c)	29(a)	30(a)	31(d)	32(c)	

I.C. Engines

33(a)	34(c)	35(d)	36(b)	37(a)	38(c)
39(c)	40(c)	41(a)	42(b)	43(d)	

Machine Tools Operations

44(c)	45(c)	46(b)	47(a)	48(d)	49(a)
50(d)	51(b)	52(d)	53(c)	54(d)	55(c)
56(d)	57(c)				

Robotics and Automation

58(b)	59(d)	60(a)	61(c)	62(a)	63(c)
64(b)	65(c)	66(a)	67(d)	68(c)	69(b)
70(b)	71(d)				

Engineering Materials and Composites

72(c)	73(d)	74(a)	75(b)	76(b)	77(d)
78(b)	79(d)	80(c)	81(b)	82(c)	83(a)
84(b)	85(d)	86(b)	87(d)	88(c)	

Soldering, brazing and welding

89(c)	90(a)	91(d)	92(c)	93(b)	94(b)
95(a)	96(d)	97(a)			

Refrigeration and air conditioning

98(b)	99(c)	100(d)	101(a)	102(a)
103(b)	104(d)	105(a)	106(b)	107(b)
108(d)				

TABLE 1

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Sat Temp °C	Specific Enthalpy *kJ/kg*			Specific Entropy *kJ/kg/K*			Specific Volume *m³/kg*	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
0.00611	0.01	0.01	2 501.3	2 501.4	0.000	9.156	9.156	0.0010002	206.14
0.010	7.0	29.3	2 484.9	2 514.2	0.106	8.870	8.976	0.0010000	129.21
0.015	13.0	54.7	2 470.6	2 525.3	0.196	8.632	8.828	0.0010007	87.98
0.020	17.0	73.5	2 460.0	2 533.5	0.261	8.463	8.724	0.001001	67.00
0.025	21.1	88.5	2 451.6	2 540.1	0.312	8.331	8.643	0.001002	54.25
0.030	24.1	101.0	2 444.5	2 545.5	0.355	8.223	8.578	0.001003	45.67
0.035	26.7	111.9	2 438.4	2 550.3	0.391	8.132	8.523	0.001003	39.50
0.040	29.0	121.5	2 432.9	2 554.4	0.423	8.052	8.475	0.001004	34.80
0.045	31.0	130.0	2 428.2	2 558.2	0.451	7.982	8.433	0.001005	31.13
0.050	32.9	137.8	2 423.7	2 561.5	0.476	7.919	8.395	0.001005	28.19
0.055	34.6	144.9	2 419.6	2 565.5	0.500	7.861	8.361	0.001006	25.77
0.060	36.2	151.5	2 415.9	2 567.4	0.521	7.809	8.330	0.001006	23.74
0.065	37.6	157.7	2 412.4	2 570.1	0.541	7.761	8.302	0.001007	22.01
0.070	39.0	163.4	2 409.1	2 572.5	0.559	7.717	8.276	0.001007	20.53
0.075	40.3	168.8	2 406.0	2 574.8	0.576	7.675	8.251	0.001008	19.24
0.080	41.5	173.9	2 403.1	2 577.0	0.593	7.636	8.229	0.001008	18.10
0.085	42.7	178.7	2 400.3	2 579.0	0.608	7.599	8.207	0.001009	17.10
0.090	43.8	183.3	2 397.7	2 581.0	0.622	7.565	8.187	0.001009	16.20
0.095	44.8	187.7	2 395.2	2 582.9	0.636	7.532	8.168	0.001010	15.40
0.10	45.8	191.8	2 392.8	2 584.7	0.649	7.501	8.150	0.001010	14.67
0.11	47.7	199.7	2 388.3	2 588.0	0.674	7.453	8.117	0.001011	13.42
0.12	49.4	206.9	2 384.2	2 591.1	0.696	7.390	8.086	0.001012	12.36
0.13	51.0	213.7	2 380.2	2 593.9	0.717	7.341	8.058	0.001013	11.47
0.14	52.6	220.0	2 376.6	2 596.6	0.737	7.296	8.333	0.001013	10.69
0.15	54.0	226.0	2 373.2	2 599.2	0.754 9	7.254 4	8.009 3	0.001014	10.022
0.16	55.3	231.6	2 370.0	2 601.6	0.772 1	7.214 8	7.986 9	0.001015	9.433
0.17	56.6	236.9	2 366.9	2 603.8	0.788 3	7.177 5	7.965 8	0.001015	8.911
0.18	57.8	242.0	2 363.9	2 605.9	0.803 6	7.142 4	7.945 9	0.001016	8.445
0.19	59.0	246.8	2 361.1	2 607.9	0.818 2	7.109 0	7.927 2	0.001017	8.027
0.20	60.1	251.5	2 358.4	2 609.9	0.832 1	7.077 3	7.909 4	0.001017	7.650
0.21	61.1	255.9	2 355.8	2 611.7	0.845 3	7.047 2	7.892 5	0.001018	7.307
0.22	62.2	260.1	2 353.3	2 613.5	0.858 1	7.018 4	7.876 4	0.001018	6.995
0.23	63.1	264.2	2 350.9	2 615.2	0.870 2	6.990 8	7.861 1	0.001019	6.709
0.24	64.1	268.2	2 348.6	2 616.8	0.882 0	6.964 4	7.846 4	0.001019	6.447
0.25	65.0	272.0	2 346.4	2 618.3	0.893 2	6.939 1	7.832 3	0.001020	6.205
0.26	65.9	275.7	2 344.2	2 619.9	0.904 1	6.914 7	7.818 8	0.001020	5.980
0.27	66.7	279.2	2 342.1	2 621.3	0.914 6	6.891 2	7.805 8	0.001021	5.772
0.28	67.5	282.7	2 340.0	2 622.7	0.924 8	6.868 5	7.793 3	0.001021	5.579
0.29	68.3	286.0	2 338.1	2 624.1	0.934 6	6.846 6	7.781 2	0.001022	5.398

TABLE 1 (continued)

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Sat Temp °C	Specific Enthalpy *kJ/kg*			Specific Entropy *kJ/kg/K*			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_S	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
0.30	69.1	289.3	2 336.1	2 625.4	0.944 1	6.825 4	7.769 5	0.001022	5.229
0.32	70.6	295.5	2 332.4	2 628.0	0.962 3	6.785 0	7.747 4	0.001023	4.922
0.34	72.0	301.5	2 328.9	2 630.4	0.979 5	6.747 0	7.726 5	0.001024	4.650
0.36	73.4	307.1	2 325.5	2 632.6	0.995 8	6.711 1	7.707 0	0.001025	4.408
0.38	74.7	312.5	2 322.3	2 634.8	1.011 3	6.677 1	7.688 4	0.001026	4.190
0.40	75.9	317.7	2 319.2	2 636.9	1.026 1	6.644 8	7.670 9	0.001026	3.993
0.42	77.1	322.6	2 316.3	2 638.9	1.040 2	6.614 0	7.654 2	0.001027	3.815
0.44	78.2	327.3	2 313.4	2 640.7	1.053 7	6.584 6	7.638 3	0.001028	3.652
0.46	79.3	331.9	2 310.7	2 642.6	1.066 7	6.556 4	7.623 1	0.001029	3.503
0.48	80.3	336.3	2 308.0	2 644.3	1.079 2	6.529 4	7.608 6	0.001029	3.367
0.50	81.3	340.6	2 305.4	2 646.0	1.091 2	6.503 5	7.594 7	0.001030	3.240
0.55	83.7	350.6	2 299.3	2 649.9	1.119 4	6.442 8	7.562 3	0.001032	2.964
0.60	86.0	359.9	2 293.6	2 653.6	1.145 4	6.387 3	7.532 7	0.001033	2.732
0.65	88.0	368.6	2 288.3	2 656.9	1.169 6	6.336 0	7.505 5	0.001035	2.535
0.70	90.0	376.8	2 283.3	2 660.1	1.192 1	6.288 3	7.480 4	0.001036	2.369
0.75	92.0	384.5	2 278.6	2 663.0	1.213 1	6.243 9	7.457 0	0.001037	2.217
0.80	93.5	391.7	2 274.0	2 665.8	1.233 0	6.202 2	7.435 2	0.001039	2.087
0.85	95.1	398.6	2 269.8	2 668.4	1.251 8	6.162 9	7.414 7	0.001040	1.972
0.90	96.7	405.2	2 265.6	2 670.9	1.269 6	6.125 8	7.395 4	0.001041	1.869
0.95	98.2	411.5	2 261.7	2 673.2	1.286 5	6.090 6	7.377 1	0.001042	1.777
1.0	99.6	417.5	2 257.9	2 675.4	1.302 7	6.057 1	7.359 8	0.001043	1.694
1.1	102.3	428.8	2 250.8	2 679.6	1.333 0	5.994 7	7.327 7	0.001046	1.549
1.2	104.8	439.4	2 244.1	2 683.4	1.360 9	5.937 5	7.298 4	0.001048	1.428
1.3	107.1	449.2	2 237.8	2 687.0	1.386 8	5.884 7	7.271 5	0.001050	1.325
1.4	109.3	458.4	2 231.9	2 690.3	1.410 9	5.835 6	7.246 5	0.001051	1.236
1.5	111.3	467.1	2 226.2	2 693.4	1.433 6	5.789 8	7.223 4	0.001053	1.159
1.6	113.3	475.4	2 220.9	2 696.2	1.455 0	5.746 7	7.201 7	0.001055	1.091
1.7	115.2	483.2	2 215.7	2 699.0	1.475 2	5.706 1	7.181 3	0.001056	1.031
1.8	116.9	490.7	2 210.8	2 701.5	1.494 4	5.667 8	7.162 2	0.001058	0.977
1.9	118.6	497.8	2 206.1	2 704.0	1.5127	5.631 4	7.144 0	0.001060	0.929
2.0	120.2	504.7	2 201.6	2 706.3	1.530 1	5.596 7	7.126 8	0.001061	0.885
2.1	121.8	511.3	2 197.2	2 708.5	1.546 8	5.563 7	7.110 5	0.001062	0.846
2.2	123.3	517.6	2 193.0	2 710.6	1.5627	5.532 1	7.094 9	0.001064	0.810
2.3	124.7	523.7	2 188.9	2 712.6	1.578 1	5.501 9	7.080 0	0.001065	0.777
2.4	126.1	529.6	2 184.9	2 714.5	1.592 9	5.472 8	7.065 7	0.001066	0.746
2.5	127.4	535.3	2 181.0	2 716.4	1.607 1	5.444 9	7.052 0	0.001068	0.718
2.6	128.7	540.9	2 177.3	2 718.2	1.620 9	5.418 0	7.038 9	0.001069	0.693
2.7	129.9	546.2	2 173.6	2 719.9	1.634 2	5.392 0	7.026 2	0.001070	0.668
2.8	131.2	551.4	2 170.1	2 721.5	1.647 1	5.367 0	7.014 0	0.001071	0.646
2.9	132.4	556.5	2 166.6	2 723.1	1.659 5	5.342 7	7.0023	0.001072	0.625

TABLE 1 (continued)

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Sat Temp °C	Specific Enthalpy kJ/kg			Specific Entropy kJ/kg/K			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_S	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
3.0	133.5	561.4	2 163.2	2 724.7	1.671 6	5.319 3	6.990 9	0.001074	0.606
3.1	134.6	566.2	2 159.9	2 726.1	1.683 4	5.296 5	6.979 9	0.001075	0.587
3.2	135.7	570.9	2 156.7	2 727.6	1.694 8	5.274 4	6.969 2	0.001076	0.570
3.3	136.8	575.5	2 153.5	2 729.0	1.705 9	5.253 0	6.958 9	0.001077	0.554
3.4	137.8	579.9	2 150.4	2 730.3	1.716 8	5.232 2	6.948 9	0.001078	0.538
3.5	138.8	584.3	2 147.4	2 731.6	1.727 3	5.211 9	6.939 2	0.001079	0.524
3.6	139.8	588.5	2 144.4	2 732.9	1.737 6	5.192 1	6.929 7	0.001080	0.510
3.7	140.8	592.7	2 141.4	2 734.1	1.747 6	5.172 9	6.920 5	0.001081	0.497
3.8	141.8	596.8	2 138.6	2 735.3	1.757 4	5.154 1	6.911 6	0.001082	0.486
3.9	142.7	600.8	2 135.7	2 736.5	1.767 0	5.135 8	6.902 8	0.001083	0.473
4.0	143.6	604.7	2 133.0	2 737.6	1.776 4	5.117 9	6.894 3	0.001084	0.462
4.2	145.4	612.3	2 127.5	2 739.8	1.794 5	5.083 4	6.877 9	0.001086	0.441
4.4	147.1	619.6	2 122.3	2 741.9	1.812 0	5.050 3	6.862 3	0.001088	0.423
4.6	148.7	626.7	2 117.2	2 743.9	1.828 7	5.018 6	6.847 3	0.001089	0.405
4.8	150.3	633.5	2 112.2	2 745.7	1.844 8	4.988 1	6.832 9	0.001091	0.390
5.0	151.8	640.1	2 107.4	2 747.5	1.860 4	4.958 8	6.819 2	0.001093	0.375
5.2	153.3	646.5	2 102.7	2 749.3	1.875 4	4.930 6	6.805 9	0.001094	0.361
5.4	154.7	652.8	2 098.1	2 750.9	1.889 9	4.903 3	6.793 2	0.001096	0.348
5.6	156.2	658.8	2 093.7	2 752.5	1.904 0	4.876 9	6.780 9	0.001098	0.337
5.8	157.5	664.7	2 089.3	2 754.0	1.917 6	4.851 4	6.769 0	0.001099	0.326
6.0	158.8	670.4	2 085.0	2 755.5	1.930 8	4.826 7	6.757 5	0.001101	0.315
6.2	160.1	676.0	2 080.9	2 756.9	1.943 7	4.802 7	6.746 4	0.001102	0.306
6.4	161.4	681.5	2 076.8	2 758.2	1.956 2	4.779 4	6.735 6	0.001104	0.297
6.6	162.6	686.8	2 072.7	2 759.5	1.968 4	4.756 8	6.725 2	0.001105	0.288
6.8	163.8	692.0	2 068.8	2 760.8	1.980 2	4.734 8	6.715 0	0.001107	0.280
7.0	165.0	697.1	2 064.9	2 762.0	1.991 8	4.713 4	6.705 2	0.001108	0.273
7.2	166.1	702.0	2 061.1	2 763.2	2.003 1	4.692 5	6.695 6	0.001110	0.265
7.4	167.2	706.9	2 057.4	2 764.3	2.014 1	4.672 1	6.686 2	0.001111	0.258
7.6	168.3	711.7	2 053.7	2 765.4	2.024 9	4.652 2	6.677 1	0.001112	0.252
7.8	169.4	716.3	2 050.1	2 766.4	2.035 4	4.632 8	6.668 3	0.001114	0.246
8.0	170.4	720.9	2 046.5	2 767.5	2.045 7	4.613 9	6.659 6	0.001115	0.240
8.2	171.4	725.4	2 043.0	2 768.5	2.055 8	4.595 3	6.651 1	0.001116	0.235
8.4	172.4	729.9	2 039.6	2 769.4	2.065 7	4.577 2	6.642 9	0.001118	0.229
8.6	173.4	734.2	2 036.2	2 770.4	2.075 3	4.559 4	6.634 8	0.001119	0.224
8.8	174.4	738.5	2 032.8	2 771.3	2.084 8	4.542 1	6.626 9	0.001120	0.219
9.0	175.4	742.6	2 029.5	2 772.1	2.094 1	4.525 0	6.619 2	0.001121	0.215
9.2	176.3	746.8	2 026.2	2 773.0	2.103 3	4.508 3	6.611 6	0.001123	0.210
9.4	177.2	750.8	2 023.0	2 773.8	2.112 2	4.492 0	6.604 2	0.001124	0.206
9.6	178.1	754.8	2 019.8	2 774.6	2.121 0	4.475 9	6.596 9	0.001125	0.202
9.8	179.0	758.7	2 016.7	2 775.4	2.129 7	4.460 1	6.589 8	0.001126	0.198

TABLE 1 (continued)

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Sat Temp °C	Specific Enthalpy kJ/kg			Specific Entropy kJ/kg/K			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
10.0	179.9	762.6	2 013.6	2 776.2	2.138 2	4.444 6	6.582 8	0.001127	0.194
10.5	182.0	772.0	2 005.9	2 778.0	2.158 8	4.407 1	6.565 9	0.001130	0.185
11.0	184.1	781.1	1 998.5	2 779.7	2.178 6	4.371 1	6.549 7	0.001133	0.177
11.5	186.0	789.9	1 991.3	2 781.3	2.197 7	4.336 6	6.534 2	0.001136	0.170
12.0	188.0	798.4	1 984.3	2 782.7	2.216 1	4.303 3	6.519 4	0.001139	0.163
12.5	189.8	806.7	1 977.4	2 784.1	2.233 8	4.271 2	6.505 0	0.001141	0.157
13.0	191.6	814.7	1 970.7	2 785.4	2.251 0	4.240 3	6.491 3	0.001144	0.151
13.5	193.3	822.5	1 964.2	2 786.6	2.267 6	4.210 4	6.477 9	0.001146	0.146
14.0	195.0	830.1	1 957.7	2 787.8	2.283 7	4.181 4	6.465 1	0.001149	0.141
14.5	196.7	837.5	1 951.4	2 788.9	2.299 3	4.153 3	6.452 6	0.001151	0.136
15.0	198.3	844.7	1 945.2	2 789.9	2.314 5	4.126 1	6.440 6	0.001154	0.132
15.5	199.8	851.7	1 939.2	2 790.8	2.329 2	4.099 6	6.428 9	0.001156	0.128
16.0	201.4	858.6	1 933.2	2 791.7	2.343 6	4.073 9	6.417 5	0.001159	0.124
16.5	202.8	865.3	1 927.3	2 792.6	2.357 6	4.048 9	6.406 5	0.001161	0.120
17.0	204.3	871.8	1 921.5	2 793.4	2.371 3	4.024 5	6.395 7	0.001163	0.117
17.5	205.7	878.3	1 915.9	2 794.1	2.384 6	4.000 7	6.385 3	0.001166	0.113
18.0	207.1	884.6	1 910.3	2 794.8	2.397 6	3.977 5	6.375 1	0.001168	0.110
18.5	208.4	890.7	1 904.7	2 795.5	2.410 3	3.954 8	6.365 1	0.001170	0.107
19.0	209.8	896.8	1 899.3	2 796.1	2.422 8	3.932 6	6.355 4	0.001172	0.105
19.5	211.1	902.8	1 893.9	2 796.7	2.434 9	3.911 0	6.345 9	0.001174	0.102
20.0	212.4	908.6	1 888.6	2 797.2	2.446 9	3.889 8	6.336 6	0.001177	0.0995
20.5	213.6	914.3	1 883.4	2 797.7	2.458 5	3.869 0	6.327 6	0.001179	0.0971
21.0	214.8	920.0	1 878.2	2 798.2	2.470 0	3.848 7	6.318 7	0.001181	0.0949
21.5	216.1	925.5	1 873.1	2 798.6	2.481 2	3.828 8	6.310 0	0.001183	0.0927
22.0	217.2	931.0	1 868.1	2 799.1	2.492 2	3.809 3	6.301 5	0.001185	0.0907
22.5	218.4	936.3	1 863.1	2 799.4	2.503 0	3.790 1	6.293 1	0.001187	0.0887
23.0	219.5	941.6	1 858.2	2 799.8	2.513 6	3.771 3	6.284 9	0.001189	0.0868
23.5	220.7	946.8	1 853.3	2 800.1	2.524 1	3.752 8	6.276 9	0.001191	0.0849
24.0	221.8	951.9	1 848.5	2 800.4	2.534 3	3.734 7	6.269 0	0.001193	0.0832
24.5	222.9	957.0	1 843.7	2 800.7	2.544 4	3.716 8	6.261 2	0.001195	0.0815
25.0	223.9	962.0	1 839.0	2 800.9	2.554 3	3.699 3	6.253 6	0.001197	0.0799
25.5	225.0	966.9	1 834.3	2 801.2	2.564 0	3.682 1	6.246 1	0.001199	0.0783
26.0	226.0	971.7	1 829.6	2 801.4	2.573 6	3.665 1	6.238 7	0.001201	0.0769
26.5	227.1	976.5	1 825.1	2 801.6	2.583 1	3.648 4	6.231 5	0.001203	0.0754
27.0	228.1	981.2	1 820.5	2 801.7	2.592 4	3.632 0	6.224 4	0.001205	0.0740
27.5	229.1	985.9	1 816.0	2 801.9	2.601 6	3.615 8	6.217 3	0.001207	0.0727
28.0	230.0	990.5	1 811.5	2 802.0	2.610 6	3.599 8	6.210 4	0.001209	0.0714
28.5	231.0	995.0	1 807.1	2 802.1	2.619 5	3.584 1	6.203 6	0.001211	0.0701
29.0	232.0	999.5	1 802.6	2 802.2	2.628 3	3.568 6	6.196 9	0.001213	0.0689
29.5	233.0	1 004.0	1 798.3	2 802.2	2.637 0	3.553 3	6.190 2	0.001214	0.0677

TABLE 1 (continued)

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure bar	Sat Temp °C	Specific Enthalpy kJ/kg			Specific Entropy kJ/kg/K			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
30.0	233.8	1 008.4	1 793.9	2 802.3	2.645 5	3.538 2	6.183 7	0.001216	0.0666
30.5	234.7	1 012.7	1 789.6	2 802.3	2.653 9	3.523 3	6.177 3	0.001218	0.0655
31.0	235.6	1 017.0	1 785.4	2 802.3	2.662 3	3.508 7	6.170 9	0.001220	0.0645
31.5	236.5	1 021.2	1 781.1	2 802.3	2.670 5	3.494 2	6.164 6	0.001222	0.0634
32.0	237.4	1 025.4	1 776.9	2 802.3	2.678 6	3.479 9	6.158 5	0.001224	0.0624
32.5	238.3	1 029.6	1 772.7	2 802.3	2.686 6	3.465 7	6.152 3	0.001225	0.0615
33.0	239.2	1 033.7	1 768.6	2 802.3	2.694 5	3.451 8	6.146 3	0.001227	0.0605
33.5	240.0	1 037.8	1 764.4	2 802.2	2.702 3	3.438 0	6.140 3	0.001229	0.0596
34.0	240.9	1 041.8	1 760.3	2 802.1	2.710 1	3.424 4	6.134 4	0.001231	0.0587
34.5	241.7	1 045.8	1 756.3	2 802.1	2.717 7	3.410 9	6.128 6	0.001233	0.0579
35.0	242.5	1 049.8	1 752.2	2 802.0	2.725 3	3.397 6	6.122 8	0.001234	0.0570
35.5	243.3	1 053.7	1 748.2	2 801.8	2.732 7	3.384 4	6.117 1	0.001236	0.0562
36.0	244.2	1 057.6	1 744.2	2 801.7	2.740 1	3.371 4	6.111 5	0.001238	0.0554
36.5	245.0	1 061.4	1 740.2	2 801.6	2.747 4	3.358 5	6.105 9	0.001239	0.0546
37.0	245.7	1 065.2	1 736.2	2 801.4	2.754 7	3.345 8	6.100 4	0.001242	0.0539
37.5	246.5	1 069.0	1 732.3	2 801.3	2.761 8	3.333 2	6.095 0	0.001243	0.0531
38.0	247.3	1 072.7	1 728.4	2 801.1	2.768 9	3.320 7	6.089 6	0.001245	0.0524
38.5	248.1	1 076.4	1 724.5	2 800.9	2.775 9	3.308 3	6.084 2	0.001247	0.0517
39.0	248.8	1 080.1	1 720.6	2 800.8	2.782 9	3.296 1	6.078 9	0.001249	0.0511
39.5	249.6	1 083.8	1 716.8	2 800.5	2.789 7	3.284 0	6.073 7	0.001250	0.0504
40.0	250.3	1 087.4	1 712.9	2 800.3	2.796 5	3.272 0	6.068 5	0.001252	0.0497
41.0	251.8	1 094.6	1 705.3	2 799.9	2.809 9	3.248 3	6.058 3	0.001255	0.0485
42.0	253.2	1 101.6	1 697.8	2 799.4	2.823 1	3.225 1	6.048 2	0.001259	0.0473
43.0	254.6	1 108.5	1 690.3	2 798.9	2.836 0	3.202 3	6.038 3	0.001262	0.0461
44.0	256.0	1 115.4	1 682.9	2 798.3	2.848 7	3.179 9	6.028 6	0.001266	0.0451
45.0	257.4	1 122.1	1 675.6	2 797.7	2.861 2	3.157 9	6.019 1	0.001269	0.0440
46.0	258.7	1 128.8	1 668.3	2 797.0	2.873 5	3.136 2	6.009 7	0.001272	0.0430
47.0	260.1	1 135.3	1 661.1	2 796.4	2.885 5	3.114 9	6.000 4	0.001276	0.0421
48.0	261.4	1 141.8	1 653.9	2 795.7	2.897 4	3.093 9	5.991 3	0.001279	0.0412
49.0	262.6	1 148.2	1 646.8	2 794.9	2.909 1	3.073 3	5.982 3	0.001282	0.0403
50.0	263.9	1 154.5	1 639.7	2 794.2	2.920 6	3.052 9	5.973 5	0.001286	0.0394
51.0	265.1	1 160.7	1 632.7	2 793.4	2.931 9	3.032 8	5.964 8	0.001289	0.0386
52.0	266.4	1 166.8	1 625.7	2 792.6	2.943 1	3.013 0	5.956 1	0.001292	0.0378
53.0	267.6	1 172.9	1 618.8	2 791.7	2.954 1	2.993 5	5.947 6	0.001296	0.0371
54.0	268.7	1 178.9	1 611.9	2 790.8	2.965 0	2.974 2	5.939 2	0.001299	0.0363
55.0	269.9	1 184.9	1 605.0	2 789.9	2.975 7	2.955 2	5.930 9	0.001302	0.0356
56.0	271.1	1 190.8	1 598.2	2 789.0	2.986 3	2.936 4	5.922 7	0.001306	0.0349
57.0	272.2	1 196.6	1 591.4	2 788.0	2.996 7	2.917 9	5.914 6	0.001309	0.0343
58.0	273.3	1 202.3	1 584.7	2 787.0	3.007 1	2.899 5	5.906 6	0.001312	0.0336
59.0	274.4	1 208.0	1 578.0	2 786.0	3.017 2	2.881 4	5.898 6	0.001315	0.0330

TABLE 1 (continued)

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Sat Temp °*C*	Specific Enthalpy *kJ/kg*			Specific Entropy *kJ/kg/K*			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_S	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
60.0	275.5	1 213.7	1 571.3	2 785.0	3.027 3	2.863 5	5.890 8	0.001318	0.0324
61.0	276.6	1 219.3	1 564.7	2 784.0	3.037 2	2.845 8	5.883 0	0.001322	0.0319
62.0	277.7	1 224.8	1 558.0	2 782.9	3.047 1	2.828 3	5.875 3	0.001325	0.0313
63.0	278.7	1 230.3	1 551.5	2 781.8	3.056 8	2.810 9	5.867 7	0.001328	0.0308
64.0	279.8	1 235.7	1 544.9	2 780.6	3.066 4	2.793 8	5.860 1	0.001332	0.0302
65.0	280.8	1 241.1	1 538.4	2 779.5	3.075 9	2.776 8	5.852 7	0.001335	0.0297
66.0	281.8	1 246.5	1 531.9	2 778.3	3.085 3	2.760 0	5.845 2	0.001338	0.0292
67.0	282.8	1 251.8	1 525.4	2 777.1	3.094 6	2.743 3	5.837 9	0.001341	0.0287
68.0	283.8	1 257.0	1 518.9	2 775.9	3.103 8	2.726 8	5.830 6	0.001345	0.0283
69.0	284.8	1 262.2	1 512.5	2 774.7	3.112 9	2.710 5	5.823 3	0.001348	0.0278
70.0	285.8	1 267.4	1 506.0	2 773.5	3.121 9	2.694 3	5.816 2	0.001351	0.0274
71.0	286.7	1 272.5	1 499.6	2 772.2	3.130 8	2.678 2	5.809 0	0.001355	0.0269
72.0	287.7	1 277.6	1 493.3	2 770.9	3.139 7	2.662 3	5.802 0	0.001358	0.0265
73.0	288.6	1 282.7	1 486.9	2 769.6	3.148 4	2.646 5	5.794 9	0.001361	0.0261
74.0	289.6	1 287.7	1 480.5	2 768.3	3.157 1	2.630 9	5.788 0	0.001364	0.0257
75.0	290.5	1 292.7	1 474.2	2 766.9	3.165 7	2.615 3	5.781 0	0.001368	0.0253
76.0	291.4	1 297.6	1 467.9	2 765.5	3.174 2	2.599 9	5.774 2	0.001371	0.0249
77.0	292.3	1 302.5	1 461.6	2 764.2	3.182 7	2.584 6	5.767 3	0.001374	0.0246
78.0	293.2	1 307.4	1 455.3	2 762.8	3.191 1	2.569 5	5.760 5	0.001378	0.0242
79.0	294.1	1 312.3	1 449.1	2 761.3	3.199 4	2.554 4	5.753 8	0.001381	0.0239
80.0	294.9	1 317.1	1 442.8	2 759.9	3.207 6	2.539 5	5.747 1	0.001384	0.0235
81.0	295.8	1 321.9	1 436.6	2 758.4	3.215 8	2.524 6	5.740 4	0.001387	0.0232
82.0	296.7	1 326.6	1 430.3	2 757.0	3.223 9	2.509 9	5.733 8	0.001391	0.0229
83.0	297.5	1 331.4	1 424.1	2 755.5	3.232 0	2.495 2	5.727 2	0.001394	0.0225
84.0	298.4	1 336.1	1 417.9	2 754.0	3.239 9	2.480 7	5.720 6	0.001397	0.0222
85.0	299.2	1 340.7	1 411.7	2 752.5	3.247 9	2.466 3	5.714 1	0.001401	0.0219
86.0	300.1	1 345.4	1 405.5	2 750.9	3.255 7	2.451 9	5.707 6	0.001404	0.0216
87.0	300.9	1 350.0	1 399.3	2 749.4	3.263 6	2.437 6	5.701 2	0.001408	0.0213
88.0	301.7	1 354.6	1 393.2	2 747.8	3.271 3	2.423 5	5.694 8	0.001411	0.0211
89.0	302.5	1 359.2	1 387.0	2 746.2	3.279 0	2.409 4	5.688 4	0.001414	0.0208
90.0	303.3	1 363.7	1 380.9	2 744.6	3.286 7	2.395 3	5.682 0	0.001418	0.0205
91.0	304.1	1 368.3	1 374.7	2 743.0	3.294 3	2.381 4	5.675 7	0.001421	0.0202
92.0	304.9	1 372.8	1 368.6	2 741.4	3.301 8	2.367 6	5.669 4	0.001425	0.0199
93.0	305.7	1 377.2	1 362.5	2 739.7	3.309 3	2.353 8	5.663 1	0.001428	0.0197
94.0	306.4	1 381.7	1 356.3	2 738.0	3.316 8	2.340 1	5.656 8	0.001432	0.0194
95.0	307.2	1 386.1	1 350.2	2 736.4	3.324 2	2.326 4	5.650 6	0.001435	0.0192
96.0	308.0	1 390.6	1 344.1	2 734.7	3.331 5	2.312 9	5.644 4	0.001438	0.0189
97.0	308.7	1 395.0	1 338.0	2 733.0	3.338 8	2.299 4	5.638 2	0.001442	0.0187
98.0	309.4	1 399.3	1 331.9	2 731.2	3.346 1	2.285 9	5.632 1	0.001445	0.0185
99.0	310.2	1 403.7	1 325.8	2 729.5	3.353 4	2.272 6	5.625 9	0.001449	0.0183

TABLE 1 (continued)

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Sat Temp °C	Specific Enthalpy kJ/kg			Specific Entropy kJ/kg/K			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_S	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
100.0	311.1	1 408.0	1 319.7	2 727.7	3.360 5	2.259 3	5.619 8	0.001452	0.0181
102.0	312.4	1 416.7	1 307.5	2 724.2	3.374 8	2.232 8	5.607 6	0.001459	0.0176
104.0	313.8	1 425.2	1 295.3	2 720.6	3.388 9	2.206 6	5.595 5	0.001467	0.0172
106.0	315.3	1 433.7	1 283.1	2 716.9	3.402 9	2.180 6	5.583 5	0.001474	0.0168
108.0	316.6	1 442.2	1 270.9	2 713.1	3.416 7	2.154 8	5.571 5	0.001481	0.0164
110.0	318.0	1 450.6	1 258.7	2 709.3	3.430 4	2.129 1	5.559 5	0.001488	0.0160
112.0	319.4	1 458.9	1 246.5	2 705.4	3.444 0	2.103 6	5.547 6	0.001496	0.0157
114.0	320.7	1 467.2	1 234.3	2 701.5	3.457 4	2.078 3	5.535 7	0.001504	0.0153
116.0	322.1	1 475.4	1 222.0	2 697.4	3.470 8	2.053 1	5.523 9	0.001511	0.0149
118.0	323.4	1 483.6	1 209.7	2 693.3	3.484 0	2.028 0	5.512 1	0.001519	0.0146
120.0	324.6	1 491.8	1 197.4	2 689.2	3.497 2	2.003 0	5.500 2	0.001527	0.0143
122.0	325.9	1 499.9	1 185.0	2 684.9	3.510 2	1.978 2	5.488 4	0.001535	0.0139
124.0	327.1	1 508.0	1 172.6	2 680.6	3.523 2	1.953 3	5.476 5	0.001543	0.0137
126.0	328.4	1 516.0	1 160.1	2 676.1	3.536 0	1.928 6	5.464 6	0.001551	0.0134
128.0	329.6	1 524.0	1 147.6	2 671.6	3.548 8	1.903 9	5.452 7	0.001559	0.0131
130.0	330.8	1 532.0	1 135.0	2 667.0	3.561 6	1.879 2	5.440 8	0.001567	0.0128
132.0	332.0	1 540.0	1 122.3	2 662.3	3.574 2	1.854 6	5.428 8	0.001576	0.0125
134.0	333.2	1 547.9	1 109.5	2 657.4	3.586 8	1.830 0	5.416 8	0.001584	0.0123
136.0	334.3	1 555.8	1 096.7	2 652.5	3.599 3	1.805 3	5.404 7	0.001593	0.0120
138.0	335.5	1 563.7	1 083.8	2 647.5	3.611 8	1.780 7	5.392 5	0.001602	0.0117
140.0	336.6	1 571.6	1 070.7	2 642.4	3.624 2	1.756 0	5.380 3	0.001611	0.0115
142.0	337.7	1 579.5	1 057.6	2 637.1	3.636 6	1.731 3	5.367 9	0.001619	0.0112
144.0	338.8	1 587.4	1 044.4	2 631.8	3.649 0	1.706 6	5.355 5	0.001629	0.0110
146.0	339.9	1 595.3	1 031.0	2 626.3	3.661 3	1.681 8	5.343 1	0.001638	0.0108
148.0	341.1	1 603.1	1 017.6	2 620.7	3.673 6	1.656 9	5.330 5	0.001648	0.0106
150.0	342.1	1 611.0	1 004.0	2 615.0	3.685 9	1.632 0	5.317 8	0.001658	0.0103
152.0	343.2	1 618.9	990.3	2 609.2	3.698 1	1.607 0	5.305 1	0.001668	0.0101
154.0	344.2	1 626.8	976.5	2 603.3	3.710 3	1.581 9	5.292 2	0.001678	0.00991
156.0	345.3	1 634.7	962.6	2 597.3	3.722 6	1.556 7	5.279 3	0.001689	0.00971
158.0	346.3	1 642.6	948.5	2 591.1	3.734 8	1.531 4	5.266 3	0.001699	0.00951
160.0	347.3	1 650.5	934.3	2 584.9	3.747 1	1.506 0	5.253 1	0.001710	0.00931
162.0	348.3	1 658.5	920.0	2 578.5	3.759 4	1.480 6	5.239 9	0.001721	0.00911
164.0	349.3	1 666.5	905.6	2 572.1	3.771 7	1.455 0	5.226 7	0.001733	0.00893
166.0	350.3	1 674.5	891.0	2 565.5	3.784 2	1.429 0	5.213 2	0.001745	0.00874
168.0	351.3	1 683.0	875.6	2 558.6	3.797 4	1.402 1	5.199 4	0.001757	0.00855
170.0	352.3	1 691.7	859.9	2 551.6	3.810 7	1.374 8	5.185 5	0.001769	0.00837
172.0	353.2	1 700.4	844.0	2 544.4	3.824 0	1.347 3	5.171 3	0.001783	0.00819
174.0	354.2	1 709.0	828.1	2 537.1	3.837 2	1.319 8	5.157 0	0.001796	0.00801
176.0	355.1	1 717.6	811.9	2 529.5	3.850 4	1.292 2	5.142 5	0.001810	0.00784
178.0	356.0	1 726.2	795.6	2 521.8	3.863 5	1.264 3	5.127 8	0.001825	0.00767

TABLE I (continued)

SATURATED WATER AND STEAM (PRESSURE) TABLE

Absolute Pressure *bar*	Sat Temp °C	Specific Enthalpy *kJ/kg*			Specific Entropy *kJ/kg/K*			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
p	T_S	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
180.0	356.9	1 734.8	779.1	2 513.9	3.876 5	1.236 2	5.112 8	0.001840	0.00750
182.0	357.8	1 743.4	762.3	2 505.8	3.889 6	1.207 9	5.097 5	0.001856	0.00733
184.0	358.7	1 752.1	745.3	2 497.4	3.902 8	1.179 2	5.082 0	0.001872	0.00717
186.0	359.6	1 760.9	727.9	2 488.8	3.916 0	1.150 1	5.066 1	0.001889	0.00701
188.0	360.5	1 769.7	710.1	2 479.8	3.929 4	1.120 5	5.049 8	0.001907	0.00684
190.0	361.4	1 778.7	692.0	2 470.6	3.942 9	1.090 3	5.033 2	0.001926	0.00668
192.0	362.3	1 787.8	673.3	2 461.1	3.956 6	1.059 4	5.016 0	0.001946	0.00652
194.0	363.2	1 797.0	654.1	2 451.1	3.970 6	1.027 8	4.998 3	0.001967	0.00636
196.0	364.0	1 806.6	634.2	2 440.7	3.984 9	0.995 1	4.980 0	0.001989	0.00620
198.0	364.8	1 816.3	613.5	2 429.8	3.999 6	0.961 4	4.961 1	0.002012	0.00604
200.0	365.7	1 826.5	591.9	2 418.4	4.014 9	0.926 3	4.941 2	0.002037	0.00588
202.0	366.5	1 837.0	569.2	2 406.2	4.030 8	0.889 7	4.920 4	0.002064	0.00571
204.0	367.3	1 848.1	545.1	2 393.3	4.047 4	0.851 0	4.898 4	0.002093	0.00555
206.0	368.2	1 859.9	519.5	2 379.4	4.065 1	0.809 9	4.875 0	0.002125	0.00538
208.0	368.9	1 872.5	491.7	2 364.2	4.084 1	0.765 7	4.849 8	0.002161	0.00521
210.0	369.8	1 886.3	461.3	2 347.6	4.104 8	0.717 5	4.822 3	0.002201	0.00502
212.0	370.6	1 901.5	427.4	2 328.9	4.127 9	0.663 9	4.791 7	0.002249	0.00483
214.0	371.3	1 919.0	388.4	2 307.4	4.154 3	0.602 6	4.756 9	0.002306	0.00462
216.0	372.1	1 939.9	341.6	2 281.6	4.186 1	0.529 3	4.715 4	0.002379	0.00439
218.0	372.9	1 967.2	280.8	2 248.0	4.227 6	0.434 6	4.662 2	0.002483	0.00412
220.0	373.7	2 011.1	184.5	2 195.6	4.294 7	0.285 2	4.579 9	0.002671	0.00373
221.2	374.1	2 107.4	0.0	2 107.4	4.442 9	0.0	4.442 9	0.003170	0.00317

TABLE 2

SATURATED WATER AND STEAM (TEMPERATURE) TABLE

Sat Temp °C	Absolute Pressure bar	Specific Enthalpy kJ/kg			Specific Entropy kJ/kg/K			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
T_s	p	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
0	0.0061	−0.02	2501.4	2501.3	0.0001	9.1566	9.1565	0.0010002	206.3
0.01	0.0061	0.01	2501.3	2501.4	0.000	9.156	9.156	0.0010002	206.2
1	0.0065	4.2	2499.0	2503.2	0.015	9.115	9.130	0.0010002	192.6
2	0.0070	8.4	2496.7	2505.0	0.031	9.073	9.104	0.0010001	179.9
3	0.0076	12.6	2494.3	2506.9	0.046	9.032	9.077	0.0010001	168.1
4	0.0081	16.8	2491.9	2508.7	0.061	8.990	9.051	0.0010001	157.2
5	0.0087	21.0	2489.6	2510.6	0.076	8.950	9.026	0.0010001	147.1
6	0.0093	25.2	2487.2	2512.4	0.091	8.909	9.000	0.0010001	137.7
7	0.0100	29.4	2484.8	2514.2	0.106	8.869	8.975	0.0010002	129.0
8	0.0107	33.6	2482.5	2516.1	0.121	8.829	8.950	0.0010002	120.9
9	0.0115	37.8	2480.1	2517.9	0.136	8.789	8.925	0.0010003	113.4
10	0.0123	42.0	2477.7	2519.7	0.151	8.750	8.901	0.0010004	106.4
11	0.0131	46.2	2475.4	2521.6	0.166	8.711	8.877	0.0010004	99.86
12	0.0140	50.4	2473.0	2523.4	0.181	8.672	8.852	0.0010005	93.78
13	0.0150	54.6	2470.7	2525.3	0.195	8.632	8.828	0.0010007	88.12
14	0.0160	58.8	2468.3	2527.1	0.210	8.595	8.805	0.0010008	82.85
15	0.0170	63.0	2465.9	2528.9	0.224	8.557	8.781	0.0010009	77.93
16	0.0182	67.2	2463.6	2530.8	0.239	8.519	8.758	0.001001	73.33
17	0.0194	71.4	2461.2	2532.6	0.253	8.482	8.735	0.001001	69.04
18	0.0206	75.6	2458.8	2534.4	0.268	8.444	8.712	0.001001	65.04
19	0.0220	79.8	2456.5	2536.3	0.282	8.407	8.690	0.001002	61.29
20	0.0234	84.0	2454.1	2538.1	0.297	8.371	8.667	0.001002	57.79
21	0.0249	88.1	2451.8	2539.9	0.311	8.334	8.645	0.001002	54.51
22	0.0264	92.3	2449.4	2541.7	0.325	8.298	8.623	0.001002	51.45
23	0.0281	96.5	2447.0	2543.5	0.339	8.262	8.601	0.001002	48.57
24	0.0298	100.7	2444.7	2545.4	0.353	8.226	8.579	0.001003	45.88
25	0.0317	104.9	2442.3	2547.2	0.367	8.191	8.558	0.001003	43.36
26	0.0336	109.1	2439.9	2549.0	0.382	8.155	8.537	0.001003	40.99
27	0.0357	113.2	2437.6	2550.8	0.396	8.120	8.516	0.001004	38.77
28	0.0378	117.4	2435.2	2552.6	0.409	8.086	8.495	0.001004	36.69
29	0.0401	121.6	2432.8	2554.5	0.423	8.051	8.474	0.001004	34.73
30	0.0425	125.8	2430.5	2556.3	0.437	8.016	8.453	0.001004	32.89

TABLE 2 (continued)

SATURATED WATER AND STEAM (TEMPERATURE) TABLE

Sat Temp °C	Absolute Pressure bar	Specific Enthalpy kJ/kg			Specific Entropy kJ/kg/K			Specific Volume m^3/kg	
		Water	Evaporation	Steam	Water	Evaporation	Steam	Water at Saturation Temperature	Dry Saturated Steam
T_S	p	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
31	0.0450	130.0	2428.1	2558.1	0.451	7.982	8.433	0.001005	31.17
32	0.0476	134.2	2425.7	2559.9	0.464	7.948	8.413	0.001005	29.54
33	0.0503	138.3	2423.4	2561.7	0.478	7.915	8.393	0.001005	28.01
34	0.0532	142.5	2421.0	2563.5	0.492	7.881	8.373	0.001006	26.57
35	0.0563	146.7	2418.6	2565.3	0.505	7.848	8.353	0.001006	25.22
36	0.0595	150.9	2416.2	2567.1	0.519	7.815	8.334	0.001006	23.94
37	0.0628	155.0	2413.9	2568.9	0.532	7.782	8.314	0.001007	22.74
38	0.0663	159.2	2411.5	2570.7	0.546	7.749	8.295	0.001007	21.60
39	0.0700	163.4	2409.1	2572.5	0.559	7.717	8.276	0.001007	20.53
40	0.0738	167.6	2406.7	2574.3	0.573	7.685	8.257	0.001008	19.52
41	0.0779	171.7	2404.3	2576.0	0.586	7.652	8.238	0.001008	18.57
42	0.0821	175.9	2401.9	2577.8	0.599	7.621	8.220	0.001009	17.67
43	0.0865	180.1	2399.5	2579.6	0.612	7.589	8.201	0.001009	16.82
44	0.0911	184.3	2397.2	2581.5	0.626	7.557	8.183	0.001010	16.02
45	0.0959	188.4	2394.8	2583.2	0.639	7.526	8.165	0.001010	15.26
46	0.1010	192.6	2392.4	2585.0	0.652	7.495	8.147	0.001010	14.54
47	0.1062	196.8	2390.0	2586.8	0.665	7.464	8.129	0.001011	13.86
48	0.1118	201.0	2387.6	2588.6	0.678	7.433	8.111	0.001011	13.22
49	0.1175	205.1	2385.2	2590.3	0.691	7.403	8.094	0.001012	12.61
50	0.1235	209.3	2382.7	2592.1	0.704	7.372	8.076	0.001012	12.03
52	0.1363	217.7	2377.9	2595.6	0.730	7.312	8.042	0.001013	10.97
54	0.1502	226.0	2373.1	2599.1	0.755	7.253	8.008	0.001014	10.01
56	0.1653	234.4	2368.2	2602.6	0.781	7.194	7.975	0.001015	9.149
58	0.1817	242.8	2363.4	2606.2	0.806	7.136	7.942	0.001016	8.372
60	0.1994	251.1	2358.5	2609.6	0.831	7.078	7.909	0.001017	7.671
62	0.2186	259.5	2353.6	2613.1	0.856	7.022	7.878	0.001018	7.037
64	0.2393	267.9	2348.7	2616.5	0.881	6.965	7.846	0.001019	6.463
66	0.2617	276.2	2343.7	2619.9	0.906	6.910	7.816	0.001020	5.943
68	0.2859	284.6	2338.8	2623.4	0.930	6.855	7.785	0.001022	5.471
70	0.3119	293.0	2333.8	2626.8	0.955	6.800	7.755	0.001023	5.042
75	0.3858	313.9	2321.4	2635.3	1.015	0.667	7.682	0.001026	4.131
80	0.4739	334.9	2308.8	2643.7	1.075	6.537	7.612	0.001029	3.407
85	0.5783	355.9	2296.0	2651.9	1.134	6.410	7.544	0.001033	2.828
90	0.7014	376.9	2283.2	2660.1	1.192	6.287	7.479	0.001036	2.361
95	0.8455	397.9	2270.2	2668.1	1.250	6.166	7.416	0.001040	1.982
100	1.0135	419.0	2257.0	2676.0	1.307	6.048	7.355	0.001044	1.673

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