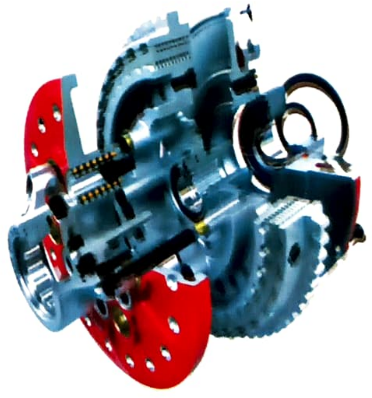
According to NEW syllabus of GTU from 2018 onwards

BASIC MECHANICAL ENGINEERING



Dr N M Bhatt Dr J R Mehta

Mahajan Publishing House®

According to the New BE Syllabus of Gujarat Technological University
(G.T.U.)
Effective from Academic Year 2018-19

For B.E. First Year Students

BASIC MECHANICAL ENGINEERING

• AUTHORS •

Dr N M Bhatt
M.Tech, Ph.D. (IIT Bombay)
Director
Gandhinagar Institute of Technology,
Gandhinagar

Dr J R Mehta
M.E., Ph.D. (IIT Bombay)
Mechanical Engineering Department,
Faculty of Technology & Engineering,
The Maharaja Sayaji Rao University of Baroda
Vadodara

MAHAJAN Mahajan Publishing House®
Ahmedabad.

Shri Nirav J. Shah
Mahajan Publishing House
Gandhi Road,
Ahmedabad-380 001.
Phone : 079-22111123

₹ 220=00

Edition : Tenth Edition (2018)

ISBN 978-93-87096-16-5

Type Setting :
Dharm Computer Graphics
Jitendra D. Bhavsar

Dedicated to

Almighty

About the Authors

Dr N M Bhatt :

Dr N M Bhatt has been working as Director of Gandhinagar Institute of Technology, Gandhinagar since 2009. He was faculty member in Mechanical Engineering Department of Institute of Technology, Nirma University, Ahmedabad for about 15 years. He has obtained his bachelor degree from Sardar Patel University and M.Tech. and Ph.D. from IIT Bombay. He has more than twenty three years of teaching experience and is involved with various subjects of Thermal and Fluid Engineering. He has 2 Indian patent and has published 45 papers at International and National levels.

Dr J R Mehta :

Dr J R Mehta is a faculty at Mechanical Engineering Department, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara. He holds PhD degree from IIT Bombay in area of solar air conditioning. He has been teaching subjects like Engineering Drawing, Thermodynamics, Thermal Engineering, Alternative Energy Sources, Heat and Mass Transferand Refrigeration and Air Conditioning. He has created excellent experimental facilities in area of Refrigeration and Air Conditioning as well as Solar Energy by bringing various sponsored projects from AICTE, UGC and GUJCOST. He is actively engaged in research and development in area of Energy and Air Conditioning. He has written and presented many papers in journals as well as national and international conferences.

FOREWORD

It gives me great pleasure to write a foreward for the book "Elements of Mechanical Engineering" by Dr N M Bhatt and Shri J R Mehta. The book covers many aspects of Mechanical Engineering with large number of neat sketches. The authors have taken great pain in solving a number of typical problems to make the basic concepts clear. The effort made by these two young teachers is most commendable.

Dr N M Bhatt is known to me for the last ten years. He is working as a faculty in Mechanical Engineering Department of Institute of Technology, Nirma University of Science and Technology. He is involved in teaching of Thermal Engineering subjects. He is one of the young and enthusiastic faculty at Nirma University. Shri J R Mehta has been involved in teaching the subjects of Machine Design Engineering. Both of them have put their sincere efforts to bring out this book for first year engineering students.

I am sure that this book will serve the need for a good textbook on basic concepts of Mechanical Engineering for undergraduate students.

Ahmedabad.
October 23, 2003

Dr N V Vasani
Director
Nirma University of
Science & Technology

SYLLABUS

GUJARAT TECHNOLOGICAL UNIVERSITY

• B. E. 1st Semester •

Sub. Name : Basic Mechanical Engineering

Sr. No.	Content	Total Hrs.	Module Weightage
1	**Introduction :** Prime movers and its types, Concept of Force, Pressure, Energy, Work, Power, System, Heat, Temperature, Specific heat capacity, Change of state, Path, Process, Cycle, Internal energy, Enthalpy, Statements of Zeroth law and First law	4	
2	**Energy :** Introduction and applications of Energy sources like Fossil fuels, Nuclear fuels, Hydro, Solar, Wind, and Bio-fuels, Environmental issues likeGlobal warming and Ozone depletion	3	25%
3	**Properties of gases :** Gas laws, Boyle's law, Charle's law, Combined gas law, Gas constant, Relation between cp and cv, Various non-flow processes like constant volume process, constant pressure process, Isothermal process, Adiabatic process, Polytropic process	5	
4	**Properties of Steam :** Steam formation, Types of steam, Enthalpy, Specificvolume, Internal energy and dryness fraction of steam, use of steam tables, steam calorimeters	6	
5	**Heat Engines :** Heat engine cycle and Heat engine, working substances, Classification of heat engines, Description and thermal efficiency of Carnot; Rankine; Otto cycle and Diesel cycles	5	30%
6	**Steam Boilers :** Introduction, Classification, Cochran, Lancashire and Babcockand Wilcox boiler, Functioning of different mountings and accessories	-	
7	**Inte rnal Combus tion Engines :** Introduction, Classification, Engine details, four-stroke/ two-stroke cycle Petrol/Diesel engines, Indicated power, BrakePower, Efficiencies	4	
8	**Pumps :** Types and operation of Reciprocating, Rotary and Centrifugal pumps, Priming	3	20%
9	**Air Compressors :** Types and operation of Reciprocating and Rotary aircompressors, significance of Multistaging	3	
10	**Refrigeration & Air Conditioning :** Refrigerant, Vapor compressionrefrigeration system, Vapor absorption refrigeration system, DomesticRefrigerator, Window and split air conditioners	4	
11	**Couplings, Clutches and Brakes :** Construction and applications of Couplings(Box; Flange; Pin type flexible; Universal and Oldham), Clutches (Disc andCentrifugal), and Brakes (Block; Shoe; Band and Disc)	-	25%
12	**Transmission of Motion and Power :** Shaft and axle, Different arrangement andapplications of Belt drive; Chain drive; Friction drive and Gear drive	-	
13	**Engineering Materials :** Types, properties and applications of Ferrous &Nonferrous metals, Timber, Abrasive material, silica, ceramics, glass, graphite, diamond, plastic and polymer	4	

Note: Topic No. 6, 11 and 12 of the above syllabus are to be covered in Practical Hours

CONTENTS

CHAPTER-3. PROPERTIES OF GASES 3.1 - 3.46

CHAPTER-4 PROPERTIES OF STEAM 4.1 -

CHAPTER-5 HEAT ENGINES 5.1 - 5.32

CHAPTER-6 STEAM BOILERS 6.1 - 6.22

CHAPTER-7 INTERNAL COMBUSTION ENGINES 7.1 - 7.24

CHAPTER-8 AIR COMPRESSORS 8.1 - 8

CHAPTER-9 PUMPS 9.1 - 9

❖ ❖ ❖

1

INTRODUCTION

1.1 PRIME MOVERS :

Prime mover is an engine or device which converts natural source of energy in to mechanical work. In olden days man was depending on his own physical strength and that of animal mainly horse, bullock, therefore, when mechanical systems were invented, the unit of power was horse power.

1.2 SOURCES OF ENERGY USED BY PRIME MOVERS :

Prime movers use different sources of energy :

(a) **Fuels :** When combustion of fuel takes place, heat energy is released depending on its calorific value. This heat energy is converted into mechanical work by a device known as heat engine. It is most widely used source of energy.

(b) **River Water :** It is another useful form of energy. Water stored at high level possesses potential energy. This potential energy is converted in to kinetic energy and ultimately into mechanical work by a prime mover known as hydraulic turbine. River water is also used to generate steam in boilers which in turn used to develop mechanical work using steam turbines and steam engines.

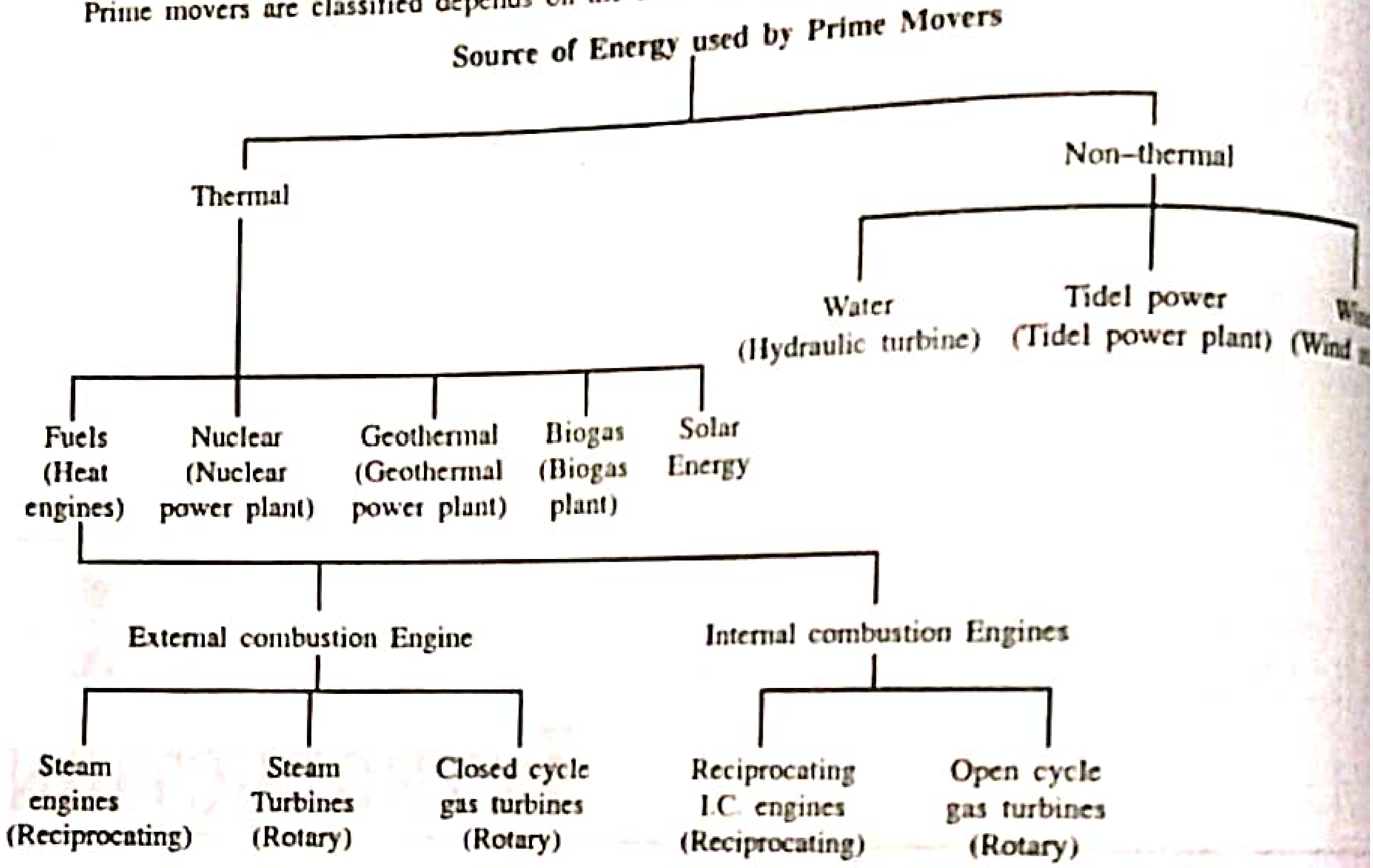
(c) **Atoms (Nuclear Energy) :** Heat energy is released by fusion and fission reaction of the atoms. This heat energy is used to produce steam which in turn used to produce mechanical work using steam turbines.

(d) **Solar Energy :** Solar energy is available freely and it is a non polluting source of energy. Solar energy can be used to produce steam to run steam turbine. Using solar photovoltaic cells one can produce electrical energy.

(e) **Wind Energy :** Kinetic energy of wind is used to produce mechanical work using wind mills. It is also freely available non polluting source of energy.

1.3 CLASSIFICATION OF PRIME MOVERS :

Prime movers are classified depends on the source of energy utillzed by them.



1.4 UNITS AND DIMENSIONS :

The basic units of SI (System International) system of units are given below.

Table 1.1 Basic units of SI system

Quantity	Unit	Symbol
Length (L)	Metre	m
Mass (M)	Kilogramme	kg
Time (t)	Second	s
Temperature (T)	Kelvin	K
Amount of Substance	Mole	mol
Electric current	Ampere	A
Luminous intensity	Candela	cd
Plane angle	Radian	rad
Solid angle	Steradian	sr

The dimensions of all other quantities are derived from the basic units. Some of them are listed in Table 1.
Often it is necessary and convenient to use multiples of various units. They are listed in Table 1.3.

Table 1.2 Derived units of SI system

Quantity	Unit	Symbol	Other/Alternate unit	Basic units
Force	Newton	N		$kg\ m/s^2$
Energy	Joule	J	Nm	$kg\ m^2/s^2$
Power	Watt	W	J/s	$kg\ m^2 s^3$
Pressure	Pascal	Pa	N/m^2	$kg/(ms^2)$
Frequency	Hertz	Hz		s^{-1}
Electric charge	Coulomb	C		As
Electric potential	Volt	V	W/A = J/C	$kg\ m^2/(s^3A)$
Capacitance	Farad	F	C/V	$s^4A^2/(kg\ m^2)$
Electrical resistance	Ohm	Ω	V/A	$kg\ m^2/(s^3A^2)$
Magnetic flux	Weber	Wb	Vs	$kg\ m^2/(s^2A)$
Magnetic flux density	Tesla	T	Wb/m^2	$kg/(s^2A)$
Inductance	Henry	H	Wb/A	$kg\ m^2/(s^2A^2)$

Table 1.3 Standard multiple of SI system

Prefix	Factor	Prefix	Factor
Milli, m	10^{-3}	kilo k	10^3
Micro, μ	10^{-6}	mega M	10^6
Nano, n	10^{-9}	giga, G	10^9
Pico, p	10^{-12}	tera, T	10^{12}

Force : Newton's second law of motion defines the force acting on a body. The unit of force is Newton (N). When a force of 1 Newton is applied to 1 kg of mass, it produces acceleration of 1 m/s^2.

$$1\ N = 1\ kg\ m/s^2$$

The weight (W) of a body is the force with which the body is attracted to the centre of the earth. It is a product of mass of the body and local gravitational acceleration (g).

$$W = mg$$

The value of 'g' at sea level is 9.80663 m/s^2. For all practical purposes it can be assumed as 9.81 m/s^2. The weight of a body varies with elevation but the mass remains constant.

Pressure (p) : Pressure is defined as the normal force exerted by a system against unit area of the bounding surface.

In SI system of units, the unit of pressure is Pascal (Pa). One Pascal equals to force of one Newton acting on an area of 1 m^2.

Pascal is very small unit and very often kilo-Pascal (kPa) and mega-Pascal (MPa) is used.

The other unit of pressure, though not belong to SI system of units are widely being used. They are the 'bar' and the 'standard atmosphere'.

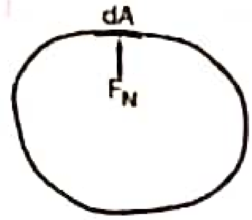


Fig. 1.1 Pressure

$$1\ bar = 10^5\ Pa = 100\ kPa = 0.1\ MPa$$

and

$$1\ atm = 101.325\ kPa = 1.01325\ bar.$$

Standard atmosphere is a pressure of atmospheric air at mean sea level. It is defined as the pressure developed by a mercury column of 760 mm. By taking density of mercury equal to 13595.09 kg/m^3 and gravitational acceleration equal to 9.80665 m/s^2, standard atmosphere will be

$$p = \rho gh = \frac{13595.09 \times 9.80665 \times 0.760}{10^5}$$

$$= \mathbf{1.01325\ bar}$$

Most of the instruments indicate pressure relative to the atmospheric pressure. The pressure relative to the atmosphere is called 'gauge pressure'. The pressure relative to perfect vacuum is called 'absolute pressure'.

Absolute pressure = Gauge pressure + Atmospheric pressure

When the system pressure is less than atmospheric pressure, the gauge pressure becomes negative. This negative gauge pressure is very often called as *vacuum*, which is positive number. 20 cm of vacuum means

$$\frac{76 - 20}{76} \times 1.01325 = 0.746 \text{ bar.}$$

Some of the pressure measuring instruments are Bourdon pressure gauge, open U tube manometer, closed U tube manometer (closed limb have vacuum so it measure absolute pressure). Barometer (which measure atmospheric pressure. It is a closed U tube manometer where atmosphere pressure acts on open limb of manometer.)

If H is the difference in the heights of fluid columns in the two limbs of U tube manometer, g is gravitational acceleration and ρ is the density of manometric fluid, then from principle of hydrostatic, the gauge pressure is given by

$$p = \rho g H \left[\frac{kg}{m^3}\ \frac{m}{s^2}\ m = N/m^2\right]$$

Specific Volume, Density and Specific Gravity : Space occupied by a substance is defined as volume (V). Its unit is m^3. The specific volume (v) of a substance is defined as the volume per unit mass. Its unit is m^3/kg.

Density (ρ) of a substance is defined as mass per unit volume of the substance. Its unit is kg/m^3. Thus density is a reciprocal of specific volume.

Specific gravity is defined as ratio of density of a substance at 20°C to density of water at 20°C. Density of water at 20°C is taken as 1000 kg/m^3.

Energy : Energy is defined as capacity to exert force through a distance. It exits in many forms. Engineering processes involve the conversion of energy from one form to another.

The unit of energy in SI system of units is Nm or Joule (J). The energy per unit mass is the specific energy. Its unit is J/kg

Power : Rate of energy transfer is known as power. Its unit is Watt (W). It is a small unit and very often kilowatt (kW) and megawatt (MW) is used.

1 W = 1 J/s = 1 Nm/s

1.5 THERMODYNAMIC SYSTEM AND CONTROL VOLUME :

A thermodynamic 'system' is defined as a quantity of matter or a region in a space upon which attention is focused for the analysis of the problem. Everything external to the system is called 'surrounding' or the environment. System boundary is a real or imaginary boundary which separates the system from surrounding. It is generally denoted by dotted line. System boundary may be fixed or moving.

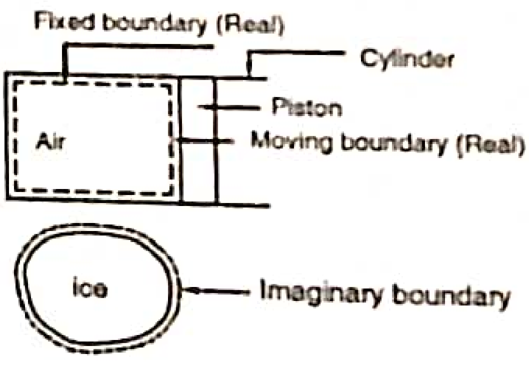


Fig. 1.2 Types of boundary

A system and its surroundings together form a 'universe'. Systems can be classified in three categories (1) closed system (2) open system (3) isolated system. Closed system is one in which there is no mass transfer across the boundary of the system thus it is a system of fixed mass. Energy interaction can be there across the system boundary. Example of closed system is air trapped in piston–cylinder arrangement as shown in Fig. 1.2. Open system is one in which both mass and energy cross the boundary of the system. Most of the engineering applications are open system. Examples of open system are gas turbine, air compressor, pump, nozzle etc. In gas turbine, gas at high pressure, high temperature enters in to the turbine and leaves at lower pressure, lower temperature. There are energy transfers across the system boundary.

In thermodynamic analysis of an open system such as gas turbine as shown in Fig. 1.3 attention is focused on certain volume surrounding the gas turbine. This volume is called 'control volume'. The bounded surface is known as 'control surface'. Mass and energy both cross the control surface. Thus there is no difference between open system and a control volume.

An isolated system is one in which neither mass nor energy crosses the boundary of the system.

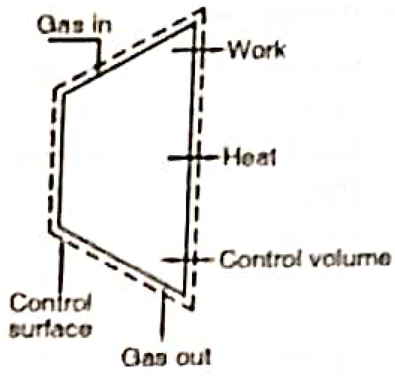


Fig. 1.3 Open system

1.6 PROPERTIES, PROCESS AND CYCLE :

Systems have certain characteristics by which its physical condition can be described, for example pressure, temperature, volume etc. Such characteristics are called 'properties' of the system. Properties are the coordinates to describe the state. There are two types of properties. Intensive properties are independent of the mass of the system. Examples are pressure, temperature, density etc. Extensive properties are dependent of mass. Examples are volume, energy etc. Extensive properties per unit mass, known as specific extensive properties are intensive properties. Example are specific volume, specific energy etc.

When all the system properties have definite values, the system is said to be in a definite 'state'. In figure 1.4, 'a', '1', etc. are different states of a system.

Any operation in which one or more of the system properties change is called a 'change of state'. In figure 1.4, 'a to 1', '1 to 2' etc. are change of state.

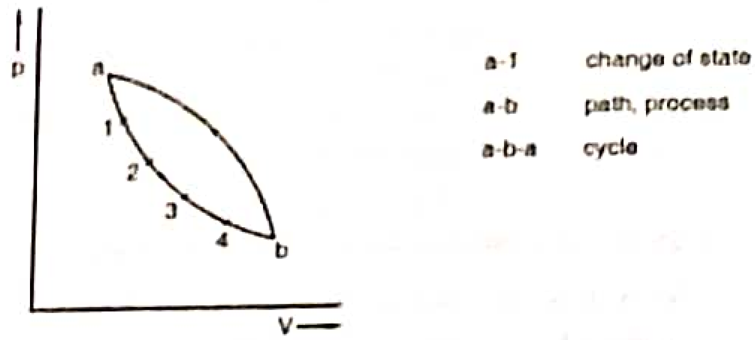


Fig. 1.4 A change of state, a process and a cycle

Sequence of states passed through during a change of state is called the 'path' of the change of state.

When path is completely specified, the change of state is known as a 'process'.

A series of change of state such that the final state is identical with initial state is called 'cycle'.

1.7 TEMPERATURE :

It is a quantitative measure of the degree of coldness or hotness of a system. Its unit in SI system of unit is Kelvin (K). Other units of temperature are Degree centigrade (°C) and Degree Fahrenheit (°F). The relations between them are as under.

$$K = {}^\circ C + 273.16$$

$${}^\circ C = \frac{5}{9}({}^\circ F - 32)$$

Temperature is property which distinguishes thermodynamics from other sciences. It helps to distinguish between hot and cold.

1.8 ZEROTH LAW OF THERMODYNAMICS :

Zeroth law of thermodynamics is stated as follows.

"When a body A is in thermal equilibrium with a body B, and also with a body C, then B and C must be in thermal equilibrium with each other".

It provides the basis of temperature measurement.

1.9 WORK TRANSFER :

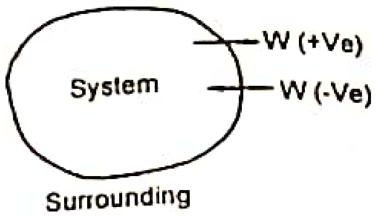


Fig. 1.5 Sign convention for work transfer

Interaction between a closed system and its surrounding can be by two ways : (i) by work transfer (ii) by heat transfer. They are also referred as energy interactions. When these energy interactions take place system under goes a change of state and its properties will change. "Work is said to be done if a body is moving in the direction of the force". The action of force through a distance or torque through an angle is called mechanical work. The magnitude of mechani-cal work is a product of the force and distance moved in the direction of force.

The symbol W is used for work transfer. The unit of work is Joule or Nm. When work is done by a system it is taken positive, while it is done on a system is taken negative.

The rate of doing work by the system or on the system is called the power. The unit of power is J/s or Watt.

1.10 DIFFERENT TYPES OF WORK TRANSFER :

(1) Displacement Work or pdV Work :

A system of piston and cylinder as shown in Fig. 1.6 contains gas at a pressure p_1 and volume V_1. Now let's assume that piston moves outward and the system has new pressure p_2 and volume V_2. Let intermediate states are denoted by general co–ordinate p and v. If 'A' is the area of the piston and piston moves infinitesimal small distance dl, the work done by gas on piston due to force F = pA.

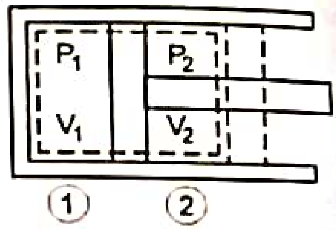


Fig. 1.6 pdV work

$$\delta W = F \cdot dl = pAdl = pdV$$

dV = Adl = infinitesimal displacement volume.

Work done by system when piston moves from 1 to 2, (volume changes from V_1 to V_2) is given by

$$W_{1\text{-}2} = \int_1^2 pdV \qquad (1.1)$$

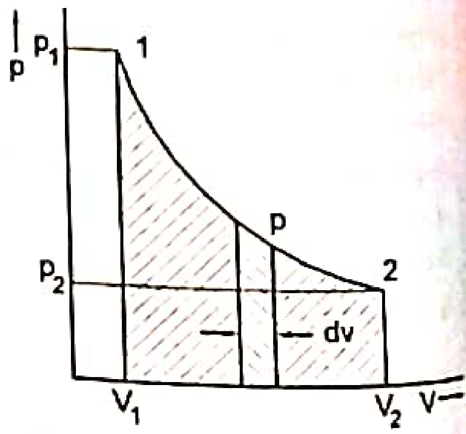


Fig. 1.7 pdV work on p-V diagram

This work will be the area under the process 1–2 on p-V diagram as shown in Fig. 1.7.

(2) Flow Work :

The flow work is the energy transferred across the system boundary because of energy imparted to the fluid by compressor, pump or blower. It is significant in open system only. The flow work is the energy required to make the fluid flow across the boundary of the open system.

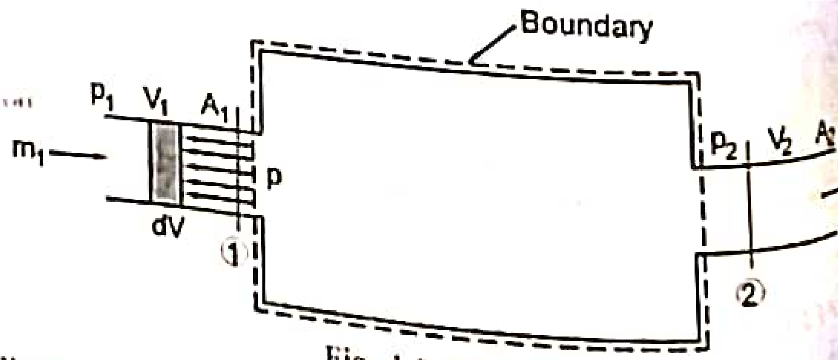


Fig. 1.8 Flow work

If p is the pressure of fluid acting normally to an imaginary plane as shown in Fig. 1.9 and dV is small volume of the fluid enters into the system, Flow work is given by

$$\delta W_{flow} = pdV$$

(3) Shaft Work :

When a shaft is rotated by a motor and shaft is considered as a system, work is said to be done on the shaft.

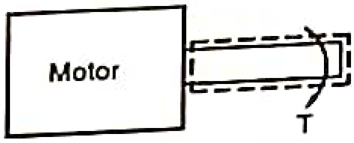


Fig. 1.9 Shaft work

If T is the torque applied to shaft and N is RPM of the shaft, the shaft power P can be written as

$$P = \frac{2\pi N T}{60} \qquad (1.2)$$

1.11 HEAT TRANSFER :

Similar to work transfer, heat transfer is also a form of energy in transit. Heat is a form of energy that is transferred across the boundary of the system by virtue of the temperature difference. There are three mode of heat transfer. Heat transfer between two bodies in direct contact is called 'conduction', heat transfer between wall and fluid system in motion can be called as 'convection' and heat transfer between two bodies separated by gases or vacuum can be referred as 'radiation'.

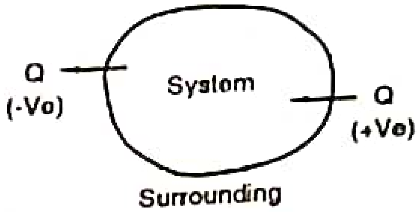


Fig. 1.10 Sign convention for heat transfer

Heat transfer is denoted by Q. If heat is added to the system then it is taken as positive and if heat is rejected by system it is taken as negative.

The unit of heat in SI system is Joule (J). The rate of heat transfer is given in W or kW.

Heat can't be stored means it is not a conserved quantity and thus it is not a property of a system. A process in which there in no heat transfer between system and surrounding is called 'adiabatic process'.

1.12 SPECIFIC HEAT :

The amount of heat required to raise the temperature of 1 kg of mass by 1°C or 1 K is termed as specific heat of the substance. It is denoted by c. If Q is amount of heat required in (J), to raise the temperature of m kg of mass by Δt K then specific heat can be written as

$$c = \frac{Q}{m \times \Delta t} \text{ J/kg K} \qquad (1.3)$$

Gases have two specific heats depend on the process in which heat transfer takes place. viz specific heat at constant pressure (c_p) and specific heat at constant volume (c_v)

As solid and liquids are incompressible, therefore they have single value of specific heat.

The product of mass and specific heat is called the heat capacity of the substance. It is denoted by C. Heat capacity at constant pressure and constant volume can be denoted by C_p and C_v respectively.

1.13 LATENT HEAT :

Solid, liquid and vapour (or gas) are the three phases in which matter can exist. The amount of heat required to change the phase of 1 kg of substance at constant pressure and temperature is defined as "latent heat".

Amount of heat transfer to melt 1 kg of solid into liquid or to freeze 1 kg of liquid into solid is called "latent heat of fusion".

Amount of heat transfer to vapourise 1 kg of liquid into vapour or to condense 1 kg of vapour into liquid is called "latent heat of vapourisation".

Amount of heat transfer needed to convert 1 kg of solid in to vapour or vice versa is called "latent heat of sublimation".

Latent heat of fusion is not much affected by pressure, where as latent heat of vapourization is highly sensitive to pressure.

1.14 ENTHALPY :

The enthalpy of a substance is defined as $H = U + pV$. Its unit is kJ. It is an extensive property. Specific enthalpy is given by $h = u + pv$ and its unit is kJ/kg. It is an intensive property of the system.

1.15 FIRST LAW OF THERMODYNAMICS :

For closed system under going a cycle, one can write first law as follows

$$(\Sigma W)_{cycle} = (\Sigma Q)_{cycle} \tag{1.4}$$

Which can also be expressed as

$$\oint \delta W = \oint \delta Q \tag{1.5}$$

The symbol $\oint$ denotes cyclic integral for the closed path.

If system under goes a change of state, during which both heat transfer and work transfer takes place, the net energy is stored by the system. If W is the amount of work transferred and Q is the amount of heat transferred, the net energy (Q–W) is stored by the system. This stored energy is called 'energy' or 'internal energy' of the system. One can write 1st law for process as

$$Q - W = \Delta E \tag{1.6}$$

Where ΔE is change in energy of the system. Energy (E) is a property of the system.

Equation 1.11 is generally written in the form

$$Q = \Delta E + W \tag{1.7}$$

Unit of ΔE must be same as that of Q and W and it is Joule or kJ.

From the sign convention of heat transfer and work transfer one can derive the sign convention of ΔE, that is, if ΔE is +Ve, internal energy of system increases and if ΔE is –Ve, internal energy of the system decreases.

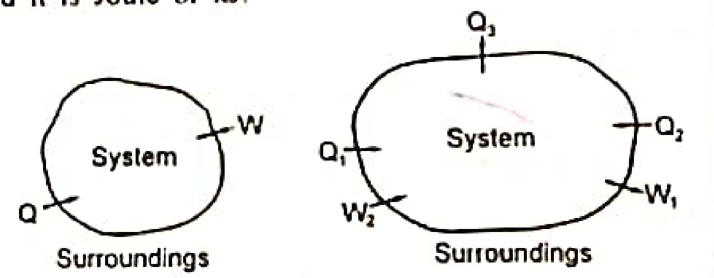


Fig. 1.11 Closed system under goes a change of state

If system involves more than one heat transfers and work transfers, first law can be written as (refer figure 1.11)

$$(Q_1 + Q_2 - Q_3) = \Delta E + (W_1 - W_2) \tag{1.8}$$

Thus in any process energy is conserved. The 1st law is also known as "law of conservation of energy".

When open system executes a process such that there is no change in any property of the system with respect to time, the process is called steady flow process.

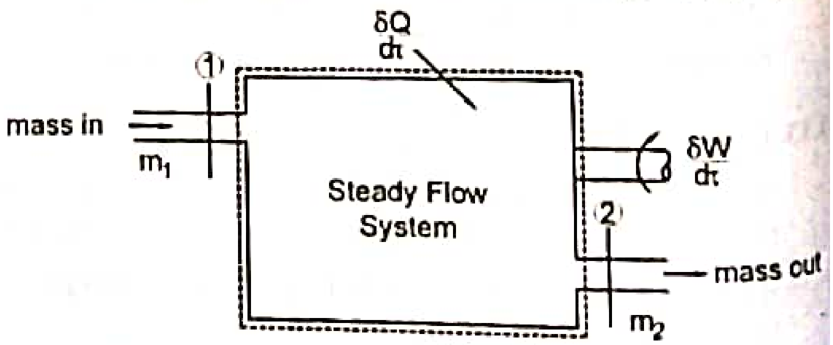


Fig. 1.12 An open system under goes a steady flow process

Following quantities are defined, subscript (1) and (2) corresponds to inlet and outlet section.

A_1, A_2 – Cross section area, m^2

p_1, p_2 – Pressure (absolute) N/m^2

m_1, m_2 – Mass flow rate, kg/s

v_1, v_2 – Specific volume m^3/kg

u_1, u_2 – Specific internal energy, J/kg

C_1, C_2 – Velocity, m/s

h_1, h_2 – Specific enthalpy J/kg

Z_1, Z_2 – Elevation above the reference datum, m

$\frac{\delta Q}{d\tau}$ – Net rate of heat transfer from system J/s

$\frac{\delta W}{d\tau}$ – Net rate of work transfer by system J/s

First law applied to steady flow process can be written as follow which is known as Steady Flow Energy Equation (SFEE).

$$m_1\left(h_1 + \frac{C_1^2}{2} + gz_1\right) + Q = m_2\left(h_2 + \frac{C_2^2}{2} + gz_2\right) + W \text{ (unit of each term is J/s)} \quad (1.9)$$

For unit mass flow rate:

$$h_1 + \frac{C_1^2}{2} + gz_1 + Q = h_2 + \frac{C_2^2}{2} + gz_2 + W \text{ (unit of each term is J/kg)} \quad (1.10)$$

SOLVED PROBLEMS

Prob. 1 : A cycle consists of four processes and heat transfer during process were + 84 kJ, – 8.4 kJ, –21 kJ and + 4.2 kJ Calculate net work done of the cycle.

Solution : For cycle we can first law

$$\oint \delta Q = \oint \delta W$$

$$\therefore \oint \delta W = +84 - 8.4 - 21 + 4.2$$

$$= 58.8 \text{ kJ} \quad \text{(by the system.)}$$

Prob. 2 : In a compression process 3kJ of mechanical work is supplied to 5 kg of working substance. The heat rejected to the cooling jacket is 700 J. Calculate the change in specific energy.

Solution : From the first law we can write

$$Q = W + \Delta U$$

$$\therefore -700 = -3000 + \Delta U$$

$$\therefore \Delta U = 2300 \text{ J}$$

$\therefore$ Change in specific internal energy

$$\Delta u = \frac{2300}{5} = 460 \text{ J/kg}$$

Prob. 3 : A certain quantity of air undergoes a change of state in such a way that 50 kJ of heat is transferred to the system. For this change of state, work produced is 40 kJ. Calculate the change in its internal energy. Assume that the process is non-flow.

Solution : For a non flow process, first law can be written as

$$Q = W + \Delta U$$

$$\therefore 50 = 40 + \Delta U \Rightarrow \Delta U = 10 \text{ kJ}$$

Prob. 4 : A gas enters a system at an initial pressure of 0.5 MPa and flow rate of 0.15 m³/s and leves it at a pressure of 0.95 MPa and flow rate of 0.09 m³/s. During the passage through the system, there is increase in internal energy of 22 kJ/sec. Calculate the change in enthalpy of the gas.

Solution : Given : $p_1 = 0.5$ MPa $\quad V_1 = 0.15$ m³/s

$p_2 = 0.95$ MPa $\quad V_2 = 0.09$ m³/s $\quad \Delta U = 22$ kJ/s

Enthalpy is defined by

$$H = U + pV$$

$$\therefore H_2 - H_1 = (U_2 - U_1) + (p_2V_2 - p_1V_1)$$

$$= 22 + (0.95 \times 10^3 \times 0.09 - 0.5 \times 10^3 \times 0.15)$$

$$= 22 + (85.5 - 75) = 32.5 \text{ kJ/s}$$

Prob. 5 : An artificial satellite has a mass of 600 kg and is moving towards Moon. Calculate its kinetic and potential energies in (MJ) relative to Earth when it is 50 km from launching and moving at 2500 km/hr. Take acceleration of Earth's gravitational field as 790 cm/s^2. **(Dec. 2010)**

Solution : Given : $m = 600$ kg $\quad z = 50$ km $= 50 \times 10^3$ m

$V = 2500$ km/hr

$g = 790$ cm/s^2 $= 7.9$ m/s^2

$$\text{Kinetic Energy KE} = \frac{1}{2} mV^2$$

$$= \frac{1}{2} \times 600 \times \left(\frac{2500 \times 1000}{3600}\right)^2$$

$$= 144675925.9 \text{ J}$$

$$= \mathbf{144.68\ MJ}$$

$$\text{Potential Energy PE} = mgz$$

$$= 600 \times 7.9 \times 50 \times 10^3$$

$$= \mathbf{237\ MJ}$$

Prob. 6 : It is required to produce ice from 36°C water. The capacity of the ice plant is 6 TR and specific heat of the water is 4.18 kJ/kgK. Determine the amount of ice produced in 3 hours. **(Summer 2019)**

Solution : Given : $T_w = 36°C$ capacity of ice plant = 6 TR

$C_{pw} = 4.18$ kJ/kgK $m_{ice} = ?$ time = 3hr = 3 × 3600 s

Note : Ton of refrigeration (TR) is unit of refrigeration. It is define in section 10.3

1 TR = 3.52 kW

To produce the ice from water, first one needs to reduce the temperature of water up to its freezing point i.e. 0°C, then latent heat is removed at 0°C to have complete conversion of water into ice. In present case, final temperature of ice is not given (which may be less than 0°C) so it is assumed that final temperature of ice is 0°C. Latent heat of ice at 0°C, $h_{sf} = 335$ kJ/kg

From energy balance one can write

$$\text{Heat removed by ice plant} = m_{ice}\left[C_{pw}(T_w - 0°C) + h_{sf}\right]$$

$$\therefore\ 6 \times 3.52 \times 3 \times 3600 = m_{ice}\,[4.18\,(36) + 335]$$

$$\therefore\ m_{ice} = 470 \text{ kg}$$

Prob. 7 : Calculate the energy consumed in one month for following conditions: **(Summer 2019)**

COP of air-conditioning unit : 5

Capacity of air conditioner : 2 TR

No of air conditioners : 8

All air conditioners run for 4 hours/day.

Solution : Given : COP = 5 $\quad$ Capacity of air condition = 2 TR

No. of AC = 8 $\quad$ AC usage 4 hr/day

Monthly energy consumption = ?

Note : COP of refrigeration and air conditioning systems is define in section 10.1. It is defined as

$$\text{COP} = \frac{\text{Refrigerating effect}}{\text{Work supplied}}$$

Work supplied for one air conditioner having capacity of 2 TR and COP = 5 is

$$W = \frac{2 \times 3.52}{5} = 1.408 \text{ kW}$$

∴ Monthly energy consumption for 8 AC used for 4 hr/day

$$= 1.408 \times 8 \times 4 \times 30$$

$$= 1351.7 \text{ kWh}$$

It may be noted that kWh is a unit of electricity consumption

EXERCISES

1. **Define the following terms :**

(a) prime movers	(b) force	(c) mass
(d) pressure	(e) work	(f) power
(g) energy	(h) temperature	(i) specific heat
(j) enthalpy	(k) internal energy	(l) system
(m) boundary	(n) surrounding	(o) property
(p) control volume	(q) control surface	(r) heat
(s) latent heat	(t) heat capacity	(u) flow work
(v) density	(w) vacuum	(x) potential energy
(y) kinetic energy	(z) steady flow process.	

2. **Differentiate :**
   (a) Open, Close and Isolated system
   (b) Intensive and Extensive property
   (c) Heat and Work
   (d) Absolute pressure and Gauge pressure

3. State Zeroth law of thermodynamics ?

4. Why gases have two specific heats ?

5. How prime movers are classified ? What are different sources of energy used by them ?

6. Write steady flow energy equation ? Explain each of its terms.

PROBLEMS

In a system 45 kg/s of working fluid enters with 10 m/s velocity and leaves with 19 m/s velocity. The system receive 46 kJ/s of heat and does 15 kW of work. The outlet is 30 m above the inlet. Calculate change in specific enthalpy of working fluid. [Ans. $h_2 - h_1 = 0.254$ kJ/kg]

The density of mercury is 13600 kg/m³. Calculate the pressure due to 600 mm of Hg in kPa and bar. [Ans. 80.05 kPa, 0.8005 bar]

3. A copper ball moving with 550 m/s is brought to rest suddenly. Assuming that 50% of its energy is transferred into heat, find rise in temperature of copper ball. Specific heat of copper ball is 0.394 kJ/kg K. [Ans. 192°C]

4. A piece of iron ball of mass 10 kg is heated to 105°C and dropped into vessel having 25 kg of water at 20°C. What is specific heat of iron, if the rise in water temperature is 7.2°C when water and iron ball attain same temperature? [Ans. 0.969 kJ/kg K]

5. Determine temperature rise of water when it falls from a height of 150 m. Assume the system of water to be adiabatic. Take c_p of water = 4.187 kJ/kg K. [Ans. 0.351°C]

6. Calculate amount of heat required to raise the temperature of 5 kg of water from 30°C to 90°C. Take c_p of water = 4.187 kJ/kg K. [Ans. 1256.1 kJ]

7. A storage battery of 24 V draws current of 10A for an hour. The decrease in stored energy is 900 kJ. Calculate rate of heat transfer from the battery. [Ans. 10W]

8. A tank contain 50 kg of fluid (c_p = 3.7 kJ/kg K) at 46°C. The fluid is stirred by a paddle wheel which consumes 200 kJ work while the tank has 650 kJ of heat interaction with ambient which is at 30°C. Calculate final temperature of the fluid. [Ans. 43.57°C]

9. A non flow system has work input of 30 kJ and heat rejection of 45 kJ. Calculate change in internal energy of the system. [Ans. –15 kJ]

OBJECTIVES TYPE QUESTIONS

1. Choose correct statement for close system.

   (a) mass does not cross the boundary but energy transfer can takes place

   (b) both mass and energy can cross the boundary of system

   (c) mass can cross the boundary of system but no energy transfer across the system boundary

   (d) neither mass nor energy can cross the boundary of a system

2. Choose correct statement for open system.

   (a) mass does not cross the boundary but energy transfer can takes place

   (b) both mass and energy can cross the boundary of system

   (c) mass can cross the boundary of system but no energy transfer across the system boundary

   (d) neither mass nor energy can cross the boundary of a system

3. For isolated system ________ can cross the boundary of system.

   (a) only mass (b) only energy

   (c) both mass and energy (d) neither mass nor energy

4. Which one of the following is an extensive property ?

   (a) pressure (b) temperature

   (c) density (d) energy

5. Which one of the following is an intensive property ?

(a) energy (b) enthalpy

(c) density (d) entropy

6. Well insulated rigid vessel contains air and an electric resistor. If air is heated by supplying current through resistor, for the system.

(a) both heat and work transfer is zero

(b) both heat and work transfer is positive

(c) heat transfer is positive and work transfer is zero

(d) heat transfer is zero and work transfer is negative

7. Temperature measurement by mercury in glass thermometer is based on

(a) zeroth law (b) first law

(c) zeroth and first laws both (d) None of above

8. First law for a close system which execute a process can be written as

(a) $\delta Q = \delta W$ (b) $Q = \Delta U + W$

(c) $Q + h_1 = W + h_2$ (d) $W = h_1 - h_2$

9. When 'path' is completely specified it is called

(a) change of state (b) process

(c) cycle (d) None of above

10. Pick up odd one

(a) heat (b) work (c) internal energy (d) pressure

11. In a compression process if work done on the 2 kg of gas equals to 10 kJ and 2 kJ of heat is rejected, change in specific internal energy of gas equals to

(a) 8 kJ (b) −8 kJ (c) 4 kJ (d) 2 kJ

12. Unit of mechanical power is ________. **(January 2011)**

(a) Joule (b) Watt (c) Pascal (d) Newton

13. 1 bar = ________ N/m^2. **(January 2011)**

(a) 10^3 (b) 10^5 (c) 10^{-3} (d) 10^{-5}

14. Barometer is used to measure ________. **(January 2013)**

(a) Pressure (b) Temperature (c) Electrical Energy (d) Force

15. The sum of internal energy (U) and the product of pressure and volume (p.v) is known as **(Winter 2016)**

(a) workdone (b) entropy (c) enthalpy (d) heat

16. In an isolated system, what transfer? (Summer 2017)

(a) mass (b) energy (c) both mass and dnergy (d) neither mass nor energy

17. Which of the following is a path function? (Summer 2017)

(a) heat (b) temperature (c) pressure (d) volume

18. In a compressor, the work done is 200kJ and heat rejected to the surrounding is 50kJ. The change in internal energy is (Winter 2017)

(a) 150kJ (b) 250kJ (c) 4kJ (d) 10000kJ

19. Which law gives the definition of temperature? (Summer 2018)

(a) Planck Law (b) Charle's law (c) Avogadro law (d) Zeroth law of thermodynamics

20. Which of the following is high grade energy? (Winter 2017)

(a) work (b) heat (c) chemical energy (d) none of above

: ANSWERS :

1. (a)	2. (b)	3. (d)	4. (d)	5. (c)	6. (d)	7. (a)	8. (b)	9. (b)	10. (d)
11. (c)	12. (b)	13. (b)	14. (a)	15. (c)	16. (d)	17. (a)	18. (a)	19. (d)	20. (a)

❖ ❖ ❖

2

ENERGY

2.1 INTRODUCTION

Energy is the ability or capacity to do work. Energy may be available in stored form (potential energy) or working form (kinetic energy). The energy in food, water stored in reservoir of a dam or in battery is potential energy. The energy in flowing wind or river is kinetic energy. Chemical energy, heat (thermal) energy are low grade energy, while mechanical energy (work) and electrical energy are high grade energy. The high grade energy can be fully converted to low grade energy but the reverse is no true.

Before industrial revolution (Around 1700 AD when steam engine was invented), energy needs of human being were small. They were mainly fulfilled usingenergy from plants and animals. Solar energy was used for some basic drying and heating needs at home and in farms. Wind mills were used in different parts of world for grinding and running water-wheels. The fossil fuel era started with invention of IC engine (1870 AD) along with expansion of mining activity for coal as well as drilling and refining technology for oil.Fossil fuels like coal and petroleum products are concentrated forms of energy andcan be easily transported. They became very convenient form of energy for mankind. Building of central power stations using fossil fuels or hydro energy and development of infrastructure for supply and transmission of electrical energy made electrical energy available at our doorsteps. This was a giant leap forward in convenience of use and abundance of energy for mankind. Nuclear energy came on the scene after the Second World War. Nuclear energy provides small but significant amount of energy requirements of many countries of the world.

Extensive use of various forms of energy has helped to improve quality of life of humankind to a great extent. In fact, per capita energy consumption is many times used as a measure of development of a country. **Fig. 2.1** shows comparison of per capita energy consumption of various countries of the world in terms of kg of oil. It is seen that this number is one of the lowest for India. Per capita energy consumption of China is more than three times that of India and it is more than eleven times in case of USA. This data indicate two things: one, many people in India still do not have proper availability of electricity and two, our standard of living is still much lower than developed countries in the world. India in fact needs add large generation capacity in order to continue its economic growth.

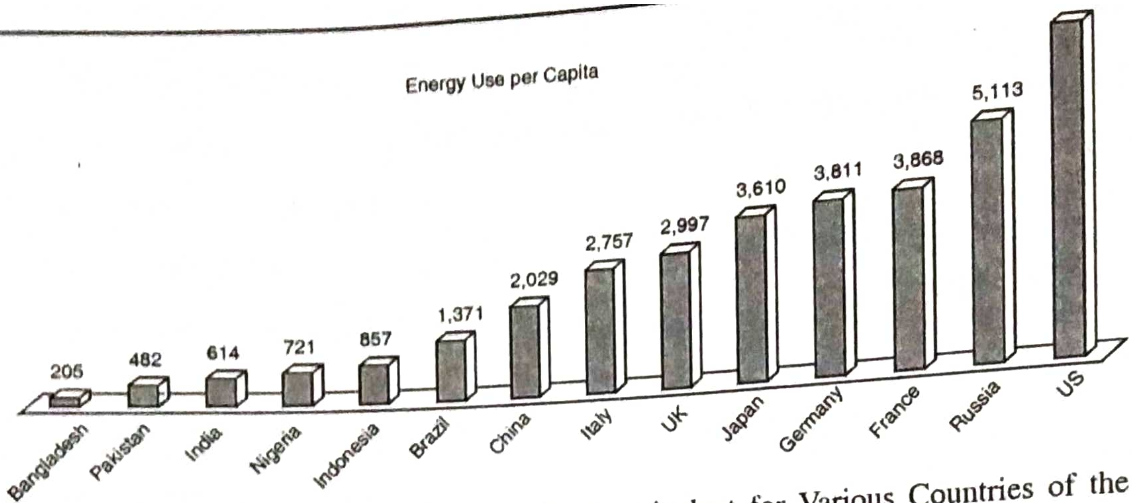


Fig. 2.1 : Per Capita Energy Consumption kg of oil equivalent for Various Countries of the World; $1 \; kg \; of \; oil \; equivalent = 41.87 \; MJ \; or \; 11.63 \; kWh$

Higher energy consumption is considered sign of development, butlavish use of energy has created concerns related to depletion of fossil fuels and environmental pollution. As availability of given source of fuel reduces, its prices start increasing rapidly; which can adversely affect the economy. Pollution and greenhouse effect has started degrading the environment, which is the foundation of life. This situation has forced us to look at energy usage and energy resources with fresh perspective. We need explore sources of energy that are renewable and environment friendly. We also need to rationalize the use of energy and reduce wastage of energy. Under this scenario, study of energy and its sources has become very important.

2.2 VARIOUS ENERGY SOURCES AND ENERGY SCENARIO

Energy sources may be divided into two groups: **renewable and non-renewable**. If recreation of given amount of energy takes much longer period as compared to its consumption period; the source is considered to be non-renewable. Fossil fuels like coal and oil fall under this category as their creation has taken millions of years, while we are using them at a very high rate. The annual cycle of evaporation of seawater, cloud formation and rain-fall is responsible for availability of potential energy in form of water stored at a height at a dam site. So, hydro-power can also be called renewable source, though it is a conventional or well-established technology for power productionnow. Solar energy and wind energy are considered as renewable sources of energy as their use does not deplete them. Biomass energy can be re-created in short period of timeby plantation or may be available from waste. So, biomass energy is also a renewable energy source. Electrical energy and hydrogen gas as fuel are **secondary forms of energy**, which are derived from primary sources of energy.

Fig. 2.2 shows contribution of various sources of energy in **total primary energy consumption** in the world for year 1973 and year 2015 in Milliions of Tonnes of Oil Equivalent, ***Mtoe*** (1 tonne = 1000 kg). The world primary energy consumption has increased from 3740 Mtoe to 5269 Mtoe, which is a rise of around 41% in above period. The rise is due to growing population of the world and expanding economies of developing countries. As seen from the chart for 2015 AD; oil, coal and natural gas are the major contributors with 36.1,26.0 and 18.0% contribution. They are followed by nuclear energy, bio-fuels and waste and hydro energy in that order. Though the contribution of other sources (mainly renewable energy sources like wind energy, solar energy and geothermal energy) is still very small (around 2.1%). It is expected to rise very rapidly in future.

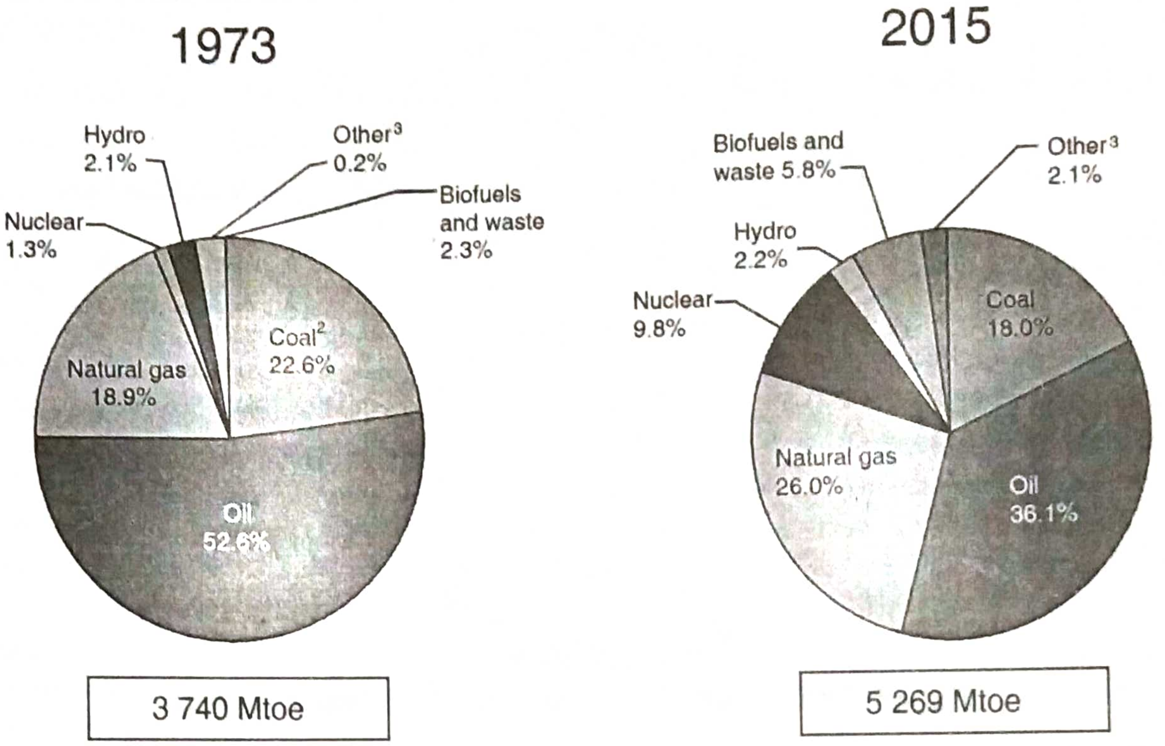


Fig. 2.2 World Total Primary Energy Consumption Division in Million Ton Oil Equivalent (Mtoe)(Source: IEA)

Fig. 2.3 shows contribution of various energy sources of energy for electrical power generation for year 1973 and 2014. Electrical power generation has increased by almost 300% from 6131 TWh to 23816 TWh (TWh is terawatthour, i.e. 10^6 kWh). As per 2014 scenario, coal, natural gas and hydroelectric energy contribute 40.8%, 21.6% and 16.4% to the total electrical power generation. Nuclear power comes fourth with significant contribution of 10.6%. Other sources, mainly renewables, contributed just 0.6% in 1973 but contributed 6.3% in total electrical power generation in 2014 AD. Thus, renewable energy has started showing its presence and importance now.

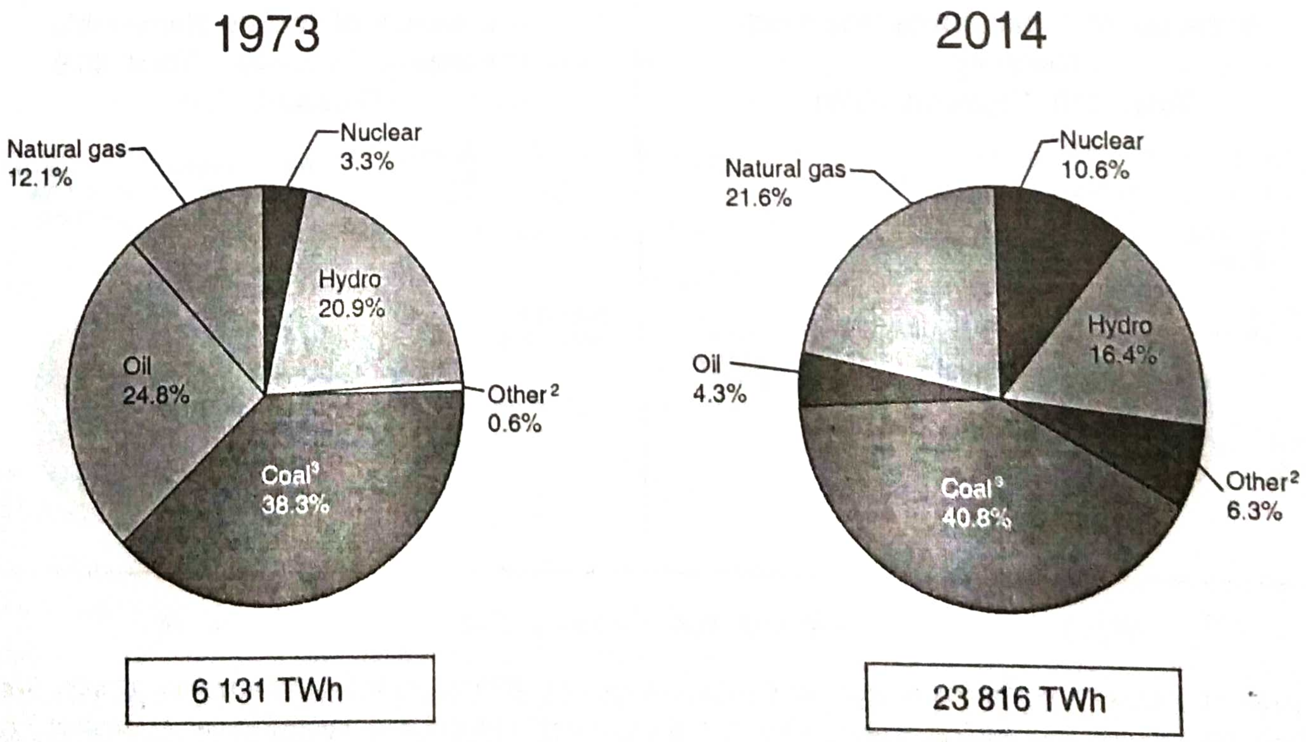


Fig. 2.3 Contribution of Energy Sources for Electrical Power (Source: IEA)

Fig. 2.4 shows contribution of various energy sources to total primary energy consumption in India. Coal/ Peat contribute highest at 40.8%, but the contribution from combustible biomass and waste is also very significant at 27.2%. Oil which is mainly used in transportation contributes 23.7%. Other renewables contribute only 0.2% out of the total energy consumption.

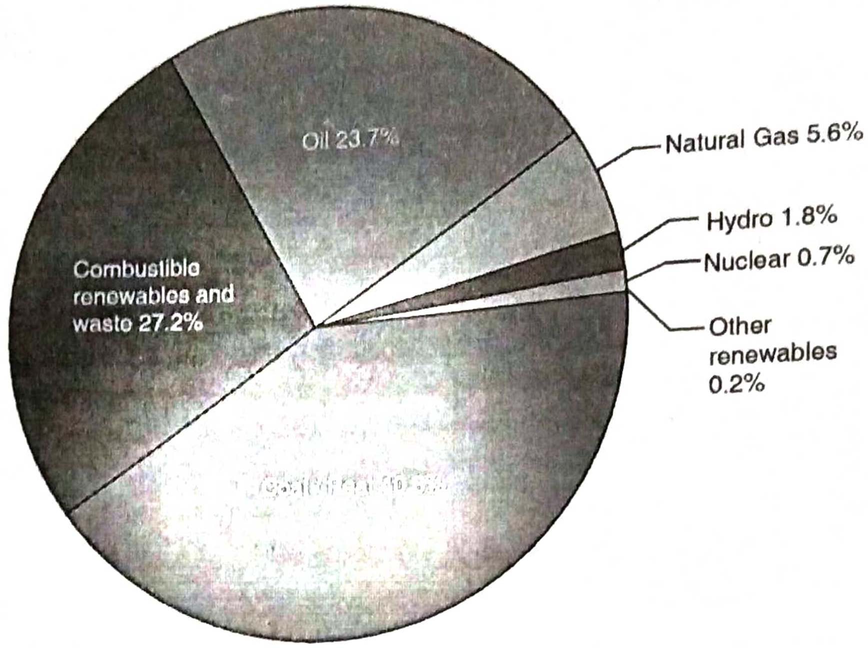


Fig. 2.4 Total Primary Energy Consumption by Sources in India

The total installed capacity of power plants in India is around 310 GW. Fig. 2.5 shows contribution of various energy sources for electrical power generation capacity. Thermal power plants which mainly use coal, contribute around 190 GW (61%) capacity. Renewableenergy sources contribute 45.9 GW (15%) capacity. Among renewable energy sources, wind energy contributes highest 28.1 GW (61.2%) capacity, while solar and biomass are second and third respectively at 18.5% and 10.6% contribution. Small hydro power plants are considered to be renewable sources here, while large hydro power plants are not considered to be renewable source. Small hydro power plants contribute around 4.3 GW (9.4%) capacity. There are plans to increase renewable energy power production to 175 GW by 2022.

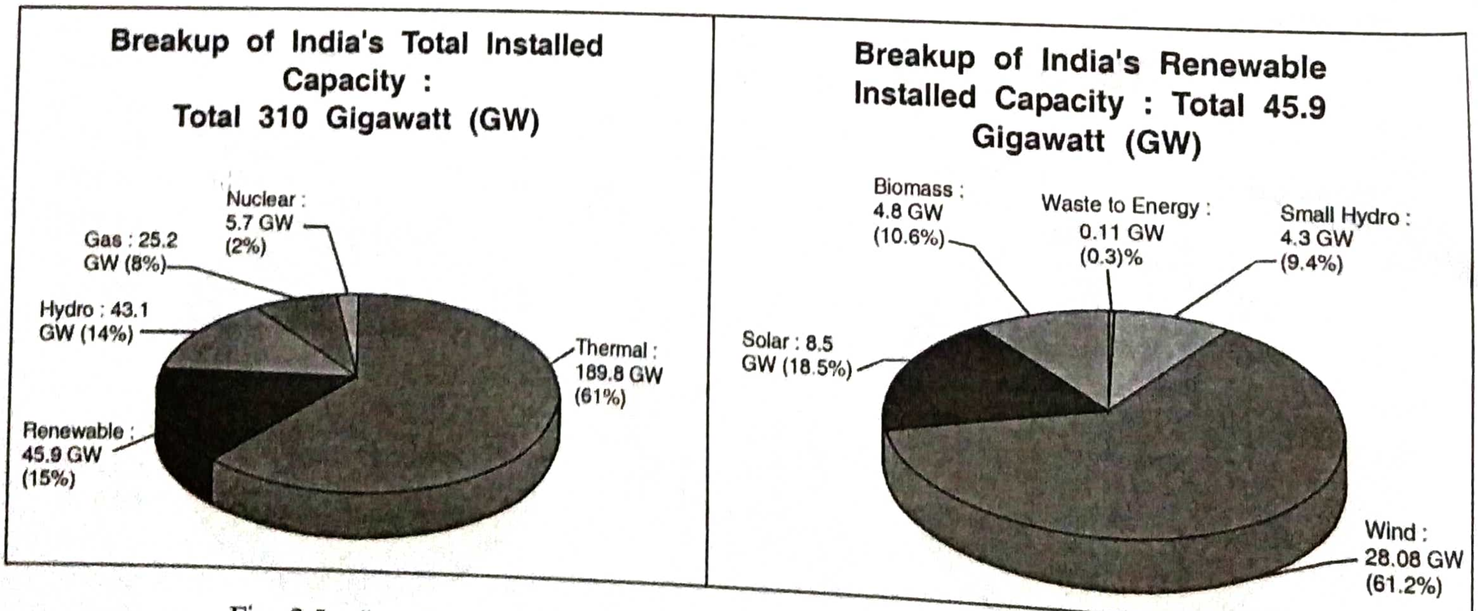


Fig. 2.5 : Installed Capacity of Power Plants in India (Total and Renewable)

Now, we will discuss various sources of energy one by one; starting with the conventional sources like fossil fuels, hydropower and nuclear power. After that, the non-conventional and renewable energy sources like solar energy, wind energyand bio-mass energy will be discussed.

2.3 FOSSIL FUELS

Coal, oils and natural gas have been formed from organic remains of pre-historic plant and animals laid down below earth's crust. So they are called fossil fuels.

2.3.1 Solid fuels

(1) **Wood :** Wood has been used as a fuel from ancient times. It is still used extensively in countries where forests exist and other sources are not readily and cheaply available. It has low calorific value. Ease of ignition, free burning quality and absense of ash disposal problems are the points of advantage for wood.

(2) **Charcoal :** It is the solid product of the carbonisation of wood. Charcoal also results from the incomplete burning of wood. Wood charcoal is a source of fairly pure carbon. It easily ignites and burns at low rates. It is extensively used as a fuel in blacksmiths' and metalworkers' forges and for numerous other cottage industries.

(3) **Peat :** It is a naturally occuring solid fuel consisting of partly decomposed plant material below ground. It is not recognized as coal but represents the first stage in the conversion of vegetable matter into coal. Peat is largely used in steam boilers, power stations and gas producers. The low temperature carbonisation of peat is practised for getting peat coke and by–products. Peat–coke is a valuable fuel for some metallurgical processes.

(4) **Coal :** Coal is fossil fuel laid down from moist vegetable matter and compacted under pressure and temperature within the surface of earth. It is most widely used of all commerical fuels for heat and electricity generation. Approximately 41% of the world electricity production uses coal. Coal constitutes 18% primary energy consumption in world. Coal is very widely used in steel production, cement, paper, chemical and pharmaceutical industries. There are environmental issues related to coal mining and burning of coal like emission of sulfur dioxide and fly ash. So use of coal is being discouraged, but it is still one of the most important fuels. Coal is generally classified into following categories:

(i) **Lignite** is inferior coal because of high ash content, high moisture content, low calorific value, small size and bad weathering properties. Lignite can be used in generation of electricity in thermal power stations, producing carbonised briquettes (lumps) which are used as smokeless fuel, making producer gas and in metallurgical furnaces.

(ii) **Bituminous coal** is denser and harder than lignite. Owing to the good heating qualities and ease of handling, it is major fuel in most countries for industrial furnaces, boilers and thermal power plants. Other important uses are carbonisation and gasification whereby coal is converted into solid fuels like coke, liquid fuels like coal tar or gaseous fuels like producer gas, water gas, coal gas etc.

(iii) **Anthracite** is the most mature and hard form of solid fossil fuel. It has low volatile matter, high carbon content and high calorific value. It is chief industrial fuel used in boilers and metallurgical furnaces.

2.3.2 Liquid fuels

Petroleum (crude) oil is generally considered to be formed from animal and vegetable debris accumulating in sea basins and buried there by sand and silt. The chemical structure of petroleum is composed of hydrocarbon chains of different lengths. Because of this, petroleum may be taken to oil refineries and the hydrocarbon chemicals separated by distillation and treated by other chemical processes, to be used for a variety of purposes. According to crude oil composition and demand, refineries can produce different shares of petroleum products. Largest share of oil products is used as energy carriers : various grades of fuel oil and gasoline. Refineries also produce other chemicals, some of which are used in chemical processes to produce plastics and other useful materials. Since petroleum often contains a couple of precent sulfur, large quantities of sulfur are also often produced as a petroleum product. Hydrogen and carbon in the form of petroleum coke may also be produced as petroleum products. The hydrogen is often used as an intermediate product for other oil refinery processes such as hydrogen catalytic cracking (hydrocracking) and hydrodesulfurization.

The petroleum products are very widely used as energy source in transportation sector, industry and electricity generation. There are many other byproducts which have become essential part of our daily life (plastics, fibres, colours, lubricants, so on and so forth). The excessive use of petroleum is also responsible for pollution and global warming.

Liquid fuels may be divided into two main classes based on their utilization :

(1) Light Oils or Spirits :

They are suitable for use with internal combustion engines and jet engines. They include :

(a) The lighter, more volatile fractions obtained by distilling or cracking natural petroleum oils or shale oils.

(b) The light fractions obtained by the hydrogenation of coal, coal tar or heavy oils.

(c) The light fractions obtained by the synthesis of hydrocarbons.

(d) Alcohols

(e) Benzole,

Gasoline or Petrol is the lightest fraction derived from petroleum oils and is distilled in lowest temperature range. The temperature ranges of other products, Naphtha, Kerosine and Gas oil can also be seen from the A.S.T.M. distillation curves.

Shale oils are derived from oil shales (soft, slate like rocks). Benzole is obtained by distillation of coal tar gas. Methayl alcohol is produced by synthesis ($2H_2 + CO = CH_3OH$) while Ethyle alcohol is produced by fermentation of sugars followed by fractional distillation of the product.

Of the above, the most volatile and cleanest products : gasoline (petrol), benzole and alcohol are suitable for spark ignition engine. The next higher fractions of petroleum oil, shale oil and synthetic oil, generally included in the class of oils known as paraffin, kerosine or naptha are suitable for jet engines. The remainder of the lighter fractions of distillation of petroleum oil, shale oil and synthetic oil are suitable for diesel engines, combustion in small furnaces or combustion appliances.

(2) Furnace Oils :

These include the heaviest grades of natural petroleum oils, or cracked oils from which the more valuable engine oil and lubricating oil fractions and bitumen have been removed. They also include less valuable, heavier products of distillation or hydrogenation of coal or synthetic oils.

Advantages of Liquid Fuels Over Coal :

(1) Oil can be handled more readily than coal. Pumps, pipes and controls are easier and cheaper than cumbersome equipment required for handling coal.

(2) Oils have higher calorific value and can be burnt at higher combustion rate. This enable much greater furnace outputs.

(3) The combustion of oil fuel can be regulated and varied more easily.

(4) Oils contain extremely small proportions of ash.

Advantages of Coals Over Oils :

(1) No special provision need to be made for storage. Any hard flat surface will be sufficient.

(2) Coal may be converted on site to the convenient pulverised form, which can be easily and rapidly burnt and controlled.

(3) Coal is more economical than oil in India.

2.3.3 Gaseous fuels :

They may be classified into Natural Gas, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG) and Manufactured gases.

2.3.1.1 Natural Gas :

Natural gas is a combustible mixture of hydrocarbon gases. Natural gas mainly contains methane, but it can also include ethane, propane, butane and pentane. Natural gas may be described as the fossil fuel of the 21^{st} century.

Found in reservoirs underneath the earth, natural gas is commonly associated with oil deposits. Production companies search for evidence of these reservoirs by using sophisticated technology that helps to find the location of the natural gas and drill wells in the earth where it is likely to be found. Once brought from underground, the natural gas is refined to remove impurities like water, other gases, sand and other compounds. After refining, the clean natural gas is transmitted through a network of pipelines.

- Natural gas is considered 'dry' when it is almost pure methane, having had most of the other commonly associated hydrocarbons removed. When other hydrocarbons are present, the natural gas is 'wet'. Some hydrocarbons are removed and sold separately, including propane and butane.
- Natural gas is colourless and odourless in its pure form.
- Unlike other fossil fuels, natural gas is clean burning and emits lower levels of potenitally harmful byproducts into the air.

Use of Natural Gas :

(1) For cooking, air heating and water heating in residences.

(2) It is used for air conditioning in absorption and desiccant technology based air conditioning plants.

(3) It is used as fuel in internal combustion engines (I.C. engines), microturbines and fuel cells for small–scale power generation. The exhaust can be utilized for space heating and cooling. Such systems are cogeneration or combined heat and power (CHP) systems Such system are known as cogeneration.

(4) It is also used as fuel in central and captive power plants for electricity generation.

(5) Natural gas is consumed in the pulp and paper, metals, chemicals, petroleum refining, stone, clay and glass, plastics and food processing industries.

2.3.1.2 Compressed Natural Gas (CNG) :

Compressed Natural Gas (CNG) is made by compressing natural gas (which is mainly composed of methane (CH_4), to less than 1% of its volume at standard atmospheric pressure. It is stored and distributed in hard containers, at a normal pressure of 200–220 bar (20–22 MPa), usually in cylindrical or spherical shapes. In response to high fuel prices and environmental concerns, compressed natural gas is now being used in auto-rickshows, cars and buses as a substitute for gasoline (petrol) or diesel.

- CNG cylinders can be made of steel, aluminium or plastic. Light weight composite (fibre-wrapped plastic) cylinders are especially beneficial for vehicular use because they offer significant weight reductions and consequent lower fuel consumptions, when compared with earlier generation steel and aluminium cylinders.
- Compressed natural gas vehicles require a greater amount of space for fuel storage than conventional gasoline power vehicles.
- Natural gas is very safe. Being lighter than air, in the event of an accident natural gas simply dissipates into the air, instead of forming a dangerous flammable pool on the ground like other liquid fuels. This also prevents the pollution of ground water in the event of a spill. While CNG–powered vehicles are considered to be safer than gasoline–powered vehicles, there are concerns about how best to fight fires involving CNG vehicles.
- Some natural gas vehicles that exist today are bi-fuel vehicles, meaning they can use gasoline or natural gas, allowing for more flexibility in fuel choice. Many of these vehicles, which were originally gasoline

only, have been converted to allow the vehicle to run on either fuel. This conversion is costly and typically results in less efficient use of natural gas.

- Natural gas vehicles are much cleaner burning than traditionally fueled vehicles due to the chemical composition of natural gas. While natural gas is primarily methane, gasoline and diesel fuels contain numerous other harmful compounds that are released into the environment through vehicle exhaust. While natural gas may emit small amounts of ethane, propane and butane when used as a vehicular fuel, it does not emit many of the other, more harmful substances emitted by the combustion of gasoline or diesel. These compounds include volatile organic compounds, sulfur dioxide and nitrogen oxides (which combine in the atmosphere to produce ground level ozone), benzene, arsenic, nickel and over 40 other substances classified as toxic.

2.3.1.3 Liquefied Petroleum Gas (LPG) :

Liquefied Petroleum Gases are mixtures of hydrocarbons, which are gaseous at normal ambient temperature and atmospheric pressure, but can be liquefied at normal ambient temperature by application of moderate pressure.

Varieties of LPG bought and sold include mixes that are primarily propane, mixes that are primarily butane and the common, mixes including both propane (60%) and butane (40%), depending on the season–in winter more propane, in summer more butane.

- LPG is manufactured during the refining of crude oil or extracted from oil or gas streams as they emerge from the ground.
- It is a clean burning, non-poisonous, dependable, high calorific value fuel.
- At normal temperature and pressures, LPG will evaporate. Because of this, LPG is supplied in pressurised steel bottles. In order to allow for thermal expansion of the contained liquid, these bottles are not filled completely; typically, they are filled to between 80% and 85% of their capacity.
- LP gases are drawn out in form of gas. They will burn only when mixed with air in certain proportions. The minimum and maximum concentrations of a fuel gas in a gas/air mixture between which the mixture can be ignited are termed as the over and upper limit of inflammability. The lower flammability limit for LPG is 2% and the higher limit is 8.5%.
- LPG in gaseous state is nearly twice as heavy as air. Any leakage of LPG, therefore, tends to settle down at floor level. Pure LPG is colourless and odourless. The leakage of liquid LPG is therefore very dangerous. A powerful odourant, ethanethiol is added so that leaks can be detected easily.
- LPG contains no toxic components such as carbon monoxide and is, therefore, non–poisonous.

When LPG is used to fuel internal combustion engines, it is often referred to as *autogas*. In some countries, it has been used since the 1940s as an alternative fuel for spark ignition engines. More recently, it has also been used in diesel engines. Its advantage is that it is non–toxic, non–corrosive and free of tetra-ethyl lead or any additives and has a high octane rating. It burns more cleanly than petrol or diesel and is especially free of the particulates from the latter.

There are two disadvantages. Firstly it has a lower energy density than either petrol or diesel, so the equivalent fuel consumption is higher, but since many governments impose less tax, it is still usually more cost effective. Secondly, some designs of internal combustion engine require the lubrication of petrol or diesel with lead or lead substitute and LPG's lack thereof can damage valves or shorten their life. Engines designed for unleaded fuel, equipped with hardened valve seats are suitable for use with LPG without added upper cylinder lubrication.

2.3.4 Manufactured Gases :

They are produced by doing different chemical and physical processes on primary fuels. The following table shows different primary fuels, processes, product gaseous fuel and its application.

Raw material	Process	Product	Application
Wood	distillation or carbonization	Wood gas	Not of much commercial interest
Peat	"	Peat gas	Heating the ovens
Coal/Coke	Carbonization	Coal gas (town gas)	For street and domestic lighting in towns, for cooking and in ga engines.
	Gasification (in air)	Producer gas	In steel industries for firing open-hearth furnace
	Gasification (in air and steam)	Water gas	Used in furnaces and for welding gas
	by-product of the reduction of ores	Blast furnace gas	For metallurgical processes
Natural gas / Refinery gases	liquification of propane and butane	Liquified petroleum Gases	Excellent fuel for combustion appliances in industries, Spark Ignition Engines. Domestic appliances
Natural gas	Steam reforming		Fuel cells, IC engine etc.

Hydrogen gas as fuel is considered as an important secondary fuel. Major **advantage** with hydrogen as fuel is that when combined with oxygen, it produces water unlike fossil fuels which produce pollutants. Its calorific value per unit mass is higher than the petroleum oils, almost three times of gasoline! The **disadvantages** are that it burns readily when come in contact with oxygen in air. Its specific volume is very large in gaseous form. If stored in liquid form, it would need a very low temperature (cryogenic) storage vessel.

Today almost all of world's **hydrogen is produced by steam reforming of natural gas**, which is an endothermic process. At temperatures between 700 to 1100°C, steam reacts with the methane in natural gas and yield mixture of carbon monoxide and hydrogen. By this method, energy consumed is more than that is supplied by hydrogen gas later on. Thus, hydrogen gas may be called energy carrier rather than energy source. Efforts are in progress to produce hydrogen gas by thermo-chemical, photo-chemical and biological methods. Hydrogen gas can be used in fuel cells and engine-generator sets to produce electrical energy. It can also be used in I.C. engines to run motor vehicles.

2.3.4.1 Advantages of Gaseous Fuels :

(1) Gas is clean in operation and use. Does not produce dust or ash.

(2) It pollutes the atmosphere less. It has low sulfer content.

(3) Handling is easier and can be automatised.

(4) No storage problems as gas is delivered by underground pipes.

2.3.4.2 Disadvantages of Gaseous Fuels :

(1) Gas is more difficult to transport by pipeline than oil.

(2) They are readily inflammable.

(3) Liquefied gases require either of high pressure or low temperature insulated tanks, which are expensive.

2.4 NUCLEAR POWER

2.4.1 The Technology :

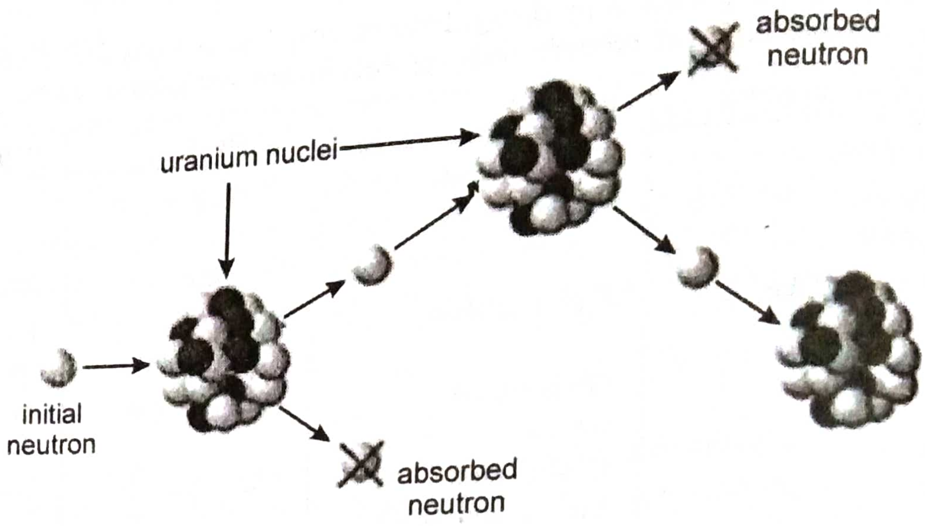


Fig. 2.6 : Controlled Chain Reaction in Nuclear Reactor

Nuclear power can be developed by **fission** (splitting into two atoms from one atom) or **fusion** (joining of two atoms into one) reactions in nuclear reactors in controlled environment. Several fusion reactors have been built, but still remain at experimental stage. When a large fissile atomic nucleus such as U^{235} or Pt^{239} absorbs a neutron, it undergoes nuclear fission. The heavy nucleus splits into two or lighter nuclei (the fission products), releasing kinetic energy, gamma radiation and free neutrons. A portion of these neutrons may later be absorbed by other fissile atoms and cause further fission events, which release more neutrons, and so on. This phenomenon is known as a **nuclear chain reaction**. Nuclear chain reaction is controlled by neutron poisons and neutron moderators that can change the portion of neutrons that will go on to cause more fission (Figure 2.6). Nuclear reactors generally have automatic and manual systems to shut the fission reaction down if monitoring detects unsafe conditions. Commonly-used moderators include regular (light) water (in 75% of the world's reactors), solid graphite (20% of reactors) and heavy water (5% of reactors). Heavy water is deuterium oxide, used as moderator in place of normal water. Though heavy water is very costly, it allows use of natural uranium, thus doing away with enrichment facility.

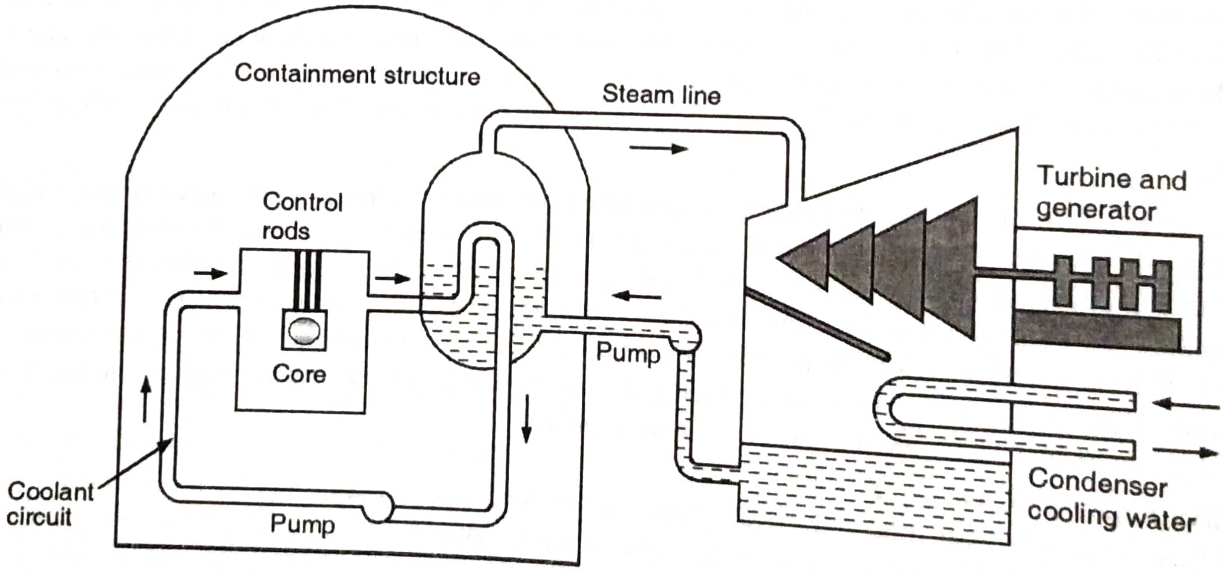


Fig. 2.7 : Nuclear Power Plant: Scheme and Components

Figure 2.7 shows **pressurized water reactor based nuclear power plant**. Pressurized water is used as coolant as well as moderator in primary circuit. This water transfers heat to water in secondary circuit and boils it, generating steam. This steam is fed to a steam turbine coupled with a generator, producing electrical energy. Steam coming out of turbine is cooled with cooling water coming from cooling tower or sea. Condensed water is recirculated in the circuit. In case of **boiling water reactor**, water boils directly in the reactor. In this plant, there is only one circuit of water in place of two in previous case.

2.4.2 Nuclear power scenario

The first nuclear power plant operation started in 1957 in USA. Initially the growth rate of this technology was very high as it was considered a clean source of energy (energy source not producing any kind of pollution).

Later on, awareness about dangers of nuclear hazard and problem of disposal of radioactive waste reduced its growth rate. The growth rate of about 24% per year during seventies, reduced to around 8% in eighties. Share of nuclear power in total primary energy sources of the world was 9.8% in 2015.

As of 2016, India has 22 nuclear reactors in operation at seven sites, having an installed capacity of 6780 MW. Eleven more reactors are under construction which have total generating capacity of 8100 MW. India is outside the Nuclear Non-Proliferation Treaty (NPT) due to its weapons program. Due to trade bans and lack of indigenous uranium, India has been developing a nuclear fuel cycle to exploit its reserves of thorium. Due to some recent developments, foreign technology and fuel are expected to boost India's nuclear power plans considerably.

The operation of the existing nuclear fleet has been constrained in the past by chronic fuel shortages, in 2008 the average load factor was as low as 40%. This constraint was eased after India became a party to the Nuclear Suppliers' Group agreement in 2008, allowing access not only to technology and expertise but also reactor parts and uranium. The average plant load factor rose to over 80% in 2013.

Though the current share of nuclear power in the generation mix is relatively small at 2%, India has ambitious plans to expand its future role, including a long-term plan to develop more complex reactors that utilize thorium - a potential alternative source of fuel for nuclear reactors. India has limited low-grade uranium reserves, but it has the world's largest reserves of thorium: developing a thorium fuel cycle will though require a range of tough economic, technical and regulatory challenges to be overcome.

The nuclear industry in India is also subject to the broader challenges that are facing the worldwide nuclear industry, including project economics, difficulties with financing and the implications of the Fukushima Daiichi accident in Japan for public acceptance of new projects. India has struggled to attract the necessary investment and to gain access to reactor technology and expertise, with the Civil Liability Nuclear Damage Act of 2010 widely seen as deterring potential suppliers (especially Japanese and US companies). However, the United States and India reached an understanding on nuclear liability issues early in 2015 that may facilitate US investment in Indian nuclear projects.

2.5 HYDRO POWER

2.5.1 The Technology

A dam is built on the route of a river at appropriate place and water is stored in a reservoir formed behind it (Figure 2.8). Energy is stored in water as potential energy, which can be converted to kinetic energy by allowing it to flow downward through a penstock. Quantity of water flowing through penstock is controlled using sluice gates. Kinetic energy in water is converted to mechanical energy using a turbine. Mechanical energy produced by turbine is converted to electrical energy by coupling a generator with the turbine.

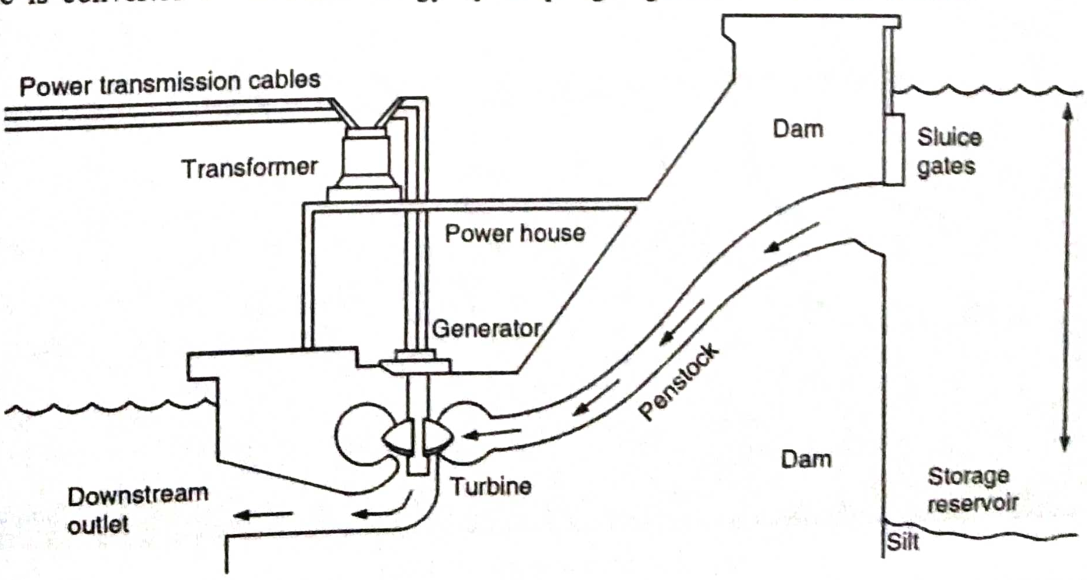


Fig. 2.8 : Scheme of a Hydro-Electric Power Plant

2.5.2 Hydro-energy scenario

Electricity production in the world and India is around **21,431 TWh** (1 TWh = 10^9 kWh; 1 kWh = 1 unit of electrical energy) and **855 TWh** respectively. Hydro-energy accounts for 16 percent of above electricity generation and it is the most widely used form of renewable energy. Total installed capacity of hydro-power plants was 926 GW (1 GW = 10^3 MW) in 2010. The production rate of electrical energy from hydro-energy is expected to increase at an average rate of 3.1% each year for the next 25 years. There is potential of generating around 14,500 TWh/yr energy from this energy source, almost four times that of current generation. Most of this potential lies in developing countries.

The present installed capacity in India is approximately 42,783 MW, out of total generation capacity of 302,088 MW. Hydro-power potential is assessed to be about 84,000 MW at 60% load factor[1]. Thus, around 442 TWh/yr (84 GW × 8760 hr/yr × 0.6) electrical energy can be produced using hydro-energy. Hydro-energy does not produce greenhouse gases or other kinds of pollution and thus considered environment-friendly technology. But there are concerns related to local ecosystem due to drying of river stream downstream of the dam and displacement of people due to submergence of land under the reservoir.

Total electrical power generation in India was 1278907 GWh in the year 2014-15. Out of this, thermal, hydro and nuclear power were 951504, 129244 and 36102 GWh. Thus, hydro-power contributed around 10% of total electrical power produced. The installed capacity of hydro power plants was 42 GW in 2014 and is expected to rise to 100 GW by 2040. Small hydro power plants contribute 2.8 GW installed capacity currently but would increase to 10 GW by 2040. The development of small hydro plants is mainly taking place in north and north-eastern regions in India.

Our Gujarat's own Sardar Sarovar Power Plant has employed six reversible Francis type turbines of 200 MW capacity each in river-bed power plant. There are 5 turbines of 50 MW capacity employed in canal head power plant. Out of the total electricity produced, the state of Gujarat gets 16% share.

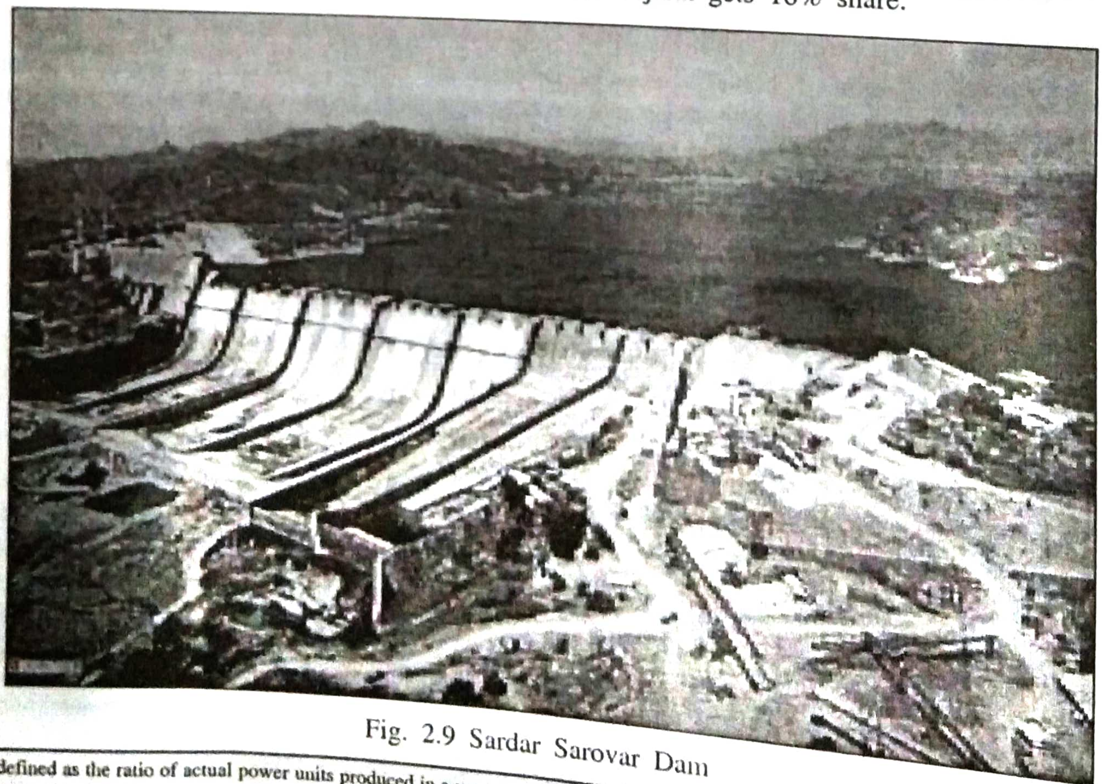


Fig. 2.9 Sardar Sarovar Dam

[1]Load factor is defined as the ratio of actual power units produced in a year to total electrical power that can be generated if the plant runs at installed capacity for all 8760 hours of the year.

2.5.3 Advantage and disadvantages of hydro-energy

Advantages :

(a) Production of Hydro-energy does not emit greenhouse gases or other kinds of pollutants.

(b) It is produced domestically in the country and thus good for energy security of the nation.

(c) It relies on annual cycle of water evaporation and rain and thus a renewable source of energy.

(d) It can give additional benefits like water supply, tourism development, fishing and flood control.

Disadvantages :

(a) It is totally dependent on nature, i.e. annual rainfall; without which no power can be produced.

(b) Local ecosystem is affected due to drying of river stream downstream.

(c) Displacement of local people is necessary due to submergence of land under the reservoir.

(d) Time taken for erection of such plant is very long and costs involved are very high.

2.6 RENEWABLE SOURCES OF ENERGY

We have already talked about one of the renewable sources of energy; i.e. hydro-energy. This energy source is a conventional source of energy, while small hydro-power plants are considered to be non-conventional sources of energy. There is more emphasis on their development now as they do not create many environmental and societal problems. Other renewable sources of energy are solar energy, wind energy, bio-mass energy, geothermal energy, tidal energy, wave energy and ocean thermal energy. The first three of these are more important for India and will be discussed further here. The total grid connected electrical power generation capacity by renewable energy sources in India is around 42.9 GW. Out of these, wind and small hydro contribute 28.1 and 4.3 GW respectively. Biomass and Bagasse cogeneration contribute 4.8 GW, while solar power contribute 8.5 GW.

2.7 SOLAR ENERGY

2.7.1 Basics of Solar Energy

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW, which is thousands of times larger than the present consumption rate of all commercial energy sources on the earth. Thus, in principle, solar energy can supply all the present and future needs of the world.

Over the period 2000 to 2011, solar PV (photovoltaic) was the fastest growing renewable power technology worldwide. Cumulative installed capacity of solar PV reached roughly 65 GW at the end of 2011, up from only 1.5 GW in 2000. In 2011, Germany and Italy accounted for over half the global cumulative capacity, followed by Japan, Spain, the United States and China.

India is gifted with vast solar energy potential. Most parts of India receive 4 to 7 kWh/m^2 per day. Hence solar thermal and solar PV, both technologies have big potential of development in India. Theoretically, even a small fraction of the total incident solar energy can meet the entire country's power requirements. India targets to reach 100 GW power generation using solar energy by 2022.

2.7.2 Advantages of solar energy

(a) Sun is an inexhaustible source of energy (because the sun will shine till the end of life or life will continue only if sun shines).

(b) Solar energy is a clean source of energy; i.e. it does not produce any kind of pollution while being produced or used. This is in contrast to fossil fuels which produce various pollutants where they are burnt for conversion from chemical to thermal energy.

(c) Solar energy is available on surface of earth without any cost.

(d) Solar can be produced indigenously and it is available in abundance in India. So, it is an important source of energy from point of view of energy security. India would be less dependent on other countries if this source of energy is developed.

2.7.3 Challenges for Solar Energy

(a) It is a dilute source of energy as against fossil fuels, which are very concentrated form of energy. The peak value of solar radiation flux falling on earth's surface at a given place could be 1000 W/m^2 area. So, large collection areas are required, which results in high collector cost and land cost.

(b) The solar radiation flux intensity varies significantly over the day and it is not available at night. It needs to be stored over the day to be able to use it at night. The energy storage would need additional space and investment.

(c) There is seasonal variation in amount of solar energy available. Very little energy is available in monsoon due to cloud cover. One needs to use some standby energy source in such conditions. This would increase the total initial cost.

2.7.4 Applications

Solar energy can be utilized to produce thermal energy (heat) or electrical energy. Solar radiation available in form of electromagnetic waves can be converted to heat and then that heat can be converted to electrical energy in a power plant. Solar radiation can be directly converted to electrical energy using solar phovoltaic cells. The devices that capture solar radiation and convert it into other usable form of energy are called **solar collectors** e.g. solar flat plate collector used for water heating. Some of the applications of solar energy are mentioned below:

(a) Lights, pumps, communication network etc. can run with solar PV cells
(b) Solar power plant based on PV cells or thermal collectors
(c) Solar water heater, used for domestic or industrial water heating
(d) Solar air heater, used for agriculture / industrial product drying or space heating
(e) Solar cooker for residential or community cooking
(f) Solar still for distilled water production
(g) Solar steam generator for industrial process heating or cooling

2.7.5 Solar Water Heater

One of the most common and popular application of solar energy is a solar water heater. Fig. 2.10 shows the photograph of a solar water heater installed on terrace of a house. The main parts of this solar water heater like flat plate collector, are labelled in the diagram.

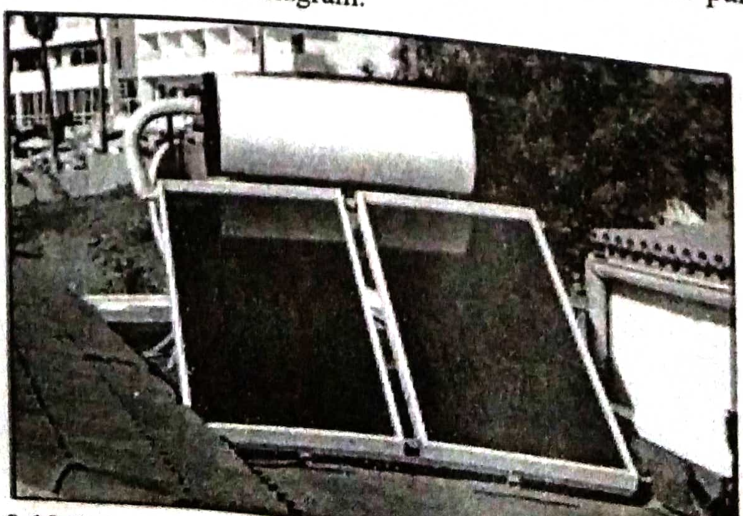


Fig. 2.10 Solar Water Heater Installed on the Terrace of a House

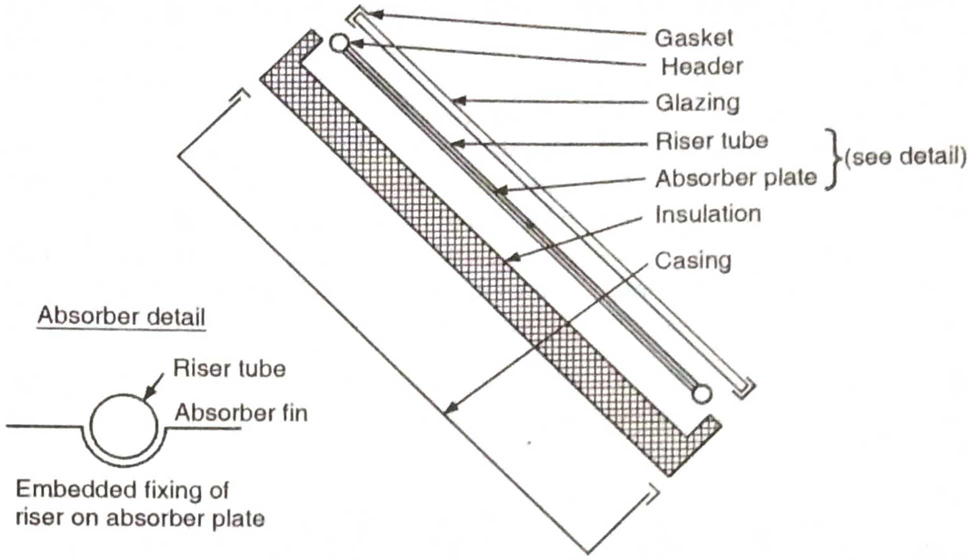


Fig. 2.11 Components of the Solar Flat Plate Collector

The details of the flat plate collector are given as an exploded view in Fig. 2.11. The solar radiation passes through the transparent glass cover or glazing and falls on the absorber plate. The absorber plate absorbs the radiation and becomes hot. The heat produced in the absorber plate is provided to water in the riser tubes. The riser tubes are connected with bottom header, which in turn is connected with the bottom of the storage tank. As the water in the riser tube rise up in the tube, cold water from the storage tank enters into it. Hot water from top of the riser tube enters into the storage tank in top portion. The required hot water is taken from the top of the storage tank. The insulation reduces the heat loss by mode of conduction from the absorber plate. The glass also helps in reducing convective and radiative heat loss from the top of the collector. All components are assembled into a metal casing to make the flat plate collector box.

2.7.6 Solar PV Techchology

Solar photovoltaic cell is generally made from semiconductor material like silicon (Si) as base material. Pure silicon is doped with trivalent materials like boron to create p-type material. Pure silicon is doped with pentavalent material like phosphorous to create n-type material. The p-type material has excess holes, while n-type material has excess electrons. The wafers of these two materials are joined together to create p-n junction. Near the junction, excess electrons from n-type material diffuse to recombine with the holes in the p-type material. Similarly excess holes from p-type material diffuse into n-type material. So a thin layer in n-type material becomes positively charged and the p-type material becomes negatively charged. This creates a barrier, which stops further flow of electrons and holes, creating a built-in potential in the solar cell.

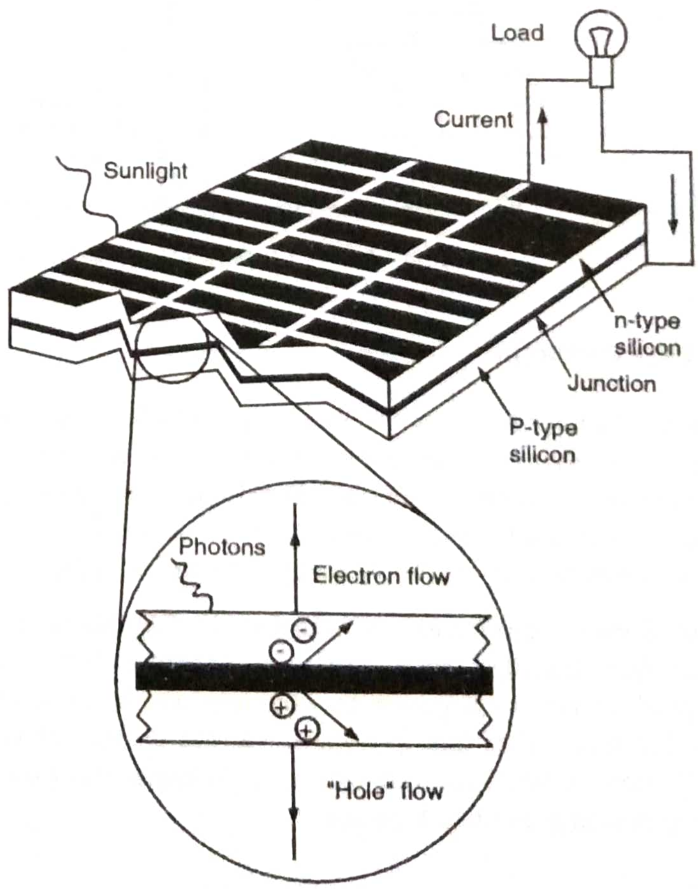


Fig. 2.12 Details and Working of a Solar Photovoltaic Cell

Details of construction and working principle of the solar photovoltaic cell are shown in Figure 2.12. Thin metal conductor grid containing silver is used on top surface of n-type material to collect electrons. Bottom surface of the p-type material is backed with conducting metal like aluminium. Solar radiation (sun's photons) strike the cell on the micro-thin n-type silicon and penetrate to the junction. They give their energy to electrons or holes at the junction and make them free to move. When connected to a load through external circuit, such free electrons travel through n-type material and are collected by the metal grid at top. Then they travel through the external circuit and recombine with holes in p-type material, entering the cell through base. The holes travel through p-type material towards base. The electrons and hole recombine in the p-type material. The direction of current I is conventionally in opposite direction to that of electron flow. An antireflective coating is applied at the top of the cell to reduce reflection of radiation. Solar cells are encapsulated in a thin transparent material in order to protect them from the environment.

Solar cells are combined to make modules and multiple modules make panels. This is shown in Fig. 2.13(a) (b), while Fig. 2.14 shows components and circuit diagram for a stand-alone solar PV system that is used to run an AC load like fan or pump.

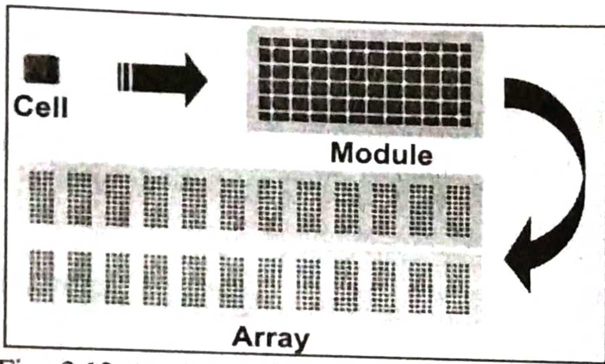


Fig. 2.13 (a) Solar Cell to Panel

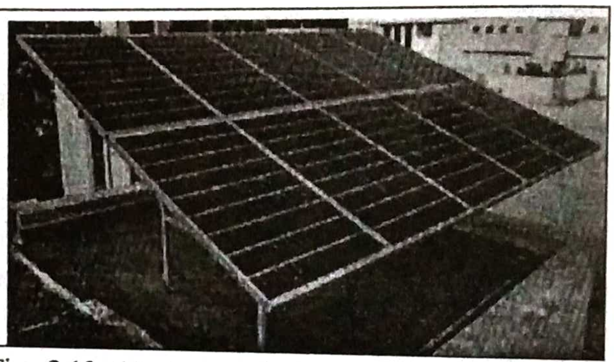


Fig. 2.13 (b) Solar PV Panel Installed on a Terrace

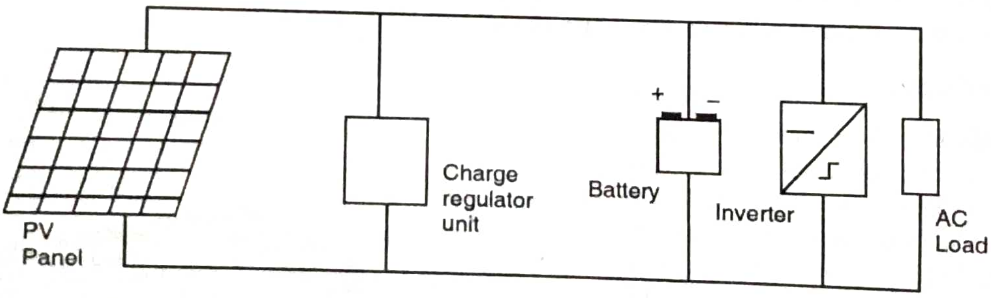


Fig. 2.14 Components of a Stand Alone Solar PV Power System.

2.8 WIND ENERGY

Windmills have been used in various parts of the world since ancient times. They were originally used for milling (grinding) grain and hence the name windmill was used. The other important application was for water pumping for farms. Windmills were considered outdated during industrial revolution period. The interest in wind energy was revived after energy crisis of 1970s. Research and development in this field brought this technology back as a commercially viable renewable energy source.

Global wind power capacity was just 18 GW at the end of 2000, which increased to 318 GW at the end of year 2013. Installed capacity of wind energy in India has crossed 28 GW. Wind energy is now mainly utilized to produce electrical power by coupling an electrical generator with the rotor, which is now generally called wind turbine rather than windmill. Various designs of wind turbines are shown in Fig. 2.15 and Fig. 2.16. Fig. 2.17 shows a wind farm in which many horizontal axis propeller type three bladed wind turbines are installed for generating electrical power.

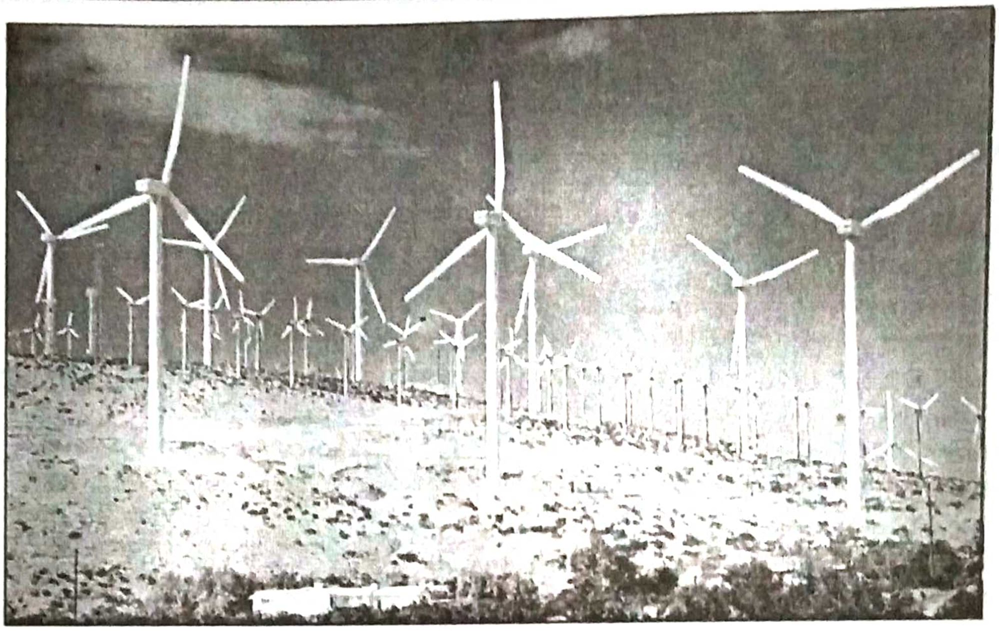


Fig. 2.15 : A Wind Farm

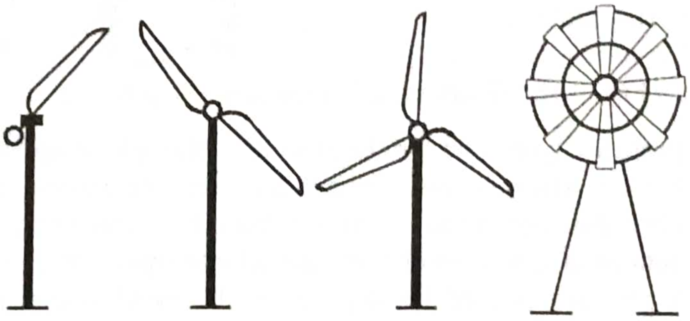
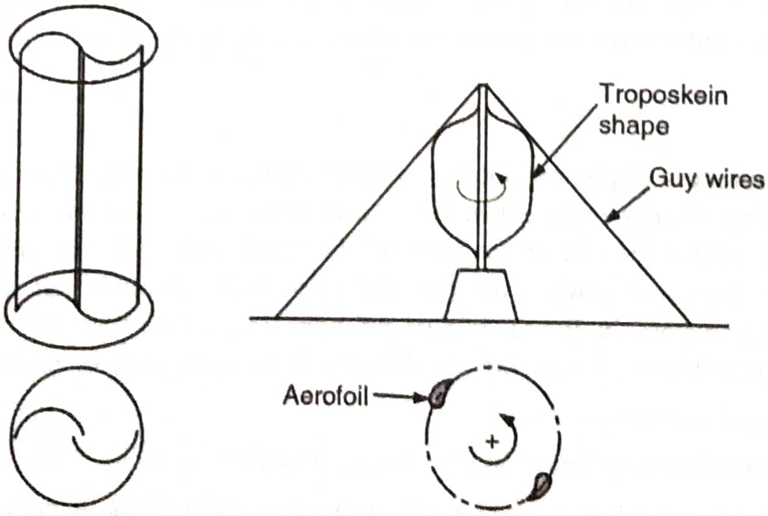


Fig. 2.16 : Various Horizontal Axis Wind Turbines



(a) Savonius type wind turbine (b) Darrieus type wind turbine

Fig. 2.17 : Various Vertical Axis Wind Turbines

2.8.1 Parts of a wind turbine

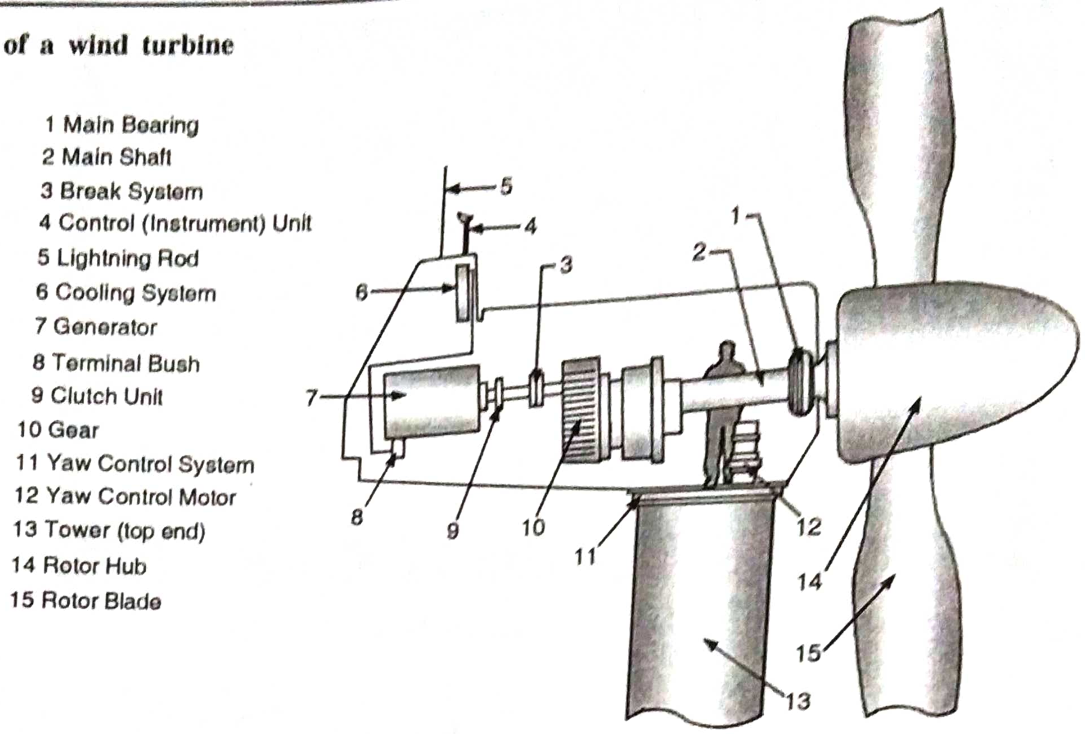


Fig. 2.18 : Parts of Wind Turbine (Side View)

Figure 2.18 show parts of propeller type wind turbine as well as principle of operation of three bladed propeller type horizontal axis wind turbine, which is most common for electricity generation. The blades of wind turbine are commonly made from fibre glass and are airfoil shaped. Rotor hub is structural attachment that holds rotating blades. The wind turbine rotates at a few revolutions per minute (rpm), while the electrical generator needs around 1400 rpm speed. A gear box is used for stepping up the speed. Brake is used to control speed or to stop the turbine in case of emergency. The shell enclosing wind turbine assembly is called nacelle. Yaw motor can rotate the turbine about the pole on which it is mounted, so that the turbine faces the wind direction. Anemometer and wind vane are used to indicate the speed of wind and its direction respectively. These measurements are necessary for automatic controls for increasing the efficiency or safety of the turbine.

2.9 BIO-FUELS

Plant matter created by process of photo-synthesis is called biomass. Biomass that can be used as fuel is called biofuel. Plants derive their energy requirement from solar radiation through the process of photosynthesis. In this process, water and carbon dioxide are converted into organic material. Biofuels can be considered to be renewable as it can be re-created much faster than the fossil fuels. Biofuels and waste provide around 5.8% of the world's fuel for transport. In Brazil, biofuel provides 23% of all transport fuel, while this is 4% and 3% in USA and European Union. Following are different biomasses used as biofuel:

(1) Wood from trees and plants

(2) Agricultural crop residues like straw, stalks, leaves, roots etc.

(3) Agro-processing residues such as oilseed shells, groundnut shells, husk, bagasse, coconut shells, saw dust etc.

(4) Trees or plants grown especially as energy plantation like Jetropha, Eucalyptus

(5) Animal manure

2.9.1 Biomass Conversion Routes

Biomass like wood can be directly used in the process of combustion to produce heat as in stoves (*chulhas*) for cooking or in boiler to heat water. Millions of households in villages in India still use wood, agricultural waste and dung cakes for cooking purpose. The traditional chulhas are very inefficient and use just around 10% of the energy in fuel. Improved design of chulhas use around 15 to 20% of heat in fuel. Direct combustion method is thus very inefficient method of use of biofuel. Some of the biomasses cannot be burnt directly and need some processing before they can be used as biofuels. Figure 2.19 shows various routes for biomass conversion for using it as biofuel.

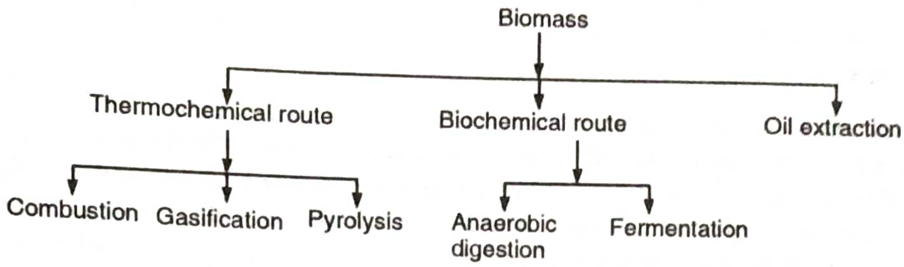


Fig. 2.19 : Biomass Conversion Routes

Direct combustion is one of the thermochemical routes. Sometimes a particular type of plant or tree is planted and harvested over regular intervals in a piece of land to get wood for combustion. This is called **energy plantation.** In India, eucalyptus, babool and casuarinas are planted for this purpose. Fuel available from these type of energy plantation may be even used to run a thermal power plant. In USA and European countries, power plants in range of 5 to 50 MW have been established, which use wood and agricultural waste as fuel.

2.9.2 Biomass gasification

Biomass gasification is process of partial combustion of solid biomass like pieces of wood or agricultural residue into combustible gas mixture. In partial combustion, the quantity of air is kept lower than that required for full combustion of biomass. The products of this process are mixture of gases like carbon monoxide, carbon dioxide, hydrogen and nitrogen. This mixture is called producer gas. Figure 2.20 shows the scheme for biomass gasification.

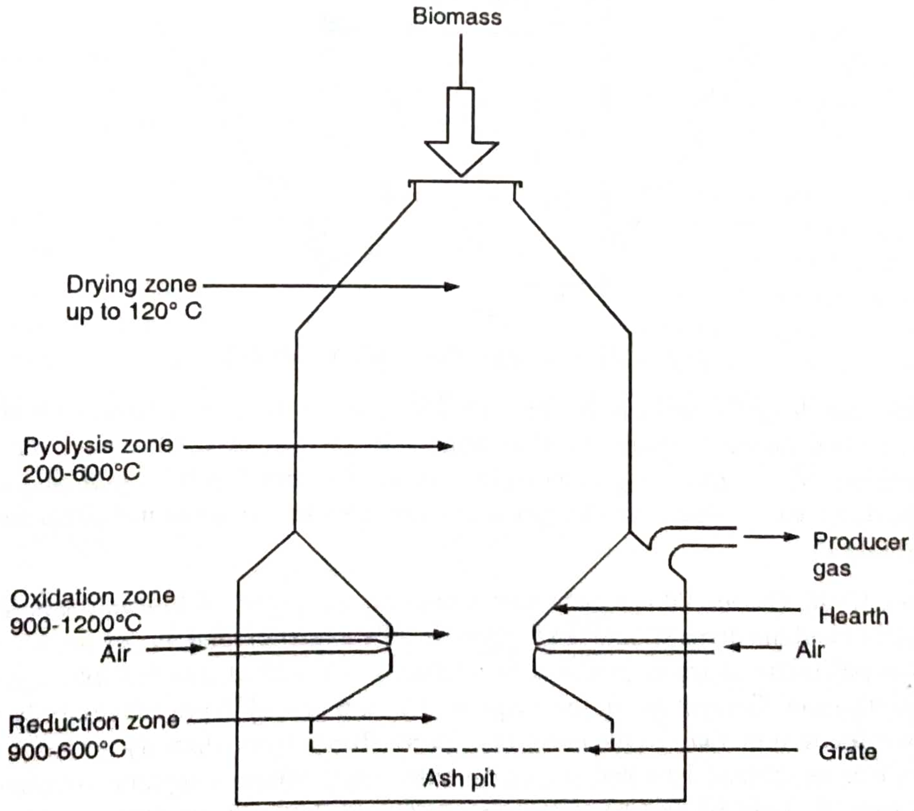


Fig. 2.20 : Biomass Gasification

Biomass is fed in at the top at regular intervals of time. In drying zone, moisture content in the upper layers of the biomass is removed by evaporation. Temperature in this zone is around 120°C. The second zone is called pyrolysis zone, where the temperature ranges from 200 to 600°C, increasing from top to bottom. In this zone, biomass loses its volatile components. In this section, water vapour, methanol, acetic acid and hydrocarbon tar are generated. This process is an exothermic process. The remaining solid is called char, which is basically carbon.

All of above products move to the third zone which is called combustion or oxidation zone. Main reactions occurring in this zone are:

$$CO_2 + C \rightarrow 2CO$$

$$C + H_2O \rightarrow CO + H_2$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2$$

These reactions are endothermic and temperature in this zone progressively decreases. The char is fully consumed and the final products are producer gas and ash. The tar and particulate matter in final product need to be removed. Producer gas contains CO, H_2, CH_4, CO_2 and N_2. The conversion efficiency of gasifier is defined as the ratio of the heat content in the producer gas to the heat content in the biomass supplied. This is around 75%, which shows that biomass gasification is much better way of using biomass as compared to direct combustion. The heating value of producer gas is around 4000 to 5000 kJ/m^3. This is much lower than gaseous fuels like natural gas. Producer gas can be used for cooking, drying, water heating, steam generation etc. Producer gas can be used in internal combustion engines as fuel after cleaning it.

2.9.3 Biogas

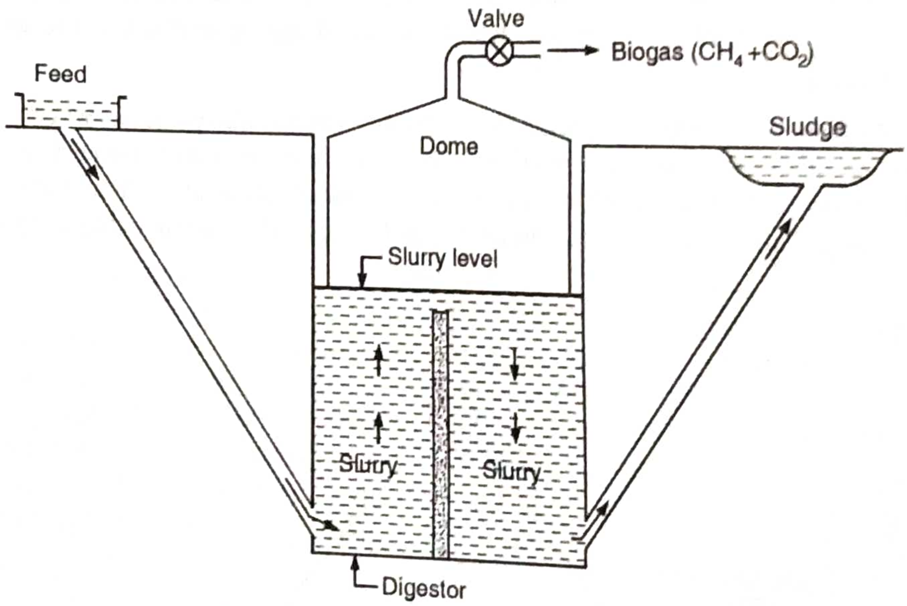


Fig. 2.21 : Biogas Plant: KVIC Model

Wet livestock like cow dung (*gobar*) can be fermented in absence of oxygen (anaerobic digestion) to produce methane gas and carbon dioxide; which is called biogas. Biogas can be used as fuel for cooking, lighting or in internal combustion (IC) engine. Biogas can replace 70 to 80% diesel in IC engine and engines running only on biogas are also designed. Production of biogas is of more relevance in India due to its large cattle population, particularly in villages.

Figure 2.21 shows KVIC (Khadi Village Industries Commission) model of biogas plant. The plant has mainly two parts: the digester and the dome. While the digester is fully below ground, upper portion of the dome projects out of ground. Animal waste slurry is prepared by mixing water with it and fed into digester through a pipe. The diameter and depth of digester are in the range of 1.2 to 6 m and depth ranges from 3 to 6 m. A vertical partition wall divides it into two equal parts and stops slurry from directly passing to outlet pipe. The digestion process can be divided into two stages. In first stage, complex organic substances contained in the waste are acted upon by acid former bacteria and produce acetic acid. In second stage; methane fermenter bacteria produce methane and carbon dioxide. The calorific value of biogas is in the range of 16000 to 25000 kJ/m^3.

2.9.4 Bio-ethanol and biodiesel

Some biomasses like sugar cane, sugar beet and sweet sorghum can be fermented to get alcohol like ethanol. Alcohols can also be produced from many starch crops such as barley, wheat, corn, potato etc. These alcohols can be blended with petrol, giving an alternative transport fuel. It may be noted that this use is justified only if there is excess land available after growing these crops for food. The country like Brazil produces large amount of ethanol as transport fuel as it has large spare land.

Bio-diesel is methyl or ethyl ester of fatty acid. These can be used in diesel engines in pure or blended form. Bio-diesels can be produced by esterification of edible or non-edible oil. Some of the examples of edible oils are palm, soybean, sunflower, peanut, olive oil etc. Jatropha, karanja, neem etc. are non-edible oils that can be converted to bio-diesel. Engines running on bio-diesel fuels emit less particulate matter, hydrocarbon and carbon monoxide. There is small increase in NO_x emission, which needs to be reduced with proper mechanism. Using edible oils as biodiesel is not a good option as these oils are in short supply. Jetropha, which can grow in most part of our country, is a promising alternative for production of biodiesel. Jethropha plantation is done in waste lands and the plantation activity can also generate jobs in villages. Bio-diesels have been successfully used to run buses and trains. Many researchers and research organizations are working on different aspects of biodiesel for its use as a transport fuel.

2.10 GLOBAL WARMING

Earth's climate is changing due to increased human and industrial activities. Some gases like CO_2, methane, CFCs, halons and N_2O trap heat or reduce radiation going back to space from earth's atmosphere. They are thus responsible for increase in average global temperature. The earth's surface temperature has increased by about 0.6°C over the last century. It is estimated to rise by 2 to 4°C by the end of this century. Due to this temperature rise, ice-berg covers will reduce and sea levels will rise by 30 to 60 mm. This can lead to flooding of rivers, submergence of low sea level areas and decrease in availability of fresh water for irrigation and other essential uses. Such changes can put survival of entire populations in danger. Energy conservation and use of energy sources, which produce less air pollution are necessary steps to reduce global warming.

Fig. 2.22 shows what happens to solar radiation as it enters into earth's atmosphere. Some radiation is reflected by clouds or water vapour and dust. This is lost into space and does not come back to earth. Some part is absorbed by ozone layer, water vapour and carbon dioxide. A part of the radiation which reaches earth's surface is absorbed by oceans, earth's surface and man-made objects. All objects on earth's surface remain at higher temperature due to this absorption. They are at a temperature higher than sky during night and they start radiating their heat back into space. This outgoing radiation is blocked by greenhouse gases and clouds in earth's atmosphere. Excess quantity of these gases keeps earth's atmosphere warmer leading to global warming.

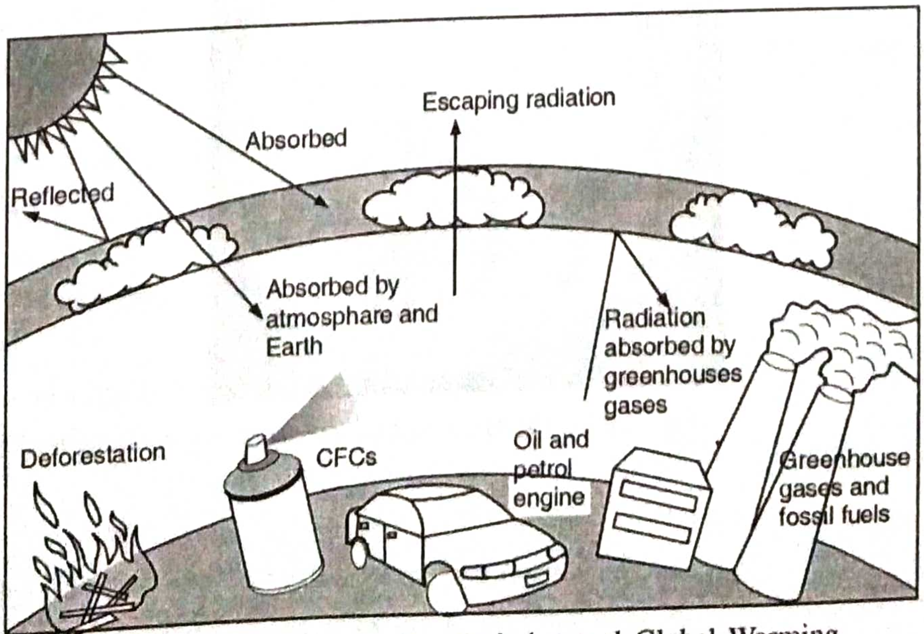


Fig. 2.22 : Greenhouse Gas Emission and Global Warming

2.11 OZONE DEPLETION

The ultraviolet (UV) rays from the sun can be divided as UVA, UVB and UVC type based on their wavelength. UVA has longest wavelength and penetrate through atmosphere. UVB rays have medium wavelength and they are partly absorbed in atmosphere. UVC rays are completely absorbed by ozone layer in atmosphere of the earth. ChloroFluoroCarbons (CFCs), halons (chlorinated and brominated organic compounds) and NO_x are responsible for ozone depletion or a hole created in this layer over Antarctica. Increased UV radiation on earth can cause increased rate of skin cancer and eye damage to humans. It is also harmful to many other organisms. CFCs which are used as refrigerants are mainly responsible for this phenomenon. In addition to this, NO_x emissions which are produced by fossil fuel and biomass combustion processes and nitrogen fertilizers are also responsible. Ozone depletion rate can be decreased or the layer can be restored by reducing consumption of CFCs. Renewable and clean energy sources should be used in place of fossil fuels to reduce emission of NO_x. Fig. 2.23 (a) and (b) explain the process of absorption of UV rays by ozone layer and also shows the hole in the ozone layer above Antartica.

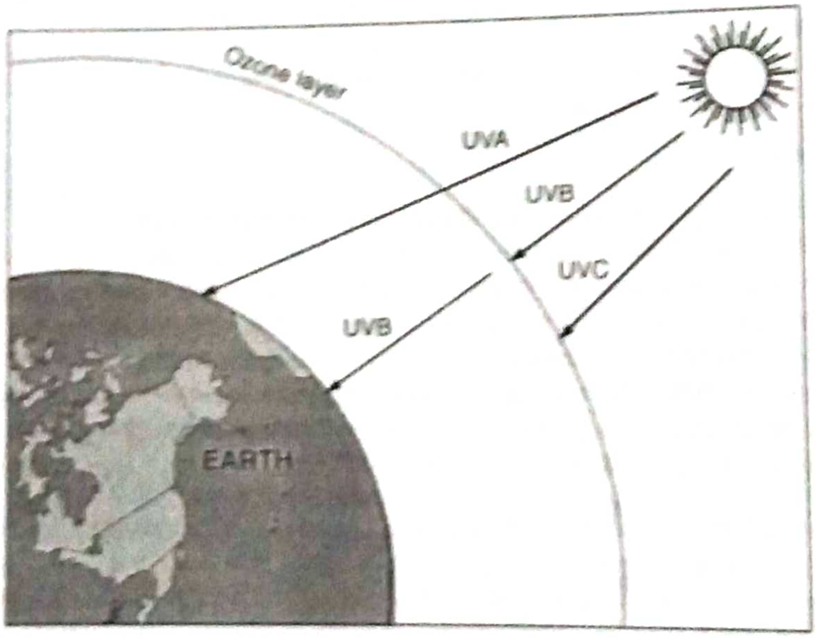


Fig. 2.23 (a) Absorption of UV rays by Ozone Layer

Fig. 2.23 : (b) Hole in Ozone Layer

EXERCISES

1. What is fuel ?
2. Which are the common solid fuels ? Write about peat and wood in short.
3. Which are the different types of coals. Give their properties and applications.
4. Classify liquid fuels. Write in short about light oils (spirits).
5. What are furnace oils ? Where are they used ?
6. Give advantanges of coals over oils.
7. Give the advantages and disadvantages of liquid fuels over coal/solid fuels.
8. How are following gases produced ? Give their applications :
   (i) Coal gas (town gas) (ii) Producer gas (iii) Water gas (iv) LPG
9. Give advantages and disadvantages of gaseous fuels.
10. Differentiate : Renwable and Non-Renewable sources of energy.
11. List Merits and Demerits of solar energy.
12. State applications of solar energy.
13. Enlist various components of wind turbine.
14. What are the sources of Bio Fuel?
15. Write short note on :
    (a) Biomass Gasification (b) KVIC Biogas Plant (c) Bio Diesel
16. Explain the concept of Global Warming.
17. What is ozone depletion? How can this rate be reduced?

OBJECTIVES TYPE QUESTIONS

(A) Fill in the Blanks

1. Fossil fuels are _________ source of energy.
2. Electrical energy and hydrogen are _________ sources of energy.
3. _________ is most inferior quality of coal.
4. CNG means _________ .
5. Producer gas is produced by _________ of coal in air.
6. Nuclear power can be produced by _________ or _________ reactions in nuclear reactor.
7. BWR means _________ in case of nuclear power plants.
8. Third largest source of energy in India is _________.
9. A turbine converts _________ energy to _________ energy.
10. In case of solar energy, PV means _________.
11. _________ water can be produced using solar still.
12. Wind turbine with _________ number of blades are most common now.
13. _________ can rotate turbine about its pole.
14. Trees planted and harvested to get wood for combustion is called _________.
15. KVIC means _________.
16 LPG means _________
17. In case of a bi-fuel vehicles, the fuel used other than natural gas is _____
18. Biomass gasification is process of _____ combustion of solid biomass.
19. The component used to increase the speed of wind turbine shaft is _____.

20. Drag and ____ are the forces created on blades of wind turbine.
21. The heat energy is stored in solar water heater in component called ____.
22. Solar still is used to produce ____.
23. Solar energy from PV panels can be stored in chemical energy form in ____.
24. Mechanical energy produced by the hydro-turbine is converted into electrical energy using a ____.
25. Nuclear power can be produced by fission or ____.
26. The gaseous fuel which can be used in power plants is ____.
27. ____ oils include the heaviest grades of natural petroleum oils.

: ANSWERS (A) :

1.	non-renewable	11.	Distilled	20.	Lift
2.	secondary	12.	three	21.	Water storage tank
3.	Lignite	13.	Yow motor	22.	Distilled water
4.	Compressed Natural Gas	14.	energy plantation.	23.	battery
5.	gasification	15.	Khadi Village Industries Commission.	24.	Generator
6.	fusion or fission			25.	Fusion
7.	Boiling Water Reactor	16	Liquefied Petrolum Gas	26.	Natural gas
8.	wind energy	17.	gasoline / petrol	27.	Furnace
9.	potential, kinetic	18.	partial		
10.	photovoltaic	19.	gear box		

(B) Multiple Choice Questions.

1. Liquid fuels are most widely used in
   (a) Transport sector (b) Commercial sector (c) Industrial sector (d) None of above
2. Which of the following are renewable source of energy
   (a) Hydropower (b) Biomass energy (c) Solar energy (d) All of above
3. Following are forms of biomass energy
   (a) Wood (b) Animal manure (c) Both of above (d) None of above
4. Following are forms of non-edible oils that can be used as bio-diesel
   (a) Jatropha (b) Neem (c) Palm (d) (a) and (b)
5. Following gases are responsible for greenhouse effect:
   (a) Corbon dioxide (b) Methane (c) CFCs (d) All of above
6. Following source of energy is known as renewable source.
   (a) Fossil fuel (b) Nuclear (c) CNG (d) None of above
7. Following source of energy is conventional but still may be considered renewable.
   (a) Hydro (b) Nuclear (c) Fossil fuel (d) All of above
8. Which of the following energy is converted into electricity in a hydro power plant? **(June 2015)**
   (a) Nuclear (b) Potential energy of water
   (c) Thermal energy (d) All of above
9. In an IC engine, from which of the following source, energy is converted into mechanical energy? **(June 2015)**
   (a) Chemical energy of fuel (b) Potential energy
   (c) Kinetic energy (d) All of above

10. Following solid fuel is actually not coal

(a) Lignite (b) Peat (c) Anthrasite (d) Bituminous

11. Following is the lightest fraction derived from petroleum oils

(a) Kerosine (b) Diesel (c) Petrol (d) Naphtha

12. Major component in Natural Gas is

(a) Butane (b) Pentane (c) CO_2 (d) Methane

13. · Following component is highest in LPG

(a) Butane (b) Ethane (c) Propane (d) Methane

14. Following are secondary sources of energy

(a) Hydrogen (b) LPG (c) CNG (d) All of above

15. The energy which is not delivered from the sun is __________. **(Winter 2016)**

(a) Biomass (b) Fossil fuels (c) Nuclear energy (d) Geo-thermal energy

16 The per capita primary energy consumption for USA is _____ that of India.

(a) two times (b) eleven times (c) one half of (d) five times

17. ______ is the highest contributor to primary energy consumption in India.

(a) Crude oil (b) Biomass (c) Coal (d) Natural gas

18. ______ is the highest contributor to power produced from renewable energy sources.

(a) Wind (b) Biomass (c) Solar (d) Coal

19. From 1973 to 2014, the electrical power consumption in world has become about ______.

(a) half (b) double (c) three times (d) four times

20. Natural gas is wet when following are present in it

(a) propane (b) butane (c) (a) and (b) (d) water

21. Combustion of natural gas does not emit following pollutant

(a) sulfur dioxide (b) nitrus oxide (c) volatile organic compound (VOC)(d) all of above

22. Following is not one of the components of LPG

(a) ethane (b) butane (c) propane (d) all of above

23. Following is the disadvantage of Hydrogen as a fuel

(a) low calorific value (b) high specific volume (c) lighter than air (d) produces water vapour after burning

24. Following is not used a moderator in nuclear power plants

(a) solid graphite (b) regular water (c) heavy water (d) carbon dioxide

25. Incident solar insolation in most part of India is in the following range

(a) 1-3 kWh/m^2 (b) 4-7 kWh/m^2 (c) 8-10 kWh/m^2 (d) 10-15 kWh/m^2

26. Following is not a component of solar water heater

(a) Silicon cell (b) riser tube (c) header (d) insulation

27. Yaw motor in wind turbine is used for

(a) Rotating nacelle about pole axis (b) Rotating blades about their axis
(c) Rotating low speed shaft (d) Rotating high speed shaft

28. Following process is not a thermochemical process for biomass processing

(a) pyrolysis (b) gasification (c) fermentation (d) combustion

29. Following is not a component in final product from biomass gasifier
(a) Oxygen (b) Hydrogen (c) tar (d) carbon dioxide

30. Calorific value of biogas is in the following range
(a) less than 15000 kJ/m^3 (b) 16000 to 25000 kJ/m^3
(c) 30000 to 35000 kJ/m^3 (d) 40000 to 44000 kJ/m^3

31. Bio-diesel is not produced from following
(a) Jetropha (b) Soybean (c) Olive (d) Potato

(Summer 2017

32. Which has the highest calorific value?
(a) Petrol (b) Diesel oil (c) Alcohol (d) Benzene

(Winter 2017

33. Bio fuels can be produced from
(a) Biomass (b) agricultural waste (c) municipal garbage (d) all of above

: ANSWERS (B) :

1. (a)	**2.** (d)	**3.** (c)	**4.** (d)	**5.** (d)	**6.** (d)	**7.** (a)	**8.** (b)	**9.** (a)	**10.** (b)
11. (c)	**12.** (d)	**13.** (c)	**14.** (a)	**15.** (c)	**16** (b)	**17.** (c)	**18.** (a)	**19.** (d)	**20.** (c)
21. (d)	**22.** (a)	**23.** (b)	**24.** (a)	**25.** (b)	**26.** (a)	**27.** (a)	**28.** (c)	**29.** (a)	**30.** (b)
31. (d)	**32.** (a)	**33.** (d)							

❖ ❖ ❖

3

PROPERTIES OF GASES

Hiren Sir

.1 PERFECT GAS :

A perfect gas is one, which obeys the Boyle's and Charles' laws and the characteristic equation of a gas which is obtained by above laws. No gas is perfect but many gases behaves nearly as perfect gas in the temperature and pressure ranges of applied thermodynamics. Many gases like Air, Oxygen, Nitrogen, Hydrogen etc. can be regarded as perfect gases. They are known as real gases.

.2 VAPOUR :

Vapour is a gaseous state of the fluid, but at a temperature not too away from its boiling point. It may have liquid particles in suspension. Such vapours are known as wet vapours. Vapours readily condenses when expanded or cooled in any process. Whereas gases remain in the gaseous state except under extreme pressure and temperatures. Behaviour of wet vapour can't be determined by Boyle's and Charles' laws. Vapours do not obey these laws but one can use for approximate solution under certain condition.

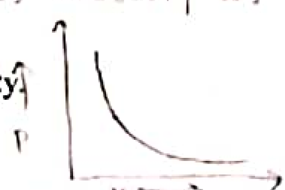
.3 BOYLE'S LAW :

It states that "The volume of a given mass of a perfect gas varies inversely as the absolute pressure when the temperature is held constant". If p is the absolute pressure of the gas and V is the volume occuppied by the gas from Boyle's law

{At const temp, volume of a given mass of a perfect gas varies inversely as to the absolute pressure.}

$$V \propto \frac{1}{p} \qquad T = \text{Constant}$$

$$\therefore \quad V = \frac{C}{p} \qquad \text{Where C is constant of proportionality}$$



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

Thus Boyle's law shows that the product of absolute pressure and volume of a given mass of gas is constant when temperature is held constant.

If certain gas changes its state from 1 (p_1, V_1) to 2 (p_2, V_2) when temperature is kept constant then from Boyle's law, $p_1V_1 = p_2V_2 = C$.

3.4 CHARLES'S LAW :

It states that "If any gas is heated at constant pressure, the change in volume is directly proportional to the temperature range." This change in volume is same for all gases.

Gay–Lussac and Regnault investigated that this change in volume is $\frac{1}{273}$ times of volume at 0°C per degree centigrate temperature rise. If V_0 is the volume of gas at 0°C and t is the temperature in °C, volume of gas (V) at t°C can be written as

$$V = V_0\left(1 + \frac{t}{273}\right)$$

$$\therefore \quad V = V_0\left(\frac{273 + t}{273}\right)$$

$$\therefore \quad V = V_0 \cdot \frac{T}{T_0} \qquad \therefore \quad \frac{V}{V_0} = \frac{T}{T_0} \qquad (3.2)$$

Where T is the absolute temperature of gas in K and T_0 is the absolute temperature equal to 0°C that is 273 K.

Thus Charles' law states that volume of a gas varies directly as the absolure temperature when pressure is constant.

$\therefore \quad V \propto T$ when p is constant.

3.5 CHARACTERISTIC GAS EQUATION :

In practice pressure, temperature and volume of gas may change simulteneously. In such condition any one of the above laws cannot be applied directly. By combination of above laws we can derive an equation which can be used in such cases

From Boyle's law $V \propto \frac{1}{p}$ if T is kept constant.

From Charles' law $V \propto T$ if p is kept constant

So, if both p and T varies

$$\therefore \quad V \propto \frac{T}{p}$$

$$\therefore \quad V = \frac{C\,T}{p}$$ Where C is constant of proportionality

$$\therefore \quad pV = C\,T$$

The constant C depends on the mass, properties of the gas used and the temperature scale used.

If gas changes its state from 1 to 2 and correoponding change in properties from p_1, V_1, T_1 to p_2, V_2, T_2, we can have

$$p_1V_1 = C\,T_1 \text{ and } p_2V_2 = C\,T_2$$

$$\therefore \quad \frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} = C \qquad (3.3)$$

The constant C is found to be mR. Where m is mass of the gas and R is specific or characteristic gas constant, so the above equation can be written as

$$\boxed{pV = mRT} \qquad (3.4)$$

This equation is known as "characteristic gas equation". If we replace total volume by specific volume the above equation can be written as $pv = RT$.

Note : Absolute value of pressure and temperature must be used in any calculation pertaining to gas laws. The characteristic gas equation is satisfactory for real gases at high temperature. (more than twice the critical temperature) or at low pressure.

3.6 SPECIFIC GAS CONSTANT (R) :

In equation 3.4 if pressure in N/m², temperature in Kelvin (K), volume in m³ and mass in kg, the unit of R will be J/kg K.

$$R = \frac{pV}{mT} = \frac{N}{m^2} \times m^3 \times \frac{1}{kg} \times \frac{1}{K} = \frac{N.m}{kg\,K} = \frac{J}{kg\,K}$$

It is obvious that R represent the work done against external resistance when 1 kg of mass is heat by one degree temperature at constant pressure.

Table 3.1 : Specific Gas Constants

Gas	Chemical symbol	Molecular Mass (kg/kg mol)	Sp. gas constant R (kJ/kg K)
Air	–	28.97	0.287
Carbon dioxide	CO_2	44.01	0.189
Hydrogen	H_2	2.016	4.124
Helium	He	4.003	2.077
Methane	CH_4	16.043	0.518
Nitrogen	N_2	28.016	0.297
Oxygen	O_2	32.0	0.2598
Water Vapour (steam)	H_2O	18.016	0.462

3.7 UNIVERSAL GAS CONSTANT :

It can be observed that product of molecular mass of the gas and its specific gas constant (R) is same for all the gases. This constant is known as Universal gas constant (R_0).

In SI system, numerical value of universal gas constant is **8.3143 kJ/kg mol K.** So for SI system of unit we have

$$R_0 = MR = 8.3143 \text{ kJ/kg mol K}$$

Where M is the molecular mass of the gas and R is the specific gas constant.

The equation of state for kg mole of any gas can be writter as

$$pV = 8.3143\ T$$

This equation is known as Clapeyron – Mendeleyev equation of state.

3.8 AVOGADRO'S LAW :

It states that "Equal volumes of all gases at the same pressure and temperature contain the same number of molecules".

In other words this can be written as "Molecular masses of all the gases occupy the same volume at NTP (0°C and 101.325 kPa)

We have pV = MRT

Now MR = 8.3143 kJ/kg mol K

Normal pressure and temperature are taken as 273 K (0°C) and 101.325 kPa.

On substitution of this values, we can have

$$V = \frac{8.3143 \times 273}{101.325} \quad \frac{kJ}{kg\,mol\,K} \times K \times \frac{m^2}{kN}$$

$$= 22.4012 \text{ m}^3\text{/kg mol}$$

So we can write as "One kg mole of all gases occupy the volume of 22.4 m³ at NTP".

Molecular volume is the volume occupied by gas at NTP. It is same for all the gases at NTP.

Stadard pressure and temperature (STP) are taken as 101.325 kPa and 15°C.

3.9 JOULE'S LAW OF INTERNAL ENERGY :

We have seen that internal energy is a property of the system and hence it depends only on the state of the system. Change in internal energy does not depend on the path followed by the system.

When any of the system parameters like, pressure, volume, temperature etc changes there may be change in internal energy because of change of state. But Joule's law of internal energy states that "the internal energy of a perfect gas is a function of temperature only." It means that change in internal energy $(u_2 - u_1)$, when temprature changes from T_1 to T_2 will be same no matter how pressure p and volume V changes. So from Joule's experiments internal energy is only function of temperature and not of pressure and volume.

3.10 SPECIFIC HEATS OF A GAS :

We have seen that amount of heat required to raise the temperature of 1 kg of mass by 1 K is known as its specific heat. Its unit is J/kg K or kJ/kg K. It has also mentioned that liquids and solids have only one value of specific heat as they are practically incompressible while gases have two values of specific heat.

Let, certain quantity of gas is trapped in a rigid vessel as shown in Fig. 3.1. When heat is supplied to gas, it will be heated at constant volume. The whole of the heat energy is used to increase the internal energy of the gas which can be viewed as increase in temperature of the gas ($Q = \Delta u + 0$, $\because W = 0$). Thus heat required to increase the temperature of 1 kg of gas by 1 K when volume is kept constant is known as specific heat at constant volume.

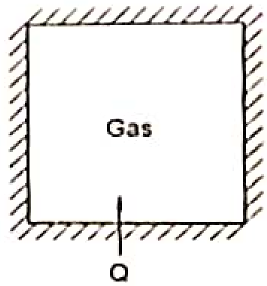


Fig. 3.1 Gas heated at constant volume

It is denoted by c_v.

As a heat supplied at constant volume is utilized to increase the internal energy of a gas we can write,

$$c_v = \left(\frac{\partial u}{\partial T}\right)_v$$

Now, let certain quantity of gas is trapped in a piston cylinder arrangement as shown in Fig. 3.2 and piston carrying fixed load W.

When heat is supplied to the gas, it will be heated at constant pressure. The pressure will be net load on piston divided by piston area. Here heat supplied will be utilized to increase the internal energy of the gas and also to lift the weight under external pressure. Thus heat supplied is used to increase the temperature and volume of the gas. Change in volume is associated with work done by the gas. Thus heat required to increase the temperature of 1 kg of gas by 1K at constant pressure is known as specific heat at constant pressure. It is denoted by c_p.

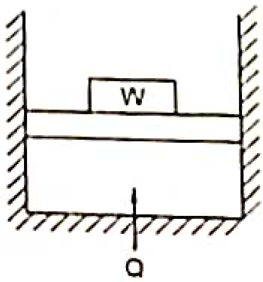


Fig. 3.2 Gas heated at constant pressure

If we apply 1st law to this process

$$Q = \Delta u + W$$

Since only pdv work is present

$$\begin{aligned} \delta Q &= du + pdv \\ &= du + d(pv) \qquad \text{(since p is const)} \\ &= d(u + pv) \\ &= dh \end{aligned}$$

Thus heat supplied at constant pressure is utilized to increase the enthalpy of gas so one can write

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

Since heat supplied at constant pressure is used to increase internal energy of the gas and also to do external work while that at constant volume is used to increase internal energy, value of c_p is alway greater than c_v.

3.11 RELATION BETWEEN TWO SPECIFIC HEAT OF A GAS AND SPECIFIC GAS CONSTANT :

Let T_1 and T_2 are the initial and final temperature of the gas respectively, v_1 and v_2 are the initial and final specific volume of the gas, p is the pressure of the gas, R is the specific gas constant and c_p and c_v are specific heat at constant pressure and volume.

Let 1 kg of gas be heated at constant volume and temperature increases from T_1 to T_2 Heat supplied at constant volume = $c_v (T_2 - T_1)$.

Since heat supplied at constant volume increases internal energy of the gas and no external work is done,

Change in internal energy $du = u_2 - u_1 = c_v (T_2 - T_1)$ (3.5)

Let one kg of gas is heated at constant pressure and temperature increases from T_1 to T_2.

Heat supplied at constant pressure = $c_p (T_2 - T_1)$ (3.6)

Heat supplied at constant pressure is utilized for

(1) To increase internal energy of the gas

Increase in internal energy of gas = $c_v (T_2 - T_1)$ (3.7)

(2) For overcoming external resistance (for doing work)

Energy to overcome external resistance = $p (v_2 - v_1)$ (3.8)

Thus from equation (3.6), (3.7) and (3.8) we can write

$$c_p (T_2 - T_1) = c_v (T_2 - T_1) + p (v_2 - v_1) \quad (3.9)$$

From characteristic gas equation we can write

$$pv_1 = RT_1 \text{ and } pv_2 = RT_2$$

$$\therefore \quad p (v_2 - v_1) = R (T_2 - T_1) \quad (3.10)$$

On substituting from equation (3.10) into (3.9).

$$c_p (T_2 - T_1) = c_v (T_2 - T_1) + R (T_2 - T_1)$$

$$\therefore \quad c_p = c_v + R$$

$$\therefore \quad c_p - c_v = R \quad (3.11)$$

3.12 RATIO OF SPECIFIC HEATS :

The ratio $\frac{c_p}{c_v}$ is denoted by greek letter 'γ' (Gamma). It is also known as adiabatic index. According to the classical kinetic theory of gases value of 'γ' should be 1.67, 1.4 and 1.33 for monoatomic, diatomic and polyatomic gases. At ordinary temperature for monoatomic and diatomic gases the actual values of γ are very close to 1.67 and 1.4 respectively For polyatomic gases the variation from theoretical value 1.33 is large. For air value of γ is 1.4.

If both the sides of equation (3.11) is divided by c_v, we get

$$\frac{c_p}{c_v} - 1 = \frac{R}{c_v}$$

$$\therefore \quad \gamma - 1 = \frac{R}{c_v}$$

$$\therefore \quad c_v = \frac{R}{\gamma - 1} \quad (3.12)$$

For, air, value of specific heat at constant pressure is taken as 1.005 kJ/kg K and value of specific heat at constant volume is taken as 0.718 kJ/kg K.

3.13 VARIOUS NON FLOW PROCESSES FOR A PERFECT GAS :

As mentioned earlier a non flow process is one in which there is no mass flow across the boundary of the system. Thus non flow processes means process undergone by closed systems. There are five important non flow processes in the study of thermodynamics. They are

(1) Constant volume process or isochoric process

(2) Constant pressure process or isobaric process

(3) Constant temperature process or isothermal process

(4) Adiabatic process (reversible) or isentropic process

(5) Polytropic process

Now we will study graphical representation of these processes on p–V diagram, work done, change in internal energy, heat transfer and change in enthalpy of the system during such processes. Suffix 1 and 2 refers to initial and final states of the system, m be the mass of the gas. The ratio $\frac{V_2}{V_1}$ is known as expansion ratio while the ratio $\frac{V_1}{V_2}$ is known as compression ratio. It is denoted by letter 'r'. Since only pdV work is important in non-flow process we will evaluate $\int pdV$ to calculate work transfer during these processes.

(1) Constant Volume Process :

(a) Representation on p–V Diagram :

Since $V_1 = V_2$, constant volume process is a straight vertical line on p–V diagram.

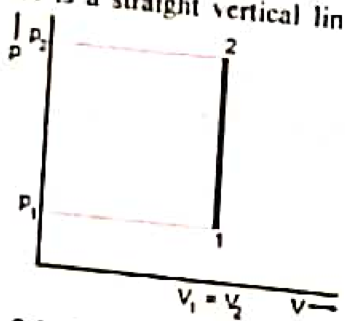


Fig. 3.3 Constant volume process

(b) Work Done during Process :

$$\text{Work done during the process } W = \int_{V_1}^{V_2} pdV$$

$$\text{As } dV = 0 \quad \int_{V_1}^{V_2} pdV = 0$$

Thus work done during constant volume process is zero and this can be seen from p–V diagram as area under the process is zero. (3.13)

(c) Relation between p, V and T :

For change of state from p_1, V_1, T_1 to p_2, V_2, T_2 we can write

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

Since $V_1 = V_2$

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

Thus at constant volume, pressure of a gas is directly proportional to its absolute temperature. (3.14)

(d) Change in Interanal Energy :

$$\text{Change in internal energy} = \int_{T_1}^{T_2} mc_v dT \tag{3.15}$$

$$\therefore \quad U_2 - U_1 = mc_v (T_2 - T_1)$$

(e) Heat Transferred :

From the 1st law.

Heat transfer = change in internal energy + work transfer

$$\therefore \quad Q = \Delta U + W$$

Since $W = 0$ (3.16)

$$Q = \Delta U = mc_v (T_2 - T_1)$$

(f) Change in Enthalpy :

By the definition of enthalpy we can write

$$H_1 = U_1 + p_1V_1$$

$$H_2 = U_2 + p_2V_2$$

Change in enthalpy $H_2 - H_1 = (U_2 - U_1) + (p_2V_2 - p_1V_1)$

We have $p_1V_1 = mRT_1$ and $p_2V_2 = mRT_2$

and $U_2 - U_1 = mc_v (T_2 - T_1)$

Change in enthalpy $H_2 - H_1 = mc_v (T_2 - T_1) + mR (T_2 - T_1)$ [$\because c_p - c_v = R$]

$$= m (T_2 - T_1) (c_v + R)$$

$$= mc_p (T_2 - T_1) \tag{3.17}$$

This is general equation for change in enthalpy during any process since no property relation pertain to any specific process is involved in the derivation.

(2) Constant Pressure Process (Isobaric process)

(a) Representation on p–V Diagram :

A constant pressure process can be represnted as a horizontal line on p-V diagram as shown in Fig. 3.4 since pressure remain constant.

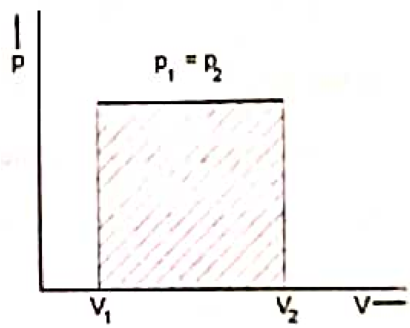


Fig. 3.4 Constant pressure process

(b) Work Done :

$$\text{Work done during the process} = \int_{V_1}^{V_2} pdV$$

$$W = p \int_{V_1}^{V_2} dV \text{ (since p is constant)}$$

$$\boxed{W = p (V_2 - V_1)} \tag{3.18}$$

It is area under the process on p–V diagram as shown in Fig. 3.4 by dashed line.

(c) Relation between p, V and T :

For change of state from p_1, V_1, T_1, to p_2, V_2, T_2 we have

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

Since $p_1 = p_2$ for constant pressure process

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \tag{3.19}$$

Thus at constant pressure, the volume of a perfect gas is directly proportional to the absolute temperature.

(d) Change in Internal Energy :

Since change in internal energy is a function of temperature alone.

The change in internal energy $\Delta U = mc_v (T_2 - T_1)$

(e) Heat Transfer :

From 1[st] law
$$Q = \Delta U + W$$
$$= mc_v (T_2 - T_1) + p (V_2 - V_1)$$
$$= mc_v (T_2 - T_1) + mR (T_2 - T_1) \quad [\because pV = mRT]$$
$$= m (T_2 - T_1)(c_v + R)$$
$$Q = mc_p (T_2 - T_1)$$

(f) Change in Enthalpy :

As discussed earlier
$$\Delta H = mc_p (T_2 - T_1)$$

(3) Constant Temperature Process or Isothermal Process

(a) Representation on p–V Diagram :

For isothermal process from Boyle's law we can write $pV = C$. It means that relation between p and V is p–V diagram represent rectangular hyperbola.

(b) Work Done :

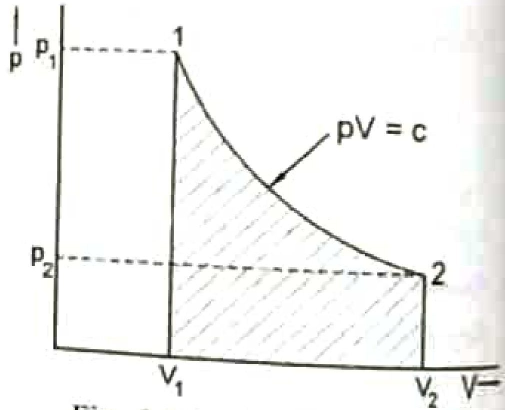


Fig. 3.5 Isothermal process

Work done $W = \int_{V_1}^{V_2} p dV$

For isothermal process $pV = C = p_1V_1$ $\qquad \therefore p = \frac{C}{V}$

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

If we substitute as $p_1V_1 = C$ we get

$$\therefore W = p_1V_1 \ln \frac{V_2}{V_1} = mRT_1 \ln \frac{V_2}{V_1}$$

For change of state from 1 to 2 we can write
$$p_1V_1 = p_2V_2 = C$$
$$\therefore \frac{V_2}{V_1} = \frac{p_1}{p_2}$$
$$\therefore \boxed{W = p_1V_1 \ln \frac{p_1}{p_2} = mRT_1 \ln \frac{p_1}{p_2}}$$

(c) Relation between p, V and T :

For change of state from p_1, V_1, T_1 to p_2, V_2, T_2 we can write
$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

Since $T_1 = T_2$ for isothermal process
$$p_1V_1 = p_2V_2$$

(d) Change in Internal Energy :

Since change in internal energy is a function of temperature only and during isothermal process temperature remain constant.

$$\Delta U = 0 \tag{3.26}$$

(e) Heat Transfer :

From the 1st law $\quad Q = \Delta U + W$

Since $dU = 0 \quad Q = W$

$$\therefore \quad Q = p_1 V_1 \, ln \frac{V_2}{V_1} = p_1 V_1 \, ln \frac{p_1}{p_2} \tag{3.27}$$

$$Q = mRT_1 \, ln \frac{V_2}{V_1} = mRT_1 \, ln \frac{p_1}{p_2} \tag{3.28}$$

(f) Change in Enthalpy :

Change in enthalpy $\Delta H = mc_p (T_2 - T_1)$

Since $T_1 = T_2$

$$\Delta H = 0 \tag{3.29}$$

(4) Adiabatic Process : (Q = 0)

A process in which there is no heat transfer to or from the system is known as adiabatic process.

Let, gas contained in a piston cylinder arrengement as shown in Fig. 3.6. If wall of piston and cylinder is assumed to be adiabatic wall there will be no heat transfer to or from the system. Gas can be expanded or compressed and depending upon the direction of work (expansion or compression), internal energy of the system will increase or decrease.

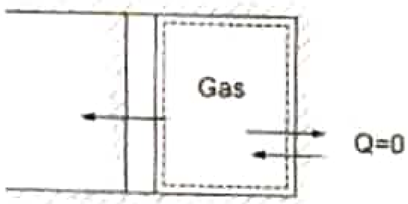


Fig. 3.6 Adiabatic process

Law of Adiabatic Process : Imp derivation

For non-flow process, first law in the differential form can be writter as

$$\delta Q = du + \delta W$$

$$\delta Q = c_v \, dT + pdv \tag{3.30}$$

[since only pdv work is significant in non flow process]

For adiabatic process $\delta Q = 0$

$$\therefore \quad 0 = c_v \, dT + pdv \tag{3.31}$$

R (air) = 0.26 KJ/kgK

We have characteristic gas equation

$$pv = RT$$

on diffentiating we get

$$pdv + vdp = RdT \tag{3.32}$$

Substitute for dT from equation (3.32) into equation (3.31)

$$c_v \cdot \frac{pdv + vdp}{R} + pdv = 0$$

$$\therefore \quad c_v (pdv + vdp) + R \times pdv = 0$$

$$\therefore \quad c_v (pdv + vdp) + (c_p - c_v) \times pdv = 0$$

$$\therefore \quad c_v \cdot vdp + c_p \cdot pdv = 0$$

$$\therefore \quad \frac{c_p}{c_v} \cdot \frac{dv}{v} + \frac{dp}{p} = 0 \quad [\because \text{ divide eq. by } pv \times c_v]$$

If we integrate the above equation we get

$\gamma \ln v + \ln p = \ln C$ where C is constant

$\therefore \quad pv^{\gamma} = C$

This is the equation for unit mass. For total mass we get

$pV^{\gamma} = C$

This is the law of adiabatic process or governing equation for adiabatic processes (Adiabatic expansion or compression)

(a) Representation on p–V Diagram :

The adiabatic process is represented on p-V diagram as shown in Fig. 3.7.

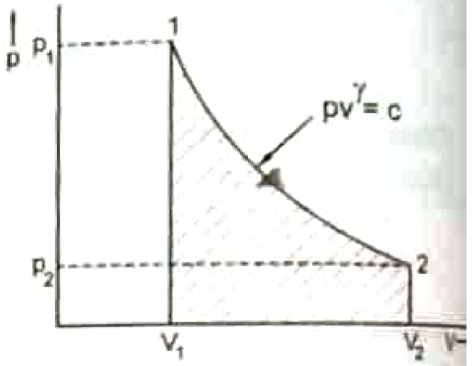


Fig. 3.7 Adiabatic process on p-V diagram

(b) Work Done during the Process :

Law of adiabatic process is $pV^{\gamma} = C$

For change of state p_1, V_1, T_1 to p_2, V_2, T_2 and generalised co-ordinate we can write

$$p_1V_1^{\gamma} = p_2V_2^{\gamma} = pV^{\gamma} = C \qquad (3.35)$$

$$\therefore \quad p = \frac{C}{V^{\gamma}}$$

$$\text{Now workdone} = \int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} \frac{C}{V^{\gamma}}\,dV = C\int_{V_1}^{V_2} \frac{dV}{V^{\gamma}}$$

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

If we substitute for C from equation (3.35)

$$= \frac{1}{-\gamma + 1}\left[p_2V_2^{\gamma} \cdot V_2^{-\gamma+1} - p_1V_1^{\gamma} \cdot V_1^{-\gamma+1}\right]$$

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

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

For ideal gas we can write $p_1V_1 = mRT_1$ and $p_2V_2 = mRT_2$

$$\therefore \quad W = \frac{mR(T_1 - T_2)}{\gamma - 1}$$

If we substitute for $R = c_p - c_v$ and $\gamma = \frac{c_p}{c_v}$

$$W = \frac{m \cdot (c_p - c_v)(T_1 - T_2)}{\frac{c_p}{c_v} - 1}$$

$$W = mc_v(T_1 - T_2)$$

(c) Relation between p, V and T :

One has two important relations the first one is law of adiabatic process $pV^{\gamma} = C$ and second from characteristic gas equation $\frac{pV}{T} = C$.

For change of state from p_1, V_1, T_1 to p_2, V_2, T_2 one can write this expressions as

$$p_1V_1^{\gamma} = p_2V_2^{\gamma} \tag{3.39}$$

and $$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} \tag{3.40}$$

To establish relation between volume and temperature we require to substitute for pressure from equation (3.39) in to equation (3.40).

From equaiton 3.39 $$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^{\gamma} \tag{3.41}$$

and from equation 3.40 $$\frac{p_1}{p_2} \cdot \frac{V_1}{V_2} = \frac{T_1}{T_2} \tag{3.42}$$

substitute in equaiton (3.42) from equation (3.41)

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

$$\therefore \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \tag{3.43}$$

From equation (3.41) we can write

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

substitute for $\frac{V_2}{V_1}$ in equation (3.43)

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \tag{3.44}$$

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

(d) Change in Internal Energy :

Change in internal energy = $mc_v (T_2 - T_1)$

Alternatevely, from the first law we can write

$$Q = \Delta U + W$$

Since $Q = 0$ for adiabatic process

$$\Delta U = -W$$

$$= -mc_v (T_1 - T_2)$$

$$\boxed{\Delta U = mc_v (T_2 - T_1)}$$

$\gamma = 1.4$ (air)

Thus, an important conclusion can be arrived at that for adiabatic process change in internal energy is numerically equal to work transfer during the process but sign is opposite.

(e) Heat Transfer :

During adiabatic process heat transfer equal to zero.

(f) Change in Enthalpy :

As seen earlier

$$\Delta H = mc_p (T_2 - T_1)$$

(5) Polytropic Process :

(a) Representation on p–V Diagram :

Many processes in actual practise follow the equation $pV^n = C$ where 'n' is a constant, such processes are called polytropic processes. All the four processes which have been discussed earlier are special cases of polytropic process. If we replace γ of an adiabatic process by 'n' for the polytropic process, we can get the relations between pressure, volume and temperature for polytropic process.

Thus we can have

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} \qquad (3.45)$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1} \qquad (3.46)$$

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^{n} \qquad (3.47)$$

Where 'n' is a polytropic index for any process.

When n = 0

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

$\therefore \quad p_1 = p_2$

i.e. the process is a *constant pressure* process.

When n = 1

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1} = \left(\frac{V_1}{V_2}\right)^{1-1} = \left(\frac{V_1}{V_2}\right)^{0} = 1$$

$\therefore$ The process is a *constant temperature* process.

When $n = \gamma$

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

$\therefore$ The process is *adiabatic* process.

When $n = \infty$

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

$$\therefore \quad \frac{V_1}{V_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} = \left(\frac{p_2}{p1}\right)^{\frac{1}{\infty}} = 1$$

$\therefore$ The process is *constant volume* process

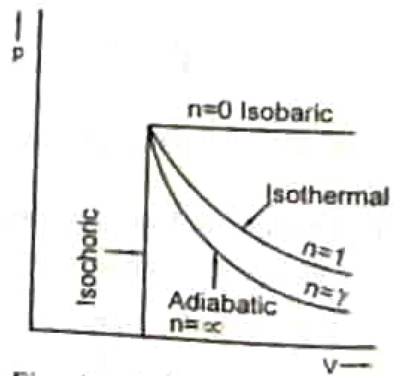


Fig. 3.8 Polytropic process

Different processes corresponding to different value of 'n' are ploted in Fig. 3.8.

(b) Work Done during Process :

$$W = \int_1^2 pdV$$

For polytropic process $pV^n = C$

$$\therefore \quad p_1V_1^n = p_2V_2^n = pV^n = C$$

$$p = \frac{p_1V_1^n}{V^n}$$

$$\therefore \quad W = p_1V_1^n \int_1^2 \frac{dV}{V^n} = p_1V_1^n \left[\frac{V_2^{-n+1} - V_1^{-n-1}}{-n+1}\right]$$

$$= \frac{p_2V_2^n \,.\, V_2^{-n+1} - p_1V_1^n \,.\, V_1^{-n+1}}{-n+1} \quad [\because p_1V_1^n = p_1V_2^n]$$

$$= \frac{p_2V_2 - p_1V_1}{-n+1} = \frac{p_1V_1 - p_2V_2}{n-1}$$

$$W = \frac{mR(T_1 - T_2)}{n-1} = \frac{p_1V_1 - p_2V_2}{n-1} \qquad (3.48)$$

(c) Relation between p, V and T :

From the law of polytropic process $pV^n = C$ and the relation $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$, by following the same procedure that was used for an adiabatic process one can establish the relation between p, V and T as

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

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

(d) Change in Internal Energy :

$$\Delta U = mc_v (T_2 - T_1)$$

(e) Heat Transfer during Process :

$$Q = \Delta U + W$$

$$= mc_v (T_2 - T_1) + \frac{p_1V_1 - p_2V_2}{n-1}$$

Now, $c_v = \frac{R}{\gamma - 1}$

$$\therefore \quad Q = \frac{mR(T_2 - T_1)}{\gamma - 1} + \frac{p_1V_1 - p_2V_2}{n-1}$$

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

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

$$= \frac{p_1V_1 - p_2V_2}{n-1}\left(\frac{\gamma - n}{\gamma - 1}\right) \qquad (3.49)$$

$$Q = \left(\frac{\gamma - n}{\gamma - 1}\right) \times \text{work done during process.}$$

(f) Change in Enthalpy :

$$\Delta H = H_2 - H_1 = mc_p (T_2 - T_1)$$

3.14 INDEX OF COMPRESSION OR EXPANSION :

If system changes its states from 1 to 2 the index of expansion or compression can be calculated as follow

From law of polytropic process $pV^n = C$, we can write for change of state from p_1, V_1 to p_2, V_2

$$p_1V_1^n = p_2V_2^n \qquad \therefore \frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^n$$

If we take logrithm on both side

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

$$\therefore \quad n = \frac{ln\left(\frac{p_1}{p_2}\right)}{ln\left(\frac{V_2}{V_1}\right)} \qquad (3.5$$

SOLVED PROBLEMS

Prob. 1 : A tank contains $3m^3$ of air at 25 bar absolute pressure. This air is cooled until its pressure and temperatu decrease to 15 bar and 21°C respectively. Determine change in internal energy, change in enthal and heat transfer. Take c_p =1.005 kJ/kg K and c_v = 0.718 kJ/kg K for air.

Solution : Since air is contained in a tank it is constant volume process.

$$V = \text{constant} = 3m^3$$

$$p_1 = 25 \text{ bar}, \ p_2 = 15 \text{ bar}, \ T_2 = 21°C = 294 \text{ K}$$

For constant volume process

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

$$\therefore \quad T_1 = \frac{25}{15} \times 294 = 490 \text{ K}$$

mass of air in the tank can be caluclated using characteristic gas equation $pV = mRT$

$$R = c_p - c_v = 1.005 - 0.718$$
$$= 0.287 \text{ kJ/kg K}$$

$$m = \frac{2500 \times 3}{0.287 \times 490} = 53.33 \text{ kg}$$

Change in enthalpy

$$H_2 - H_1 = mc_p (T_2 - T_1)$$
$$= 53.33 \times 1.005 (294 - 490)$$
$$= \mathbf{-10504.9 \ kJ}$$

i.e. enthalpy of air decreases by 10504.9 kJ during the process.

Change in internal energy

$$U_2 - U_1 = mc_v (T_2 - T_1)$$
$$= 53.33 \times 0.718 \times (294 - 490)$$
$$= \mathbf{-7505 \ kJ}$$

i.e. internal energy of air decreases by 7505 kJ during the process.

Since it is a constant volume process $W = 0$

From first law $Q = \Delta U + W$

since $W = 0 \qquad Q = \Delta U$

$\therefore \quad Q = -7505$ kJ

i.e. system rejects 7505 kJ of heat.

OBJECTIVE TYPE QUESTIONS

1. According to Boyle's law

(a) $V \propto \frac{1}{p}$ T = constant

(b) $V \propto p$ T = constant

(c) $p \propto \frac{1}{T}$ V = constant

(d) $p \propto T$ V = constant

2. According to Charle's law

(a) $V \alpha \frac{1}{T}$ p = constant

(b) $V \alpha \frac{1}{p}$ T = constant

(c) $V \alpha T$ p = constant

(d) $V \alpha p$ T = constant

3. Relation between specific gas constant (R) and Universal gas constant R_0, (M = molecular mass of a gas)

(a) $R = R_0M$ (b) $R_0 = RM$ (c) $R = R_0^2M$ (d) $R = R_0M^2$

4. Numerical value of Universal gas constant in SI system

(a) 8.3143 J/kg mol K (b) 8.3143 kJ/kg mol K (c) 8314.3 kJ/kg mol K (d) 831.43 kJ/kg mol K

5. At NTP one kg mol of all gases occupy _______ m^3 volume

(a) 2.24 (b) 22.4 (c) 224 (d) 0.224

6. Choose correct one

(a) $\frac{c_p}{c_v} = R$ (b) $\frac{c_v}{c_p} = R$ (c) $\frac{c_p}{c_v} = \gamma$ (d) $c_v - c_p = R$

7. Choose correct one

(a) $c_p = \frac{R}{\gamma - 1}$ (b) $R = \frac{c_p}{\gamma - 1}$ (c) $R = \frac{c_v}{\gamma - 1}$ (d) $c_v = \frac{R}{\gamma - 1}$

8. For constant pressure process which one of the following statements is correct ?

(a) W = Q (b) $W = \Delta U$ (c) $Q = \Delta H$ (d) $Q = \Delta U$

9. For isothermal process, which one of the following statements is correct ?

(a) W = Q (b) $W = -\Delta U$ (c) $Q = \Delta H$ (d) $Q = \Delta U$

10. For constant volume process, choose the wrong statement

(a) W = 0 (b) $Q = \Delta U$ (c) $W = -\Delta U$ (d) $\Delta U = mc_v\Delta T$

11. For adiabatic process, choose the wrong statement

(a) Q = 0 (b) $W = -\Delta U$ (c) $Q = \Delta U$ (d) $pV^\gamma = C$

12. Constant pressure process is a special case of polytropic process when value of polytropic index is

(a) 0 (b) 1 (c) γ (d) ∞

13. Isothermal process is a special case of polytropic process when value of polytropic index is

(a) 0 (b) 1 (c) γ (d) ∞

14. Specific heat constant volume (c_v) is defined as

(a) $c_v = \left(\frac{\partial u}{\partial T}\right)_v$ (b) $c_v = \left(\frac{\partial h}{\partial T}\right)_p$ (c) $c_v = \left(\frac{\partial u}{\partial T}\right)_p$ (d) $c_v = \left(\frac{\partial h}{\partial T}\right)_v$

15. Specific heat at constant pressure (c_p) is defined as...

(a) $c_p = \left(\frac{\partial u}{\partial T}\right)_v$ (b) $c_p = \left(\frac{\partial h}{\partial T}\right)_p$ (c) $c_p = \left(\frac{\partial u}{\partial T}\right)_p$ (d) $c_p = \left(\frac{\partial h}{\partial T}\right)_v$

16. Choose the wrong statement for isothermal process

(a) $p_1V_1 = p_2V_2$ (b) $p_1V_1 = mRT_2$ (c) $p_2V_2 = mRT_1$ (d) $\frac{p_1}{T_1} = \frac{p_2}{T_2}$

17. Constant Volume Process is also known as (January 2013)
(a) Isentropic Process (b) Isobaric Process
(c) Isothermal Process (d) Isochoric Process

18. $PV^n = C$ represents constant temperature process, when the value of n is (January 2013)
(a) n (b) 0 (c) γ (d) 1

19. Which one is correct? (January 2013)
(a) $PV = mRT$ (b) $PV = C_v(\gamma-1)mT$ (c) $P/\rho = RT$ (d) All above

20. An adiabatic process is one in which (Winter 2016)
(a) no heat enters or leaves the gas (b) the temperature of the gas changes
(c) the chnage in internal energy is equal to the mechanical work done
(d) all of the above

21. The ratio of specific heat at constant pressure (c_p) and specific heat at constant volume (c_v) is (Winter 2016)
(a) equal to one (b) less than one (c) greater than one (d) none of these

22. The behaviour of a perfect gas, undergoing any change in the variables which control physical properties, is governed by (Winter 2016)
(a) Boyle's law (b) Charles' law (c) Gay-Lussac law (d) All of these

23. Choose the incorrect relationship. (Summer 2017)
(a) $C_P + C_V = R$ (b) $C_P - C_V = R$ (c) $\gamma = \dfrac{C_P}{C_V}$ (d) $C_V = \dfrac{R}{(\gamma - 1)}$

24. Air is assumed to be (Winter 2017)
(a) Ideal gas (b) Real gas (c) Condensed gas (d) None of the above

25. During isothermal process __________ (Summer 2018)
(a) Work transfer is equal to heat transfer (b) Work transfer is zero
(c) Enthalpy remains constant (d) Heat transfer is zero

: ANSWERS :

1. (a) 2. (c) 3. (b) 4. (b) 5. (b) 6. (c) 7. (d) 8. (c) 9. (a) 10. (c)
11. (c) 12. (a) 13. (b) 14. (a) 15. (b) 16. (d) 17. (d) 18. (d) 19. (d) 20. (d)
21. (c) 22. (d) 23. (a) 24. (a) 25. (a) & (c)

❖ ❖ ❖

4

PROPERTIES OF STEAM

4.1 VAPOUR :

Under normal working conditions, fluids which can exist in a liquid as well as gaseous state are known as vapours. Examples : Steam (vapour phase of water), ammonia, Freon etc. They do not obey ideal gas equation and ideal gas law like Boyles' law, Charles' law etc. Under certain conditions they are used for approximate calculations.

4.2 PURE SUBSTANCE :

A pure substance is one which has homogeneous molecular structure and invariable chemical composition. Pure substance can exist in any of the three phases viz. solid, liquid and gas or it may exist in more than one phase. But its molecular structure and chemical composition is always remain same at all conditions. Example : Water.

Air is not a pure substance since at very low temperatures gases present in the air like N_2, O_2 liquefies at their boiling temperatures and chemical composition and molecular structure of air changes.

4.3 STEAM FORMATION :

Consider 1 kg of ice at −15°C and standard atmospheric pressure (101.325 kPa). Heat is now added at constant pressure. Various states pass through by the system is plotted on T–h diagram.

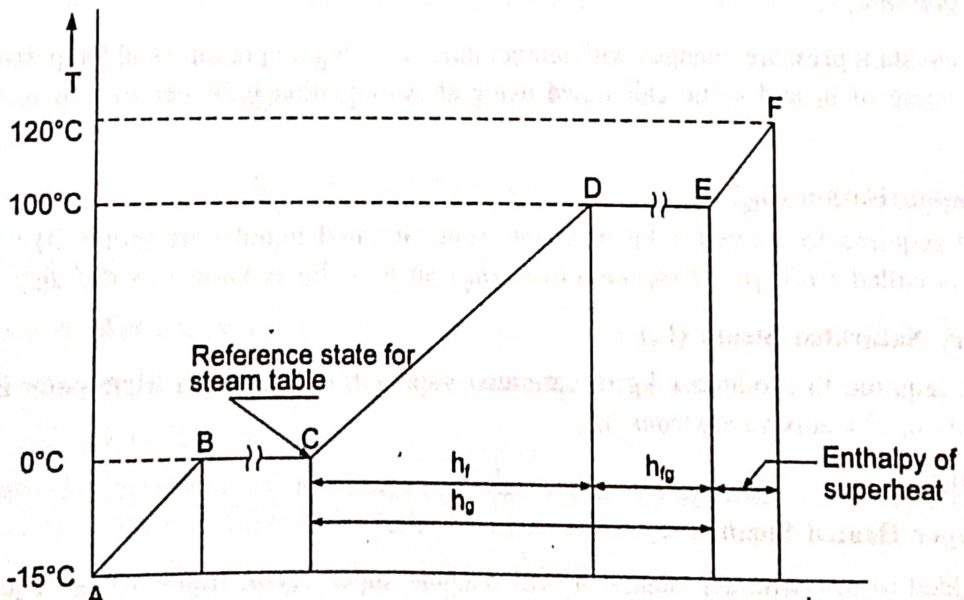


Fig. 4.1 Formation of steam

A–B : Sensible heat is added to ice and its temperature will increase up to its melting temperature (0°C).

B–C : Latent heat is added and ice starts melting at its melting temperature (0°C). Ice converts into water from and at 0°C. Heat added during this process is known as "latent heat of fusion of ice".

C–D : On further addition of heat, water temperature will increase up to its saturation temperature (at 101.325 kPa pressure, saturation temperature of water is 100°C). Point D is said to be saturated liquid state i.e. at point D we have *saturated water*.

D–E : During this process temperature remain constant and latent heat is added. At point D water starts boiling and it continues up to point E. At point E boiling ends. Amount of heat added during this process is called "latent heat of vapourisation".

Steam between the states D and E contain suspended water particles, such steam is known as *wet steam*. At point E we have complete conversion of water into steam and so steam does not have any suspended particles, such steam is known as *dry saturated steam*.

E–F : On further addition of heat, steam temperature will increase. Steam having temperature higher than its saturation temperature at particular pressure in called *superheated steam*. Steam having state beyond point E is superheated steam.

Difference between temperature of superheated steam and its saturation temperature is called *degree of superheat*. Here difference between t_F and t_E is called degree of superheat.

4.4 ENTHALPY OF STEAM :

From the 1st law, we know that heat added at constant pressure is equal to enthalpy change of the substance.

$$Q = \Delta U + W$$
$$Q = U_2 - U_1 + p(V_2 - V_1)$$
$$Q = (U_2 + pV_2) - (U_1 - pV_1)$$
$$= (H_2 - H_1)$$

(a) Enthalpy of Saturated Liquid (h_f) :

Amount of heat required to produce 1 kg of saturated liquid (point D) from the triple point of water (point C) at constant pressure is called *enthalpy of saturated liquid (h_f)*. Enthalpy of water at point D is called enthalpy of saturated water (h_f). In steam tables (Refer section 4.6) all property values for water is tabulated with reference to 0°C (point C) so h_f can be approximately calculated as

$$h_f = c_{pw}\,(T_{sat} - 0) \tag{4.1}$$

Where c_{pw} = Specific heat of water = 4.187 kJ/kg K

T_{sat} = Saturation temperature corresponding to steam formation pressure, °C

Specific heat at constant pressure changes with temperature, so at higher pressure and temperature, the difference between actual value of h_f and value calculated using above equation is higher so it is recommended to use tables.

(b) Enthalpy of Vapourisation (h_{fg}) :

Amount of heat required to convert 1 kg of water from saturated liquid state (point D) to saturated vapour state (point E) is called *enthalpy of vapourisation (h_{fg})* so $h_E - h_D$ is known as enthalpy of vapourisation.

(c) Enthalpy of Dry Saturated Steam (h_g) :

Amount of heat required to produce 1 kg of saturated vapour (point E) from triple point of water (point C) is called *enthalpy of dry saturated steam (h_g)*.

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

(d) Enthalpy of Super Heated Steam :

When heat is added to dry saturated steam, it will become superheated. Amount heat required to produce 1 kg of superheated steam (point F) from reference state (point C) is called enthalpy of superheated steam.

We can write $h_{sup} = h_g + c_{ps} (T_{sup} - T_{sat})$

Where c_{ps} = Specific heat of superheated steam. For practical calculation this value is assumed to be 2.1 kJ/kg K

T_{sup} = temperature of superheated steam, °C

h_{sup} can also be directly read from steam tables of superheated steam.

(e) Heat of Superheat :

Amount of heat required for superheating of steam from dry saturated state is called "heat of superheat".

$\therefore$ Heat of superheat = $c_{ps} (T_{sup} - T_{sat})$ kJ/kg

(f) Dryness Fraction :

Ratio of the mass of dry saturated vapour, to the total mass of wet vapour is called dryness fraction. It is designated by x.

$$\therefore \quad x = \frac{m_s}{m_s + m_w} \tag{4.2}$$

Where m_s = mass of dry saturated vapour

m_w = mass of liquid particles in suspension.

At saturated liquid state dryness fraction is zero and its value at saturated vapour state is 1. So $0 \le x \le 1$.

(g) Quality of Vapour :

When dryness fraction is expressed in percentage it is called quality of vapour

Quality of vapour = $100 \cdot x$

(h) Wetness Fraction :

$$\text{Wetness fraction} = \frac{m_w}{m_s + m_w} \tag{4.3}$$

Thus it is $(1 - x)$.

(i) Priming :

When wetness fraction is expressed in percentage, it is called priming.

(j) Enthalpy of Wet Vapour (h) :

One kg of wet vapour having dryness fraction x contains x kg of dry saturated steam at saturation temperature (T_{sat}) and (1 – x) kg of liquid particles at the same temperature. So enthalpy of 1 kg of wet vapour is equal to enthalpy of x kg of dry saturated vapour plus enthalpy of (1 – x) kg of saturated liquid. Hence,

$$h = (1 - x) \cdot h_f + x \cdot h_g$$

$$= (1 - x)\, h_f + x\, (h_f + h_{fg}) \qquad [\, h_g = h_f + h_{fg}]$$

$$h = h_f + x \cdot h_{fg} \tag{4.4}$$

So we can say that *specific enthalpy of vapourisation* of wet vapour is equal to '$x \cdot h_{fg}$'.

4.5 SPECIFIC VOLUME :

(a) Specific Volume of Wet Steam (v) :

Similar to enthalpy, specific volume of wet steam can be written as

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

At low pressures the specific volume of saturated liquid (v_f) is negligible compared to specific volume of saturated vapour (v_g). hence generally the term $(1 - x)\, v_f$ is neglected.

$$\therefore \quad v = x \cdot v_g \tag{4.5}$$

(b) Specific Volume of Superheated Steam (v_{sup}) :

For steam generation at constant pressure specific volume of superheated steam can be calculated using Charles' law.

$$\frac{v_{sup}}{T_{sup}} = \frac{v_{sat}}{T_{sat}} \qquad (4.6)$$

$$\therefore \quad v_{sup} = \frac{v_g}{T_{sat}} \times T_{sup} \qquad [\because v_{sat} = v_g]$$

Since density (ρ) is reciprocal of specific volume density of wet, saturated and superheated steam can be calculated by $\rho = \frac{1}{v}$ (kg/m³).

4.6 STEAM TABLES :

- → From experimental study, various properties of steam like enthalpy, volume, internal energy are tabulated at various pressure and temperature.
- → It may be pressure base or temperature base.
- → It is tabulated for specific properties.
- → Properties are tabulated from triple point of water (≈ 0°C) to critical point of steam.
- → All values are calculated with triple point of water (≈ 0°C) as reference point, means at 0°C enthalpy, internal energy and entropy is taken as zero.
- → Steam tables are given in Appendix-I.

4.7 INTERNAL ENERGY OF STEAM :

Internal energy of steam can be calculated using definition of enthalpy.

We have $h = u + pv$

$\therefore \quad u = h - pv$

To calculate internal energy (u) of saturated, wet or superheated steam, appropriate value of enthalpy (h) and specific volume (v) is to be substituted. Here 'pv' is known as *work done during evaporation.*

4.8 THROTTLING OF STEAM :

When fluid passes through restricted opening it is said to be throttled. It is a *steady flow process*. Steady flow energy equation (SFEE) is

$$h_1 + \frac{C_1^2}{2} + gz_1 + Q = h_2 + \frac{C_2^2}{2} + gz_2 + W$$

During throttling no work is developed or consumed hence W = 0.

Change in elevation is neglegible $\therefore z_1 = z_2$

Change in K.E is also neglegible $\therefore C_1 = C_2$

If we assume the process to be adiabatic, SFEE can be reduced to $h_1 = h_2$

i.e. throttling is an *isenthalpic process.*

4.9 MEASUREMENT OF DRYNESS FRACTION :

Four types of steam calorimeters are used to measure dryness fraction of steam.

(1) Barrel or Bucket Calorimeter :

Construction :

As shown in Fig. 4.2 Barrel calorimeter consists of copper calorimeter with wooden cover. Steam from the main steam pipe is taken to the calorimeter through sampling tube. Quantity of steam to the calorimeter is controlled by control valve. Pressure gauge indicate the pressure of steam and thermometer is to measure temperature of water in the calorimeter.

Working :

First the calorimeter is weighted and with known value of specific heat of copper, the water equivalent is calculated. Generally this value is given by supplier. Known quantity of water is taken into calorimeter. From main steam pipe certain quantity of steam is taken to steam calorimeter through sampling tube. In calorimeter, steam and water mixes together and hence condensation of steam takes place. Latent and sensible heat of steam is given to water and its temperature will increase. Due to condensation of steam mass of water in the calorimeter increases.

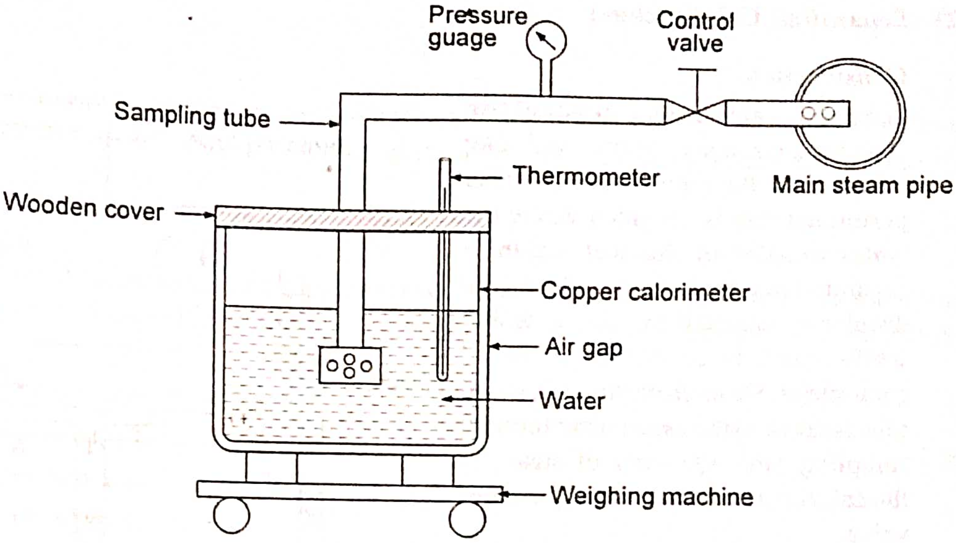


Fig. 4.2 Barrel calorimeter

Calculation :

From energy balance we can write

Amount of heat lost by steam = Heat gain by water and calorimeter.

$$m_s (h_{f_1} + x \cdot h_{fg_1} - h_{f_2}) = m_c c_{pc} (t_2 - t_1) + m_w c_{pw} (t_2 - t_1)$$

$$= (m_c c_{pc} + m_w c_{pw}) (t_2 - t_1) \qquad (4.7)$$

$$= \left(\frac{m_c c_{pc}}{c_{pw}} + m_w\right) c_{pw} (t_2 - t_1)$$

Where $\left(\frac{m_c c_{pc}}{c_{pw}} + m_w\right)$ is called 'Water equivalent of calorimeter'.

Here,

m_w = initial mass of water in calorimeter

m_s = mass of steam, it is difference between final mass and initial mass of water in calorimeter

t_1 = initial temperature of water in calorimeter, in °C

t_2 = final temperature of water in calorimeter, in °C

h_{f_1} = specific enthalpy of saturated liquid at steam pressure, kJ/kg

h_{f_2} = specific enthalpy of saturated liquid at t_2, kJ/kg

h_{fg_1} = latent heat of evaporation at steam pressure, kJ/kg

c_{pc} = specific heat of calorimeter

c_{pw} = specific heat of water

x = dryness fraction of sample steam which is to be determined

In above calculation heat loss from calorimeter is neglected.

Limitation :

(1) At higher temperature heat losses are higher and calculated value is lower than actual value.

(2) It is an approximate method.

(2) Separating Calorimeter :

Construction :

Separating calorimeter consists of two chambers, viz. inner chamber and outer chamber. At the top of inner chamber perforated tray is provided where the water droplet in the wet steam is separated due to its inertia. Separated droplet is collected in inner chamber while steam is condensed in barrel calorimeter. Steam from the main steam pipe is taken to the calorimeter through sampling tube. Quantity of steam to the calorimeter is controlled by control valve.

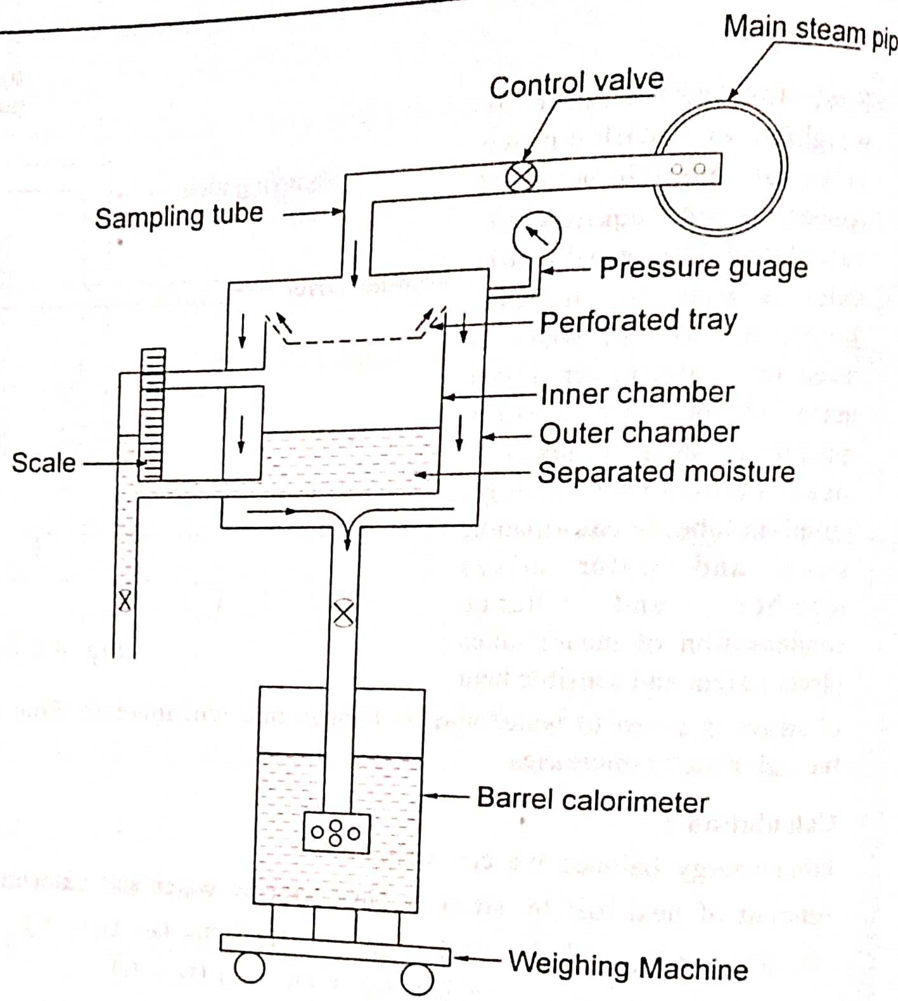


Fig. 4.3 Separating calorimeter

Working :

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

Calculation :

Let m_w = mass of water collected in inner chamber, kg

m_s = mass of steam condensed in barrel calorimeter, kg

then dryness fraction x can be calculated from its definition.

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

Limitations :

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

(3) Throttling Calorimeter :

Construction :

Fig. 4.4 shows throttling calorimeter which essentially consists of throttle valve, pressure gauge, thermometer and manometer. Through sampling tube steam is taken to throttle valve where steam is throttled from higher pressure to lower pressure. Pressure gauge is used to measure pressure before throttling and manometer is used to measure pressure after throttling. Thermometer is used to

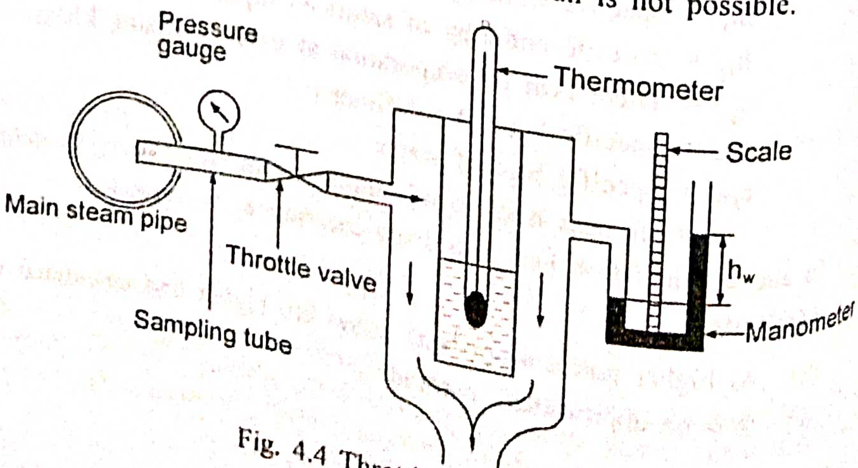


Fig. 4.4 Throttling calorimeter

measure temperature after throttling.

Working :

With full open steam stop valve, steam is allowed to throttle until steady pressure and temperature is reached. At steady state condition pressure before throttling (p_1) and after throttling (p_2) and temperature after throttling is measured.

Calculation :

As seen earlier during throttling process, enthalpy of fluid remain constant. This fact is used to measure dryness fraction of wet steam using this calorimeter. To measure dryness fraction condition of steam after throttling must be superheated steam.

Enthalpy before throttling = Enthalpy after throttling

$$\therefore h_{f1} + x \cdot h_{fg_1} = h_{g_2} + c_{ps} (T_{sup} - T_{sat}) \qquad (4.8)$$

Where h_{f_1} = enthalpy of saturated liquid at p_1, kJ/kg

h_{fg_1} = latent heat of steam at p_1, kJ/kg

h_{g_2} = enthalpy of saturated vapour at p_2, kJ/kg

c_{ps} = specific heat of steam, generally assumed 2.1 kJ/kg K

T_{sup} = temperature of superheated steam after throttling, °C

T_{sat} = saturation temperature at p_2, °C

x = dryness fraction of steam which is to be calculated

Limitation :

Condition of steam after throttling must be superheated.

Due to this limitation, dryness fraction of the steam should not be too low (generally dryness fraction before throttling should be greater than 0.9).

(4) Combined Separating and Throttling Calorimeter :

As it is known that complete separation of water droplets from steam by mechanical means is not possible but separating calorimeter improve the dryness fraction of steam. Throttling calorimeter requires high quality steam at its inlet so that after throttling, steam is superheated. So the limitations of both calorimeters can be overcome if they are used in series and one can have accurate estimation of dryness fraction.

Construction :

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

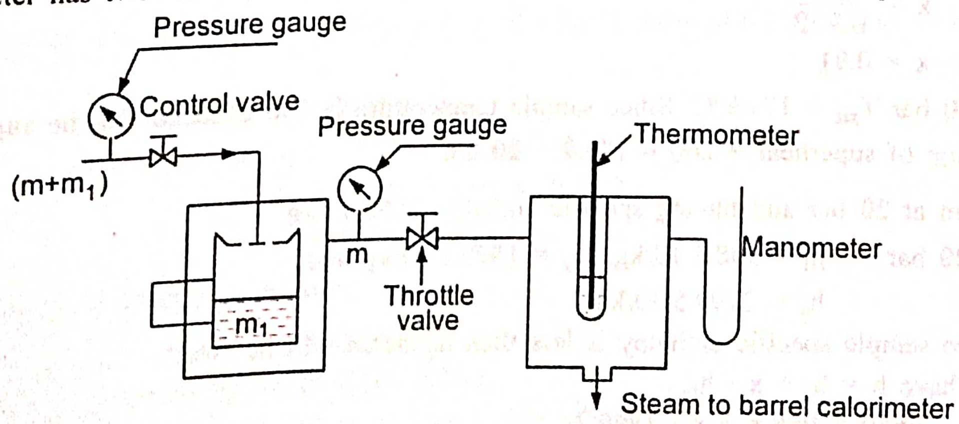


Fig. 4.5 Combined separating and throttling calorimeter

Working :

Steam first passes through separating calorimeter where moisture is separated from wet steam and its dryness fraction improves. Then steam passes through throttling calorimeter and at steady state condition various readings are taken.

Calculation :

Let $(m + m_1)$ amount of wet steam enters the separating calorimeter. Where 'm' is mass of steam entering the throttling calorimeter which is condensed after passing through it. m_1 is mass of water droplet separated in separating calorimeter.

If x_1 is the dryness fraction of steam measured by separating calorimeter then

$$x_1 = \frac{m}{m + m_1}$$

If x_2 is the dryness fraction of steam entering throttling calorimeter, then x_2 can be calculated using equation

$$h_{f_1} + x_2 \cdot h_{fg_1} = h_{g_2} + c_{ps} (T_{sup} - T_{sat})$$

Where h_{f_1}, h_{fg_1}, h_{g_2}, T_{sup} and T_{sat} has same meaning as in case of throttling calorimeter.

Let 'x' be the initial dryness fraction of steam then the original water droplet in the sample is $(1 - x)(m + m_1)$ kg. Out of this $(1 - x_1)(m + m_1)$ is removed by separating calorimeter and $(1 - x_2) \cdot m$ kg is passed through throttling calorimeter.

$$\therefore \quad (1 - x)(m + m_1) = (1 - x_1)(m + m_1) + (1 - x_2) \cdot m$$

$$\therefore \quad 1 - x = (1 - x_1) + \frac{(1 - x_2)\, m}{m + m_1}$$

but we have $x_1 = \dfrac{m}{m + m_1}$

$$\therefore \quad 1 - x = 1 - x_1 + x_1 - x_1 \cdot x_2$$

$$\therefore \quad x = x_1 \cdot x_2$$

EXERCISES

1. Explain steam formation at constant pressure.
2. Differntiate among wet, dry saturated and superheated steam.
3. Define dryness fraction of steam.
4. Define enthalpy of saturated liquid, enthalpy of evaporation, enthalpy of wet steam, enthalpy of dry saturated steam and enthalpy of superheated steam.
5. How internal energy of steam in various conditions can be calculated ?
6. Explain throttling process ?
7. With neat sketch explain (a) Barrel calorimeter (b) Separating calorimeter (c) Throttling calorimeter (d) Combined separating and throttling calorimeter.
8. State limitations of above calorimeters.
9. For combined separating and throttling calorimeter prove $x = x_1 \cdot x_2$.

PROBLEMS

1. Determine condition of steam for following cases :
   (a) Pressure 10 bar, Specific enthalpy 2640 kJ/kg
   (b) Pressure 15 bar, Temperature 197.4°C
   (c) Pressure 10 bar, Temperature 200°C
   (d) Pressure 7 bar, Specific volume 0.26 m^3/kg
   (e) Pressure 10 bar, Enthalpy = 5000 kJ, mass = 2 kg

   [Ans. wet, wet, superheated, wet, wet]

2. For following cases calculate enthalpy, work done during evaporation and internal energy of steam when steam is at 15 bar pressure. (a) dryness fraction 0.9 (b) dry saturated steam (c) temperature of steam 250°C.

[Ans. (a) $h = 2597.47$ kJ/kg $W = 178.2$ kJ/kg
$u = 2419.27$ kJ/kg
(b) $h = 2792.2$ kJ/kg $W = 198$ kJ/kg
$u = 2594.2$ kJ/kg
(c) $h = 2923.3$ kJ/kg $W = 228$ kJ/kg
$u = 2695.3$ kJ/kg

3. Two kg of saturated water at 100°C is converted into dry saturated steam at same temperature. Determine the percentage of energy supplied that goes to increase the internal energy of steam. How is the remaining energy utilised ? **[Ans.** 92.5%, Rest is to do external work]

4. A stream of steam at 10 bar and 300°C is mixed with the other stream of steam at 10 bar with $x = 0.87$ in the ratio of 1:1.2. Calculate the final condition and specific enthalpy of steam.
[Ans. Wet steam, $x = 0.986$, $h = 2748$ kJ/kg]

5. Steam at 15 bar is throttled to 2 bar and 135°C. Determine condition of steam before throttling. Hence calculate dryness fraction or degree of superheat whichever may be the case. **[Ans.** Wet steam, $x = 0.973$]

6. In a test with combined separating and throttling calorimeter following data was obtained.

Steam discharge from throttling calorimeter	22 kg
Water separated in separating calorimeter	2.3 kg
Initial pressure of steam	13 bar
Pressure of steam after throttling	114 mm of Hg
Barometer reading	748.8 mm of Hg
Temperature of steam in throttling calorimeter	150°C

Calculate dryness fraction of steam at entry to the calorimeter. **[Ans.** 0.9012]

7. A combined separating and throttling calorimeter is used to determine the dryness fraction of steam in main. The pressure of the steam in the main and the separator is 6.9 bar. After throttling to 1.5 bar the temperature is 127°C. During a ten minute test 0.09 kg of water is collected at the separator and 1.53 kg of condensate is collected after throttling. Calculate the dryness fraction of steam in the main. **[Ans.** 0.927]

8. A spherical shell of 30 cm in radius contains saturated steam and water at 300°C. Calculate the mass of each if their volumes are equal. **[Ans.** $m_w = m_f = 40.242$ kg, $m_s = m_g = 2.616$ kg]

9. A tank contains 100 kg of liquid water and 5 kg of water vapour under saturation condition at 20°C. Calculate the volume of tank and moisture content of the mixture. **[Ans.** $V = 289$ m^3, $x = 0.0476$]

10. Two boilers A and B are delivering steam in equal proportion to common main. Both the boilers operate at pressure of 14 bar which is also the pressure of steam in the main. The boiler A is fitted with superheater and supplies steam at 300°C. If the temperature of resulting mixture in the steam main is 235°C, estimate the quality of steam supplied by the boiler B. **[Ans.** $x = 0.973$]

OBJECTIVES TYPE QUESTIONS

1. When heat is added to the water and if its temperature does not change, the heat added is called
(a) latent heat (b) isothermal heat (c) sensible heat (d) constant pressure heat

2. Condition of steam between saturated liquid and saturated vapour state is called
(a) superheated (b) saturated (c) wet (d) subcooled

3. Normal boiling point (boiling point at atmospheric pressure) of water is equal to
(a) 273°C (b) 0°C (c) 418.7°C (d) 100°C

4. Dryness fraction of steam is defined as
(a) $x = \frac{m_w}{m_s + m_w}$ (b) $x = \frac{m_s + m_w}{m_w}$ (c) $x = \frac{m_s}{m_s + m_w}$ (d) $x = \frac{m_s + m_w}{m_s}$

5. If dryness fraction of steam equals to 1, condition of steam will be
(a) subcooled (b) wet (c) dry saturated (d) superheated

6. Specific enthalpy of vaporization of wet steam is given by
(a) h_{fg} (b) $x \cdot h_{fg}$ (c) pv_g (d) $x \cdot pv_g$

7. Throtting is
(a) isothermal process (b) isenthalpic process
(c) constant pressure process (d) constant entropy process

8. Water equivalent of barrel calorimeter is defined by the relation
(a) $\frac{m_c c_{pc}}{m_w}$ (b) $\frac{m_c c_{pc}}{c_{pw}}$ (c) $\frac{m_w c_{pw}}{m_c}$ (d) $\frac{m_w c_{pw}}{c_{pc}}$

9. To have accurate estimation of dryness fraction by separating calorimeter, the dryness fraction of steam leaving the calorimeter must be
(a) 1 (b) > 0.9 (c) > 0.95 (d) < 1

10. To determine dryness fraction of steam using throttling calorimeter, the condition of steam after throttling must be
(a) wet (b) superheated (c) dry saturated (d) $x > 0.95$

11. For combine separating and throttling calorimeter, dryness fraction of steam can be calculated using relation
(a) $x = x_1 + x_2$ (b) $x = x_1 \cdot x_2$ (c) $x = \frac{x_1}{x_2}$ (d) $x = x_1 - x_2$

12. For steam, an isothermal process is also a constant ________ process in wet region
(a) volume (b) enthalpy (c) internal energy (d) pressure

13. For steam, which one of the following is the correct statement
(a) $v_f << v_g$ (b) $v_f >> v_g$ (c) $h_f << h_g$ (d) $h_f >> h_g$

14. Dryness fraction of wet steam is ________. (Jan. 2011)
(a) greater than 1 (b) = 1 (c) less than 1 (d) 0

15. Superheated vapour behaves (Winter 2016)
(a) exactly as gas (b) as steam (c) as ordinary vapour (d) approximately as a gas

16. Steam coming out of the whistle of pressure cooker is ________. (Summer 2017)
(a) Dry and saturated vapour (b) Wet vapour
(c) Superheated vapour (d) Ideal gas

17. Superheating of steam is done at constant (Summer 2017)
(a) pressure (b) volume (c) temperature (d) enthalpy

18. When heat is added to the water and if its temperature does not change, the heat added is called (Summer 2017)
(a) latent heat (b) isothermal heat (c) sensible heat (d) constant pressure heat

19. Dryness fraction of fully wet steam is ________. (Winter 2017)
(a) 0 (b) 1 (c) 0.5 (d) None of the above

: ANSWERS :

1. (a)	2. (c)	3. (d)	4. (c)	5. (c)	6. (b)	7. (b)	8. (b)	9. (a)	10. (b)
11. (b)	12. (d)	13. (a)	14. (c)	15. (d)	16. (b)	17. (a)	18. (a)	19. (a)	

❖ ❖ ❖

5

HEAT ENGINES

5.1 HEAT ENGINE :

Heat engine is a device in which net heat is added to the engine and net work transfer from the engine. Thus for heat engine net heat transfer and net work transfer both are positive in a cycle executed by the engine.

Heat engines can be classified in two catagories

(1) External combustion engines

(2) Internal combustion engines

External Combustion Engines :

In this type of engines combustion of fuel take place outside the engine. Generally heat liberated by combustion of fuel is transferred to working fluid of the engine.

Examples : Steam engines, steam turbines, close cycle gas turbines

In steam engines and steam turbines combustion of fuel take place in boiler, which produces high pressure steam. This steam is expanded in steam engines or steam turbines which produce mechanical work.

Internal Combustion Engines (I. C. Engines) :

In I. C. Engines combustion of of fuel take place in the engines. Combustion of fuel takes place with help of air. Combustion product itself are the working fluid of engines.

Examples : Petrol engines, Diesel engines, Open cycle gas turbines

Difference between External Combustion Engines and Internal Combustion Engines :

Internal Combustion Engines	External Combustion Cngines
(1) They are compact in size and hence suitable for small capacity.	(1) They are bulky and hence designed for large capacity.
(2) More refined fuel is required which is costly. Generally used with liquid and gaseous fuel.	(2) Cheaper fuels can be used. Generally solid, liquid and gaseous fuels are used.
(3) Due to less components, comp-lexity is less.	(3) More complex.
(4) Lower efficiency.	(4) Higher efficiency.
(5) More pollutent.	(5) Less pollutent.

5.2 WORKING FLUID :

All thermodynamic systems require some working substance in order to perform various operations to execute a thermodynamic cycle. These working substance are known as working fluids. They can readily be compressed or expanded. They also receive or reject heat. Common examples of working fluids are air and steam. *Analysis of all heat engine cycles involve calculation of various properties of these working fluids.*

5.3 ESSENTIAL COMPONENTS OF HEAT ENGINES :

A thermodynamic cycle is executed by heat engine to produce net positive work from net positive heat addition to the engine. This cycle is known as heat engine cycle. Sometime it also refers as power cycle. A heat engine cycle consists of series of processes. Each process requires some device or component for process to take place. The essential component of heat engine are as follows.

(1) **Heat Source :** It is a reservoir of heat from which heat is supplied to working fluid. Examples : Furnace of boiler, Combustion chamber of I.C Engines.

(2) **Heat Sink :** A heat sink is a low temperature reservoir where heat is rejected by the working fluid.

(3) **Working Fluid :** Substance which receive and reject heat and undergoes various processes of heat engine cycle is called working fluid.

(4) **Expander or Turbine :** It is a device in which working fluid is expanded and work is available.

(5) **Compressor or Pump :** It is a device in which pressure of working fluid increases. It may be coupled to expander or it may be connected to separate power source.

5.4 CARNOT CYCLE :

Carnot conceived an ideal cycle in which all processes are reversible. Carnot cycle is represented on p-V diagram (Fig. 5.1). Processes of Carnot cycle are as follow.

Process 4–1 : Heat is added to the system (of working fluid) at constant temperature T_H from the source. Working substance is expanded reversibly at constant temperature.

Process 1–2 : Working fluid undergoes a reversible adiabatic expansion. Temperature will reduce from T_H to T_L.

Process 2–3 : Working fluid rejects heat at constant temperature T_L to sink reversibly. Working fluid is said to be compressed at constant temperature T_L.

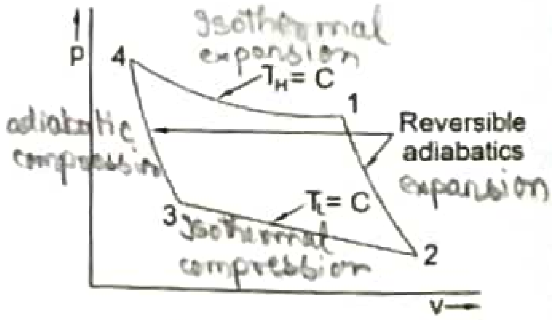


Fig. 5.1 Carnot cycle

Process 3–4 : Working fluid undergoes a reversible adiabatic compression and its temperature will increase from T_L to T_H.

5.4.1 Efficiency of Carnot Cycle :

Process 4–1 is reversible isothermal heat addition process

From 1st law $Q = \Delta U + W$

For ideal gas internal energy depends only on temperature hence for this process $\Delta U = 0$

$$\therefore \quad Q = W$$

W for constant temperature process (and hence hyperbolic process, pV = C)

$$Q_S = W = p_4 V_4 \ ln \frac{V_1}{V_4} = mR \ T_H \ ln \frac{V_1}{V_4}$$

Where Q_S is heat supplied

Process 2–3 is isothermal heat rejection process so similar to process 1–2 we can write

$$\therefore \quad Q_R = W = p_2 V_2 \ ln \frac{V_2}{V_3} = mR \ T_L \ ln \frac{V_2}{V_3}$$

Where Q_R is heat rejected

[equation is written is such a way that Q_R is +Ve number]

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{mR\,T_L\,ln\,\frac{V_2}{V_3}}{mR\,T_H\,ln\,\frac{V_1}{V_4}}$$

$$= 1 - \frac{T_L\,ln\,\frac{V_2}{V_3}}{T_H\,ln\,\frac{V_1}{V_4}}$$

{ Ideal carnot engine is also less than 100% efficient }

Now for process 2–3 and 4–1 we can write

$$\frac{T_H}{T_L} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$$

$$\therefore \quad \frac{V_2}{V_1} = \frac{V_3}{V_4} \quad \text{OR} \quad \frac{V_1}{V_4} = \frac{V_2}{V_3}$$

$$\therefore \quad \eta = 1 - \frac{T_L}{T_H} \qquad (5.1)$$

From the equantion it is evident that *efficiency of Carnot cycle does not depend on working substance, but depends only on temperatures of heat addition and heat rejection.*

5.4.2 Limitation of Carnot Cycle :

(1) To have heat addition and heat rejection at constant temperature piston has to move as slowly as possible. While during adiabatic expansion and compression piston has to move as quickly as possible. Since isothermal and adiabatic processes take place during the same stroke piston has to move slowly during part of the stroke and quickly during remaining stroke. This is practically impossible.

(2) In actual practice friction is always present.

(3) Perfectly adiabatic wall is hypothesis.

(4) In actual practice, finite temperature difference is always required for heat transfer. This means heat transfer is not reversible.

5.5 CARNOT VAPOUR CYCLE :

Components of Carnot vapour cycle is shown in Fig. 5.2 and same is represented on p–V diagram in Fig. 5.3.

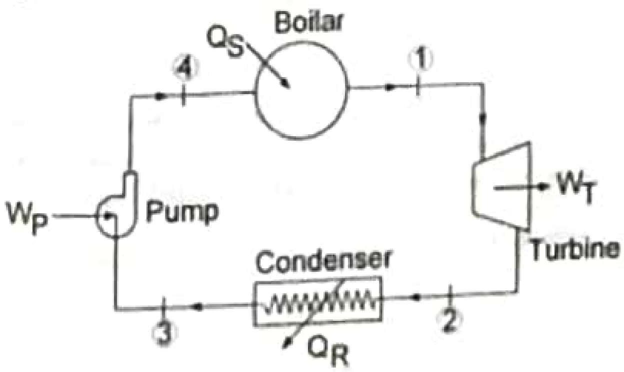


Fig. 5.2 Components of Carnot vapour cycle

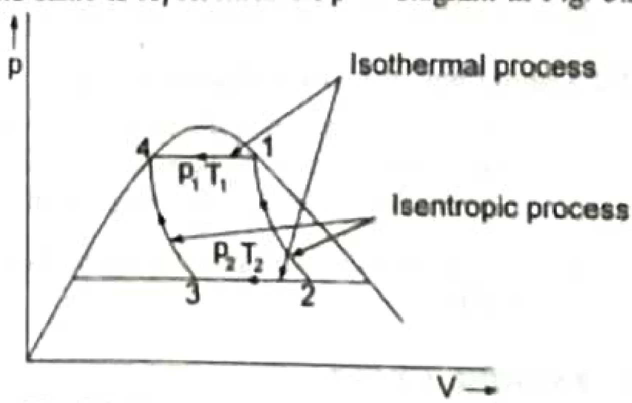


Fig. 5.3 Carnot vapour cycle on p-V diagram

As shown, during process 4–1 heat is added in boiler at constant pressure which is also an isothermal process in wet region. Process 1-2 is expansion of steam in turbine which develops work W_T. During process 2–3 heat is rejected in condenser to cooling medium (generally water) at constant pressure and temperature. Process 3-4 is pumping/compression of wet steam from condenser pressure to boiler pressure which requires work input of W_P.

5.5.1 Efficiency of Carnot Vapour Cycle :

For unit mass of substance

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

Work input during pumping/compression $W_P = (h_4 - h_3)$

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

$= (h_1 - h_2) - (h_4 - h_3)$

Heat supplied = $h_2 - h_1$

$$\eta_{Carnot} = \frac{\text{Net work developed}}{\text{Heat supplied}}$$

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

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

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

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

Entropy is defined as $ds = \frac{\delta Q_{rev}}{T}$

So heat rejected (Q_R) can be written as $Q_R = T_2 (s_2 - s_3)$ and heat supplied (Q_S) can be written as $Q_S = T_1 (s_1 - s_4)$. Since processes 1–2 and 3–4 are isentropic, $s_1 = s_2$ and $s_3 = s_4$.

$$\therefore \quad \eta_{Carnot} = 1 - \frac{T_2 (s_2 - s_3)}{T_1 (s_2 - s_3)}$$

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

$$= 1 - \frac{T_L}{T_H} \quad (5.2)$$

Thus from the analysis of *Carnot vapour cycle also it is evident that efficiency of Carnot cycle does not depend upon working fluid but depends only on temperatures of heat addition and heat rejection.*

5.5.2 Limitations of Carnot Vapour Cycle :

(1) Steam is partially condensed in the condenses at point 4. At this point steam is a mixture of water and vapour which is to be pumped at state 1 which is saturated liquid. Practically it is impossible to built a pump which can pump a mixture of water and steam and delivers it as saturated liquid.

(2) Complete expansion process takes place in wet region which causes errosion and corrosion of turbine blades.

5.6 RANKINE CYCLE :

We have seen that it is difficult to pump mixture of vapour and liquid and deliver it as saturated liquid. This is eliminated in Rantjne cycle by complete condensation of vapour in condenser and then pumping the water isentropically to the boiler pressure. Similary in boiler heat is added at constant pressure rather then at constant temperature. In superheat region, heat addition at constant temperature requires expansion of steam which is eliminated in constant pressure heat addition.

Rankine cycle consists of four processes. This processes take place in four components as shown in Fig. 5.4. (1) Boiler (2) Turbine (3) Condenser (4) Feed pump.

Working of Rankine cycle : Various processes of Rankine cycle are represented on p–V diagram in Fig. 5.5.

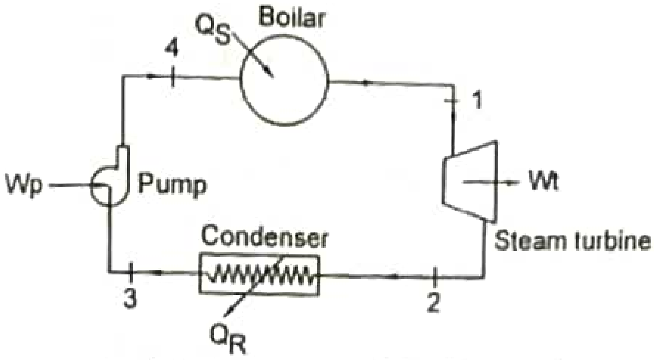


Fig. 5.4 Components of Rankine cycle

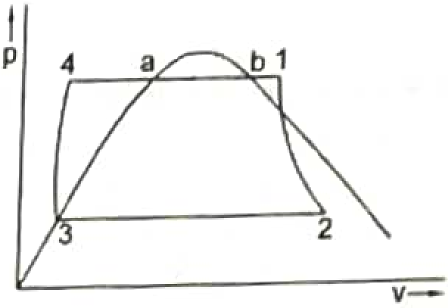


Fig. 5.5 Rankine cycle

Process 1–2 : Superheated, dry saturated or wet steam expanded isentropically by steam turbine from boiler pressure to condenser pressure. In practical cycle state 1 is always superheated steam.

Process 2–3 : Steam is condensed in condenser at constant pressure. It leaves the condenser as saturated liquid. Steam is condensed by transferring heat to cooling water.

Process 3–4 : Saturated water at condenser pressure is pumped to boiler pressure.

Process 4–1 : Heat is supplied to water at constant pressure in boiler. During process 4–a, sensible heat is added to water and its temperature is increased to saturation temperature corresponding to boiler pressure. This is done by feed water heater and economiser. During process a–b latent heat is supplied to water and saturated water converts into saturated vapour. During process b–1 steam is superheated in superheater.

Assuming steady flow and neglecting change in K.E. and P.E., thermal efficiency of Rankine cycle can be obtained by applying the steady flow energy equation (SFEE) to each of the four components of Rankine cycle.

Boiler : Since heat is supplied in boiler and no work developed by it we can write

$$Q_S = h_1 - h_4 \tag{5.3}$$

Turbine : For isentropic (reversible adiabatic) expansion for which Q = 0.

$$W_T = h_1 - h_2 \tag{5.4}$$

Condenser : Since heat is rejected to cooling water in condenser and no work is developed by it.

$$Q_R = h_2 - h_3 \tag{5.5}$$

Pump : For reversible adiabatic pumping Q = 0

$$W_P = h_4 - h_3 \tag{5.6}$$

$$\eta_{Rankine} = \frac{\text{Net work output}}{\text{Heat supplied in Boiler}}$$

Net work output $= W_T - W_P = (h_1 - h_2) - (h_4 - h_3)$

Heat supplied in boiler $= Q_S = h_1 - h_4$

$$\therefore \quad \eta_{Rankine} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)} \tag{5.7}$$

Generally pump work is very small compared to work developed by turbine and hence it is neglected.

$$\therefore \quad \eta_{Rankine} = \frac{h_1 - h_2}{h_1 - h_4} \tag{5.8}$$

5.7 AIR STANDARD CYCLES :

In gas power plants like gas turbine or internal combustion engine working fluid is always in gaseous state. In most gas power cycles, the working fluid consists mainly of air. In internal combustion engine air fuel ratio varies from 10 : 1 to 24 : 1 depending upon type of engine. In gas turbine plants this ratio varies from 50 : 1 to 250 : 1. Hence properties of working fluid is similar to properties of air. Therefore gas power cycle analysis can be done by idealised cycle known as Air standard cycle which uses pure air as working fluid.

5.7.1 Assumptions for Air Standard Cycle :

(1) The working fluid is air and it follows the ideal gas laws and hence follows pV = mRT.

(2) The working fluid is homogeneous throughout at all time and no chemical reaction takes place.

(3) Specific heat of air is constant and do not vary with temperature One may take $c_p = 1.005$ kJ/kg K and $c_v = 0.718$ kJ/kg K.

(4) The mass of air in cycle remains fixed. The cycle is execuated by closed system and there is no suction or exhaust process

(5) Combusion process is replaced by equivalent heat transfer process (Heat addition to cycle).

(6) Since exhaust process is not there it is replaced by equivalent heat rejection.

(7) All processes of the cycle are reversible.

Thermal efficiency of air standard cycle is also known as air standard efficiency which can be given by

$$\eta_a = \eta_{th} = \frac{\text{Workdone}}{\text{Heat supplied}} = \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}} = \frac{Q_S - Q_R}{Q_S}$$

Relative efficiency or efficiency ratio is defined as

$$\eta_r = \frac{\text{Actual thermal efficiency}}{\text{Air standard efficiency}}$$

5.8 OTTO CYCLE (CONSTANT VOLUME CYCLE) :

An air standard Otto cycle which is also known as constant volume cycle consists of four processes. Two of them are reversible adiabatic (isentropic) and the other two are constant volume processes. An air standard Otto cycle on p–V diogram is shown in Fig. 5.6.

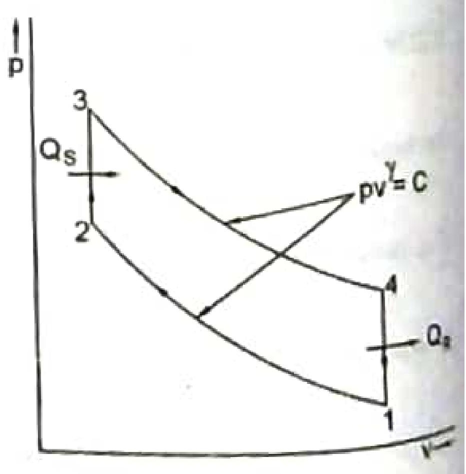


Fig. 5.6 Otto cycle

Various processes are :

1–2 : Reversible adiabatic (isentropic) compression of air. Pressure and temperature of air will increase.

2–3 : Heat is added at constant volume. Further rise is pressure and temperature of air.

3–4 : Reversible adiabatic (isentropic) expansion of air. Pressure and temperature of air will decrease. Work is developed during the process.

4–1 : Constant volume heat rejection process. Pressure and temperature will restore to its initial value.

For Otto cycle heat supplied and heat rejection are constant volume processes.

$$\therefore \quad Q = \Delta u = c_v \Delta T$$

Heat supplied = $Q_S = c_v (T_3 - T_2)$

Heat rejected = $Q_R = c_v (T_4 - T_1)$

Work done in cycle = Heat added – Heat rejected

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

$$\therefore \quad \text{Air standard efficiency } \eta_a = \frac{\text{Workdone}}{\text{Heat added}}$$

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

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

Now we need to substitute for T_2, T_3 and T_4 in terms of T_1.

For process 1–2 : (reversible adiabatic compression)

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

$$\therefore \quad T_2 = T_1 \cdot \left(\frac{v_1}{v_2}\right)^{\gamma-1} = T_1 \cdot r^{\gamma-1}$$

Where $r = \frac{v_1}{v_2}$ = Compression ratio

For process 2–3 : (constant volume heat addition)

$$\frac{T_3}{T_2} = \frac{p_3}{p_2} \qquad [\because \text{ 2–3 is constant volume process}]$$

$$\therefore \quad T_3 = \frac{p_3}{p_2} \cdot T_1 \cdot r^{\gamma-1} = r_p \cdot r^{\gamma-1} \cdot T_1$$

Where $r_p = \frac{p_3}{p_2}$

For process 3–4 : (reversible adiabatic expansion)

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma-1}$$

since $v_1 = v_4$ and $v_2 = v_3$

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

$$T_4 = r_p \cdot T_1$$

Substitute for T_2, T_3 and T_4 in terms of T_1 in equation for air standard efficiency

$$\eta_a = 1 - \frac{r_p \cdot T_1 - T_1}{r_p\, r^{\gamma-1}\, T_1 - r^{\gamma-1}\, T_1}$$

$$= 1 - \frac{(r_p - 1)}{(r_p - 1)\, r^{\gamma-1}}$$

$$\therefore \quad \eta_a = 1 - \frac{1}{r^{\gamma-1}} \qquad (5.9)$$

From above equation it is clear that *efficiency of Otto cycle is a function of compression ratio only*. In actual engine working on Otto cycle, the compression ratio varies from 5 to 8.

5.9 DIESEL CYCLE (CONSTANT PRESSURE HEAT ADDITION CYCLE) :

Diesel cycle is ideal cycle for compression ignition internal combustion engines or the engines working on diesel oil. The cycle consists of four reversible processes. Two processes are reversible adiabatic, one is constant pressure and one is constant volume. Fig. 5.7 shows Diesel cycle on p–V diagram.

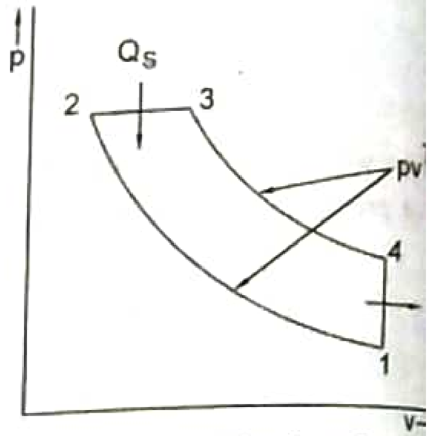


Fig. 5.7 Diesel cycle

The processes of Diesel cycle are :

1–2 : Reversible adiabatic (isentropic) compression of air. Pressure and temperature of air will increase.

2–3 : Heat addition at constant pressure. During this process pressure of air remain constant and volume and temperature will increase.

Volume ratio $\frac{v_3}{v_2}$ is called cut–off ratio

3–4 : Reversible adiabatic (isentropic) expansion of air. Pressure and temperature of air will decrease

4–1 : Heat rejection at constant volume, Pressure and temperature of air will decrease.

As $Q_S = \Delta h = c_p \Delta T$ and $Q_R = \Delta u = c_V \Delta T$

Heat supplied $Q_S = c_p (T_3 - T_2)$

Heat rejected $Q_R = c_v (T_4 - T_1)$

Work done per cycle $= Q_S - Q_R$

$$\text{Air standard efficiency } \eta_a = \frac{\text{Workdone}}{\text{Heat supplied}}$$

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

$$= 1 - \frac{(T_4 - T_1)}{\gamma (T_3 - T_2)}$$

Similar to Otto cycle, here also we will substitute for T_2, T_3 and T_4 in terms of T_1.

For process 1–2 : (reversible adiabatic compression)

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

$$\therefore \quad T_2 = T_1 \left(\frac{v_1}{v_2}\right)^{\gamma-1} = T_1 \cdot r^{\gamma-1}$$

Where $r = \frac{v_1}{v_2}$ = Compression ratio

For process 2–3 : (constant pressure heat addition)

$$\frac{T_3}{T_2} = \frac{v_3}{v_2} = \rho$$

Where ρ = cut off ratio

$$\therefore \quad T_3 = \rho \cdot T_2 = \rho \cdot r^{\gamma-1} \cdot T_1$$

For process 3–4 : (reversible adiabatic expansion)

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma-1}$$

$$\therefore \quad T_4 = T_3 \left(\frac{v_3}{v_4}\right)^{\gamma-1} = T_3 \left(\frac{v_3}{v_2} \cdot \frac{v_2}{v_4}\right)^{\gamma-1}$$

$$\therefore \quad T_4 = T_3 \left(\frac{\rho}{r}\right)^{\gamma-1} \qquad [\because v_1 = v_4]$$

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

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

Substitute for T_2, T_3 and T_4 in equation of η_a

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

$$\therefore \quad \eta_a = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right] \qquad (5.10)$$

Since $\gamma = 1.4$ for air and ρ is always greater than 1, the quantity in the bracket is always greater than one. So *for same compression ratio efficiency of Otto cycle is greater than that of Diesel cycle*.

PROBLEMS

1. The following data is available for an engine working on ideal Otto cycle. Temperature at the beginning and end of compression is 50°C and 373°C respectively. Calculate compression ratio and air standard efficiency of Otto cycle. **[Ans.** 5.66, 50%]
2. An engine working on air standard Otto cycle has bore of 140 mm and stroke length of 160 mm. Clearance volume for the engine is 370 cm^3. Calculate air standard efficiency of the engine. **[Ans.** 55.7%]
3. An engine working on Otto cycle has temperature and pressure at the beginning of compression are 25°C and 1 bar respectively. Air standard efficiency is 48%. Calculate compression ratio, pressure and temperature at the end of compression. **[Ans.** 5.13, 9.87 bar, 300°C]
4. An Otto cycle having compression ratio 8 has pressure and temperature at the beginning of compression are 1 bar and 27°C respectively. If heat transfer per cycle is 1900 kJ/kg calculate (a) pressure and temperature at the end of each process (b) air standard efficiency.
   [Ans. p_2 = 18.38 bar, T_2 = 416.2°C, p_3 = 88.95 bar, T_3 = 3062.45°C, p_4 = 4.84 bar, T_4 = 1179°C, 56.47%]
5. An engine working on Otto cycle has a volume of 0.5 m^3, pressure 1 bar and temperature 27°C at the beginning of compression stroke. The pressure at the end of compression is 10 bar. The heat added is 200 kJ. Calculate (a) percentage clearance (b) Air standard efficiency. **[Ans.** 23.46%, 47.2%]
6. In a Diesel cycle 1 kg air at a pressure of 1 bar and temperature of 15°C is compressed through a ratio of 15. Heat added is 1850 kJ. Calculate air standard efficiency. **[Ans.** 55.1%]
7. In a Diesel cycle pressure and temperature at the beginning of compression are 1 bar and 27°C. The compression ratio is 16 and heat added per kg of air is 2500 kJ/kg. Calculate (a) maximum pressure and temperature (b) air standard efficiency (c) power output for 0.25 kg/s of air flow rate.
   [Ans. 48.5 bar, 3397 K, 54.08%, 338 kW]
8. A C.I engine working on Diesel cycle has bore of 150 mm and stroke of 250 mm. Clearance volume is 400 cm^3. The fuel injection takes place at constant pressure for 5% of the stroke. Find air standard efficiency. If the fuel cut off is delayed from 5 to 8% of the stroke, calculate loss in efficiency if compression ratio is same. **[Ans.** 59.4%, 2%]
9. In air standard Otto cycle the maximum and minimum temperatures are 1400°C and 15°C. Heat supplied per kg of air is 800 kJ. Calculated air standard efficiency and ratio of maximum pressure to minimum pressure. **[Ans.** 48.5%, 30.5]
10. In an ideal Diesel cycle the compression ratio is 15 and expansion ratio is 7.5. The pressure and temperature at the beginning of compression is 1 bar and 47°C. The pressure at the end of expansion process is 2.6 bar. Determine cut off ratio, maximum temperature and thermal efficiency of the cycle.
    [Ans. 2, 1589.2°C, 60.37%]
11. In an engine working on Otto cycle, air has a pressure and temperature of 1 bar and 67°C at the beginning of compression. The compression ratio is 6 and heat is added at constant volume until temperature rises to 1400°C. Calculate (a) Air standard efficiency (b) Heat supplied (c) Pressure and temperature at the end of compression (d) Mean effective pressure.
    [Ans. (a) 51.16% (b) 701.3 kJ/kg (c) 12.29 bar, 696.2 K (d) 4.41 bar]
12. Calculate air standard efficiency of Otto cycle with compression ratio of 4, 6 and 9. Comment on the result. **[Ans.** 42.57%, 51.16%, 58.48%, with increase in compression ratio efficiency of Otto cycle increases. It can be shown that for same percentage increase in compression ratio, increase in efficiency decreases with increase in compression ratio.
    % increase in η when r changes 4 to 6 = 20.2%
    % increase in η when r changes 6 to 9 = 14.3%]

OBJECTIVES TYPE QUESTIONS

1. For heat engines
   (a) net heat transfer and net work transfer are positive
   (b) net heat transfer and net work transfer are negative
   (c) net heat transfer is positive but net work transfer is negative
   (d) net heat transfer is negative but net work transfer is positive

2. Which one of the following is not an example of internal combustion engine ?
(a) Petrol engine (b) Diesel engine (c) close cycle gas turbines (d) open cycle gas turbines
3. Carnot cycle consists of
(a) two constant volume and two constant temperature processes
(b) two constant volume and two constant pressure processes
(c) two constant temperature and two constant pressure processes
(d) two constant temperature and two adiabatic processes
4. Efficiency of Carnot cycle is given by
(a) $1 - \frac{T_L}{T_H}$ (b) $1 - \frac{T_H}{T_L}$ (c) $\frac{T_L}{T_H} - 1$ (d) $\frac{T_H}{T_L} - 1$
5. Rankine cycle consists of ________ processes
(a) two isothermal and two adiabatic (b) two constant pressure and two adiabatic
(c) two isothermal and two constant pressure (d) two isothermal and two constant volume
6. Thermal efficiency of air standard cycle is known as
(a) relative efficiency (b) air standard efficiency
(c) brake thermal efficiency (d) mechanical efficiency
7. Air standard Otto cycle is also called _______ cycle **(Summer 2017, Winter 2017)**
(a) constant volume (b) constant pressure (c) dual pressure (d) isothermal
8. Efficiency of Otto cycle is function of _______ only.
(a) compression ratio (b) ratio of c_p and c_v
(c) difference between c_p and c_v (d) pressure ration only
9. Diesel cycle is also called ________ cycle
(a) constant volume (b) constant pressure (c) dual pressure (d) isothermal
10. For same compression ratio, efficiency of Otto cycle is always ___ Diesel cycle. **(Summer 2018)**
(a) less than (b) equal to (c) greater than (d) less than or equal to
11. Compression ratio is defined as
(a) $\frac{V_1}{V_2}$ (b) $\frac{V_2}{V_3}$ (c) $\frac{V_3}{V_1}$ (d) $\frac{V_2}{V_1}$
Where V_1, V_2 and V_3 carry usual meaning.
12. Cut off ratio is defined as
(a) $\frac{V_1}{V_2}$ (b) $\frac{V_3}{V_2}$ (c) $\frac{V_2}{V_3}$ (d) $\frac{V_2}{V_1}$
Where V_1, V_2 and V_3 carry usual meaning.
13. For Otto cycle compression ration varies between
(a) 5 and 8 (b) 10 and 15 (c) 16 and 22 (d) 25 and 30
14. For Diesel cycle compression ratio varies between
(a) 5 and 8 (b) 10 and 15 (c) 16 and 22 (d) 25 and 30
15. The efficiency of Diesel cycle increases with **(Winter 2016)**
(a) decrease in cut-off (b) increase in cut-off (c) constant cut-off (d) none of these

: ANSWERS :

1. (a)	2. (c)	3. (d)	4. (a)	5. (b)	6. (b)	7. (a)	8. (a)	9. (b)	10. (c)
11. (a)	12. (b)	13. (a)	14. (c)	15. (a)					

❖ ❖ ❖

6

STEAM BOILERS

6.1 INTRODUCTION :

A boiler is a device used for generating steam from water. This steam is utilized for power generation, for process heating or for space heating. Sometimes only hot water is produced in a boiler and utilized for heating purposes.

According to Indian Boiler Regulations (I.B.R.), a boiler is a closed pressure vessel with capacity exceeding 22.75 litres used for generating steam under pressure. It includes all the mountings fitted to such vessels which remain wholly or partly under pressure when steam is shut–off.

The capacity of the boiler used for power generation is considerably large. The steam is also produced at high pressure due to requirement of high efficiency. The boilers used for process heating are generally smaller in size, simpler in design and generate steam at a much lower pressure.

6.2 ESSENTIAL QUALITIES OF A GOOD BOILER :

A good boiler should have the following qualities :

(1) It should produce maximum steam with minimum fuel consumption, i.e. it should have higher efficiency.

(2) It should be able to deliver desired quantity of steam quickly after starting.

(3) It should be able to meet large load fluctuations. (It should be able to vary steam production rate as per the requirement, in a wide range)

(4) It should be light and simple in construction.

(5) It should occupy less space.

(6) It should be easy to maintain and inspect.

(7) The joints should be accessible for inspection and should not face the impact of flame directly.

(8) The velocity of water and that of flue gases should be minimum.

(9) Tubes should be sufficiently strong to resist wear and corrosion.

(10) Mud and other deposits should not collect on heated plates.

(11) It should comply with safety regulations laid by competent authority. (I.B.R. in India)

6.3 CLASSIFICATION OF BOILERS :

The boilers may be classified in different ways as follows :

6.3.1 According to Relative Position of Water and Hot Gases :

(1) **Fire Tube Boilers :** In this type of boilers, hot gases pass through tubes, (a single tube or a bunch of tubes) which are surrounded with water. The Cochran, Locomotive and Lancashire boiler are fire tube boilers.

(2) **Water Tube Boilers :** Here the water circulates through the tubes and hot gases surround them. Steam is generated inside the tubes and collected in cylindrical vessel known as boiler drum. e.g. Babcock & Wilcox boiler, Stirling boiler.

Table 6.1 Comparison between Fire Tube and Water Tube Boilers

Parameters	Fire tube boilers	Water tube boilers
1. Capacity (Rate of steam generation)	low	high, used in wide range of pressures and steam rates
2. Operating steam pressure	limited to 25 bar	can well exceed 125 bar
3. Cost and construction effort	less	more
4. Floor space requirement	more	less
5. Skill required for efficient operation	less	more
6. Water treatment	Not very necessary as minor scaling do not lead to overheating or explosion.	Required as scaling will lead to tube bursting
7. Chances of explosion	less due to low pressure	more due to higher pressure
8. Damage due to explosion	much more	much less
9. Use	Paper, sugar and chemical industries for producing process steam	For process steam as well as power generation
10. Accessibility of various parts	Various parts are not easily accessible for inspection, cleaning and repair.	various parts are easy to access.

6.3.2 According to Geometric Orientation of Boilers :

(1) **Horizontal Boiler :** They have their principal axis (axis of boiler shell) horizontal or slighty inclined e.g. Locomotive boiler, Lancashire boiler.

(2) **Vertical Boilers :** They have their principal axis (axis of boiler shell) vertical. e.g. Cochran boiler.

6.3.3 According to Location of Furnace :

(1) **Externally Fired Boilers :** The furnace is placed outside the boiler shell. This type of boilers have the advantage that the fire place is simple and may be enlarged easily. Watertube boilers are always externally fired e.g. Babcock and Wilcox boiler.

(2) **Internally Fired Boilers :** The furnace is placed inside the boiler shell. Most of the fire–tube boilers are of this type. e.g. Lancashire boiler, Cochran boiler.

6.3.4 According to Method of Water Circulation :

(1) **Natural Circulation Boilers (Fig. 6.1) :** The water convection currents (in the direction of the arrow shown) are set up due to the temperature difference. The water from steam drum falls under gravity to header where its temperature rises and density reduces. So it travels upward to steam drum through evaporator.

(2) **Forced Circulation Boilers (Fig. 6.2) :** Water is circulated through boiler circuit by a pump. Low capacity boilers use natural circulation, while only high pressure–high capacity boilers use forced circulation.

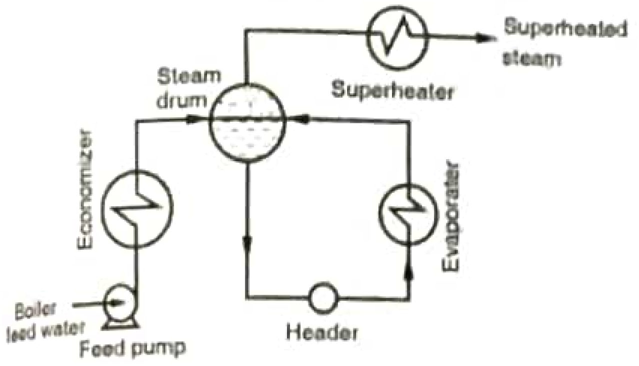


Fig. 6.1 Natural Circulation

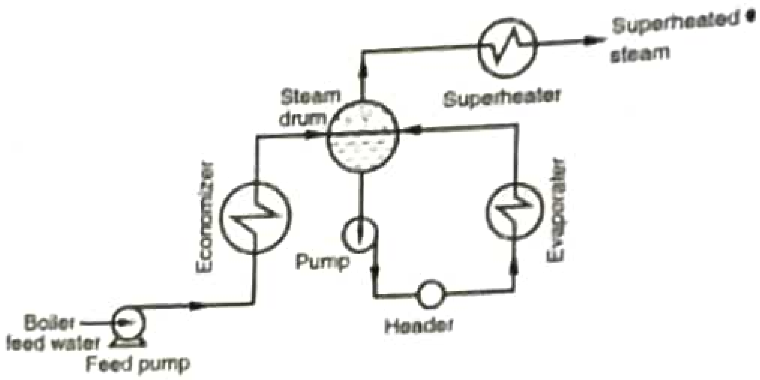


Fig. 6.2 Forced Circulation

6.3.5 According to Magnitude of Working Pressure :

(1) **High Pressure Steam Boiler :** The working pressure for this boiler is more than 25 bar. e.g. Babcock and Wilcox boiler.

(2) **Medium Pressure Steam Boiler :** The working pressure range is 10 bar to 25 bar. e.g. Lancashire boiler and Locomotive boiler.

(3) **Low Pressure Steam Boiler :** The range of working pressure is between 3.5 to 10 bar. e.g. Cochran and Cornish boiler.

6.3.6 According to Mobility of Boiler :

(1) **Stationary Boiler :** Most industrial boilers and boilers used for power generation are stationary boilers. e.g. Lancashire boiler, Babcock and Wilcox boiler.

(2) **Mobile Boiler :** They are used to run locomotives and ships e.g. Locomotive boiler.

6.4 FACTORS AFFECTING THE SELECTION OF A BOILER :

Following factors are considered while selecting a boiler :

(1) Type (quality) of steam to be produced, i.e. wet steam, dry steam or superheated steam.

(2) Steam generation rate and steam pressure required. This pressure becomes the operating pressure of boiler.

(3) Quality and quantity of fuel and water available.

(4) Cost of installation and erection (Initial cost).

(5) Cost of operation and maintenance.

(6) Availability of floor space.

(7) Probable load factor.

6.5 PARTS OF A BOILER :

Here we will describe the parts of a boiler in short so that you can understand them in context of a complete boiler later on.

(1) **Cylindrical Shell :** It is the shell in which different parts of the boiler are enclosed and on which the mountings are fitted.

(2) **Grate :** It is the platform on which the fuel is burnt.

(3) **Fire Hole :** It is the hole through which coal is added to the furnace, when needed.

(4) **Fire Box :** This chamber contains hot gases produced by combustion of fuel. This chamber is surrounded by water. The walls of fire box are at very high temperature due to radiative heat transfer from flames and due to contact with hot gases. These walls conduct heat to water surrounding them.

(5) **Ash Pan (Ash Pit) :** It is the area in which the ash of burnt coal is collected.

(6) **Smoke Box (Smoke Chamber) :** After using the heat available with the flue gases (hot gases that are produced due to combustion in furnace/firebox) to raise steam, they enter a chamber called smoke box. They are then released to atmophere through chimney.

(7) **Man Hole :** It is a hole provided in the boiler shell so that a workman can go inside the boiler for inspection, cleaning and maintenance. It is generally oval in shape and a door is provided to close it.

(8) **Hand Holes :** They are made to give easy access for the purpose of cleaning the water tubes or some other internal parts of boiler. They are also fitted with covers. To prevent leakage of steam, gaskets are used around the man holes as well as hand holes before the covers are placed in their positions.

(9) **Mud Box :** Sediments in water settle down in this box and they are blown off from time to time.

(10) **Steam Collecting Pipe :** Steam always contain some amount of water particles when it is in contact with the surface of water. Water particles have higher specific gravity. So, as the steam moves up, water particles tend to fall back.

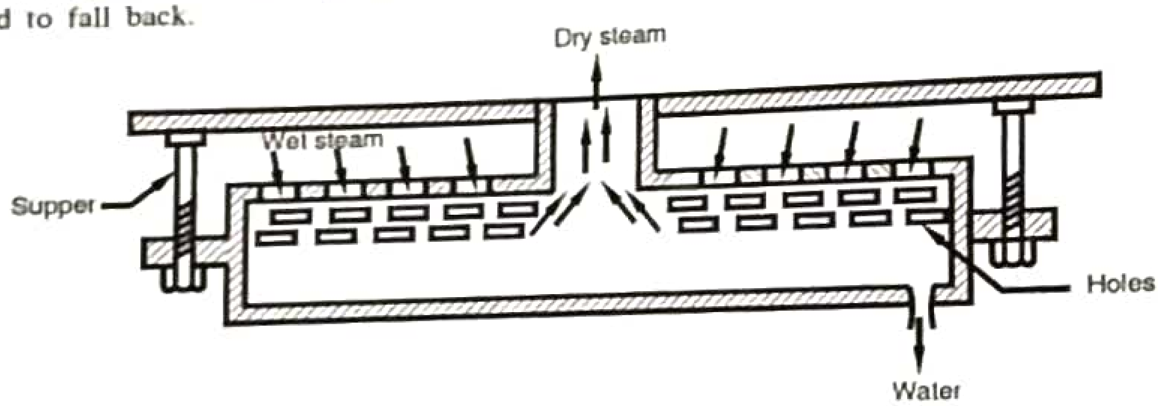


Fig. 6.3 Steam collecting pipe

Again, if a deflection is provided in the path of steam, water particles with more weight and higher inertia, cannot follow the steam path and fall back. This principle is used in steam collecting pipe or antipriming pipe. It is a horizontal perforated pipe placed on the top of the steam space of the boiler. The wet steam enters into the pipe through rectangular holes in downward direction as shown in figure. Now the steam again has to change direction and move up. But water particles fall back and settle at the bottom of the pipe. Water can be drained out from a hole provided at the bottom of the pipe.

(11) **Boiler Stays :** The boilers are generally provided with stays to prevent bulging of the plates due to pressure of the steam. The principal kinds of stays in use are : (1) direct stays (2) diagonal or gusset stays and (3) girder stays.

(12) **Flue and Fire Tube :** Generally when the diameter of a tube through which hot gases flow is upto 6 inches, it is called a fire tube. For diameter or passage larger than this, it is called a flue.

6.6 BOILER MOUNTINGS :

Different types of valves, gauges and other connections or devices are attached directly to the boiler. They are necessary for operation and safety of a boiler. They are called boiler mountings.

Water level indicator (water gauge), different types of safety valves, pressure gauge, steam stop valve, feed check valve, blow–off cock and fusible plug are some of the important boilers–mountings.

6.6.1 Bourden Pressure Gauge :

Function :

It indicates the pressure of steam inside the boiler.

Construction :

A Bourden gauge with its interior mechanism is shown in Fig. 6.4. The bent bourden tube of oval–cross section is closed at one end and connected at the other end to boilers pressure. Closed end of tube is attached by links and pins to a toothed quadrant. This quadrant meshes with a small pinion on the central spindle.

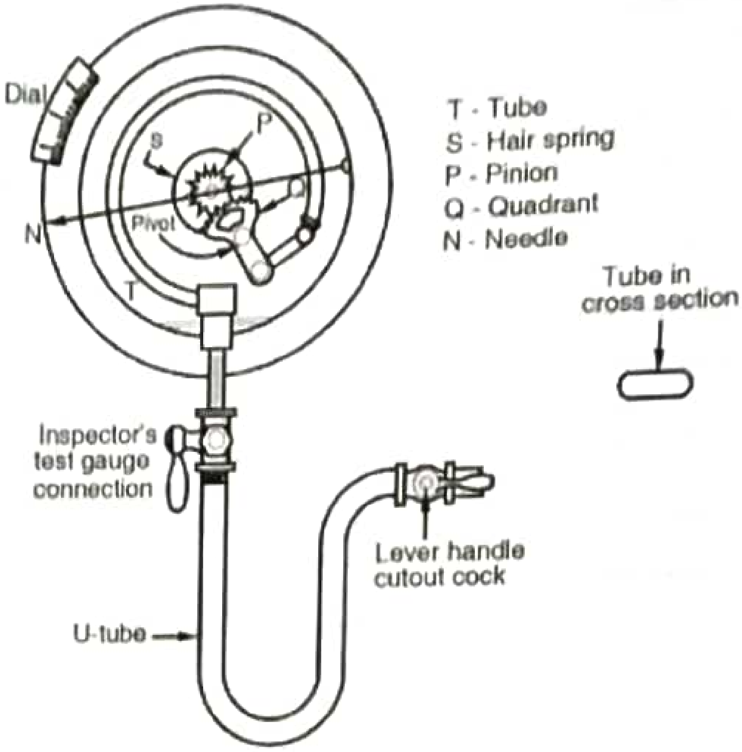


Fig. 6.4 Bourden guage

Working :

When pressure is applied to interior of oval tube, it tends to assume a circular cross-section. But before the tube can do so, it must straighten out. This tendency to straighten moves the free end, turning the spindle by the links and gearing This causes the needle to move and register the pressure on graduated dial. A U–tube or some other type of siphon is used to prevent steam from entering pressure gauge.

6.6.2 Water Level Indicator (Water Gauge) :

Function :

It indicates water level inside the boiler to the observer. Two water level indicators are fitted in front of the boiler. The water level indicators show the level of water in the boiler drum and warns the operator if by chance the water level goes below a fixed mark, so that corrective action may be taken in time to avoid any accident.

Construction :

A water level indicator used in low pressure boilers is shown in Fig. 6.5. It consists of three cocks and a glass tube. The steam cock connects or disconnets the glass tube with the steam space in boiler. The water cock connects or disconnects the glass tube from water in the boiler. The water in the, glass tube is drained out at intervals opening the drain cock. This ensures that steam and water cocks are clear in operation. The glass tube is generally protected with shield.

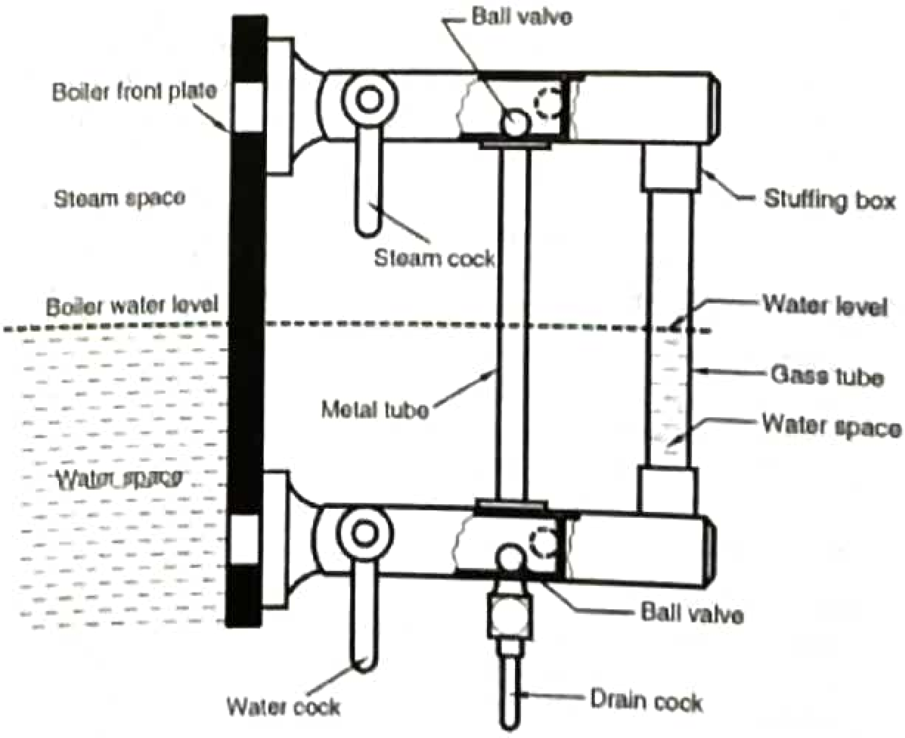


Fig. 6.5 Water guage

Working :

To observe the water level in the boiler, the steam and water cocks are opened and drain cock is kept closed. The steam enters the glass tube through upper tube and water enters through lower glass tube. The level of water in the glass tube will be the same as the level of water in boiler.

The rectangular passage at the ends of the glass tube contain two balls. In case the glass tube is broken, the balls are carried along the passage to the ends of glass tube and then close the reduced passage. Thus flow of water or steam out of boiler is prevented.

6.6.3 Steam Stop Valve :

Function :

It is used to control the passage of steam from the boiler to the steam pipe or from one steam pipe to the other. When it is placed directly over the boiler, it is called 'junction valve', otherwise it is called the stop valve.

Construction :

It is the largest valve on the steam boiler and usually fitted to the highest part of the boiler shell. A commonly used steam stop valve is shown in Fig. 6.6. The main body is made of cast steel. The valve, valve seat and the nut through which the valve spindle works are made of brass for smooth working. The spindle is passed through a gland to prevent the leakage of steam.

Working :

The spindle is rotated by means of a hand wheel. The rotation of spindle causes the valve to move up and down. When the valve sits over the valve seat, the passage of steam is completely closed. The passage may be partially or fully opened for the flow of steam by moving the valve up, rotating the handwheel.

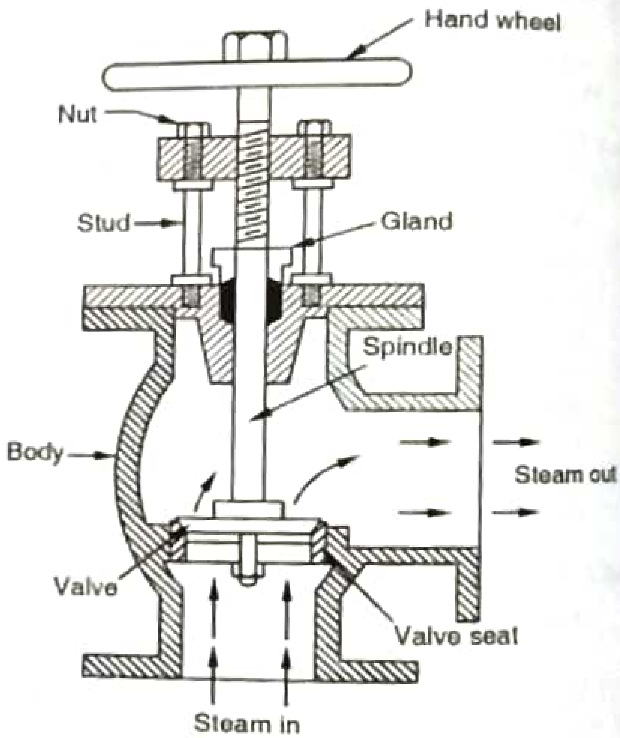


Fig. 6.6 Steam stop valve

In locomotive boilers, the flow of steam is controlled by means of a regulator which is placed inside boiler shell and operated by a handle from driver's cabin.

6.6.4 Feed Check Valve :

Function :

Feed check valve controls the water from pump to the boiler. It does not allow the back flow from the boiler to pump when the pump pressure is less than boiler pressure or the pump has stopped.

Construction :

Feed check valve is fitted on the delivery pipe from feed pump, as near to boiler as possible. The main parts of the valve are : non return valve, water inlet pipe (from feed pump), water outlet pipe (to boiler), spindle, gland and hand wheel. (Refer Fig. 6.7)

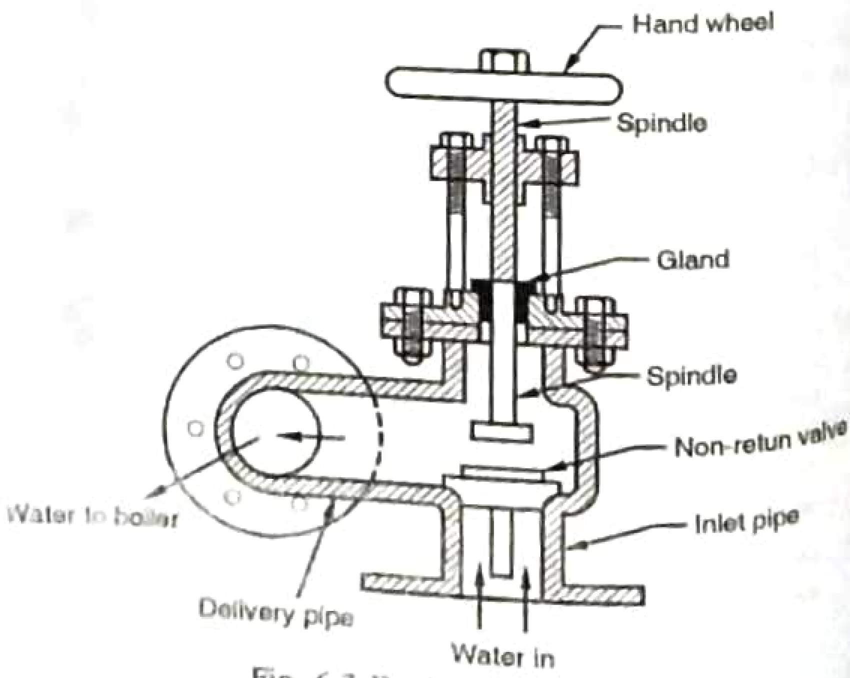


Fig. 6.7 Feed check valve

Working :

Pump pressure acts from below the non–return valve and boiler pressure acts from above it. Under normal working conditions, the pump delivery pressure is higher than the boiler pressure. So the valve is lifted from it seat and allows the water to flow to boiler. The lift of the valve is controlled by moving the spindle up and down with the help of the handwheel. Thus, the flow of water can be controlled.

If boiler pressure is higher than pump pressure or the pump is stopped, the upward force on non–return valve is higher. So it sits on its seat and closes the passage. Thus water from boiler is not allowed to flow backward i.e. towards the pump.

6.6.5 Blow–off Cock :

Function :

(i) The water fed to boiler always contain some sediments and dissolved salts. The water is evapourated but these get accumulated near the bottom of the boiler. The blow-off cock is used to periodically discharge a portion of water from the bottom of boiler which has higher density of sediments and salts. (ii) It is necessary to empty the boiler periodically, for cleaning and inspection. The boiler is emptied opening the blow-off cock. The blow-off cock is fitted in lowest part of boiler.

Construction :

A common type of blow–off cock is shown in Fig. 6.8. A conical plug is fitted accurately into a similar casing. The plug has a rectangular opening.

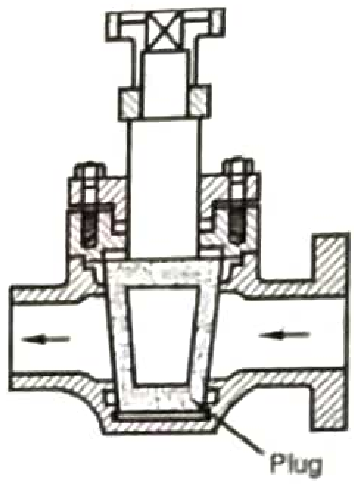


Fig. 6.8 Blow-off valve

Working :

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

6.6.6 Fusible Plug :

Function :

To put off the fire in the furnace of boiler when water level in the boiler falls below an unsafe level. If this is not done, the tubes and the shells may get overheated resulting in an explosion.

This plug is generally fitted over the crown of the furnace or over the combustion chamber.

Construction :

A common type of fusible plug is shown in Fig. 6.9. 'A' is a hollow gun metal body screwed into the crown of the boiler grate. 'B' is another hollow gun metal plug screwed into the plug 'A'. A third plug 'C' is locked with plug 'B' by pouring a low melting point metal (lead or tin) into the grooves provided for the same.

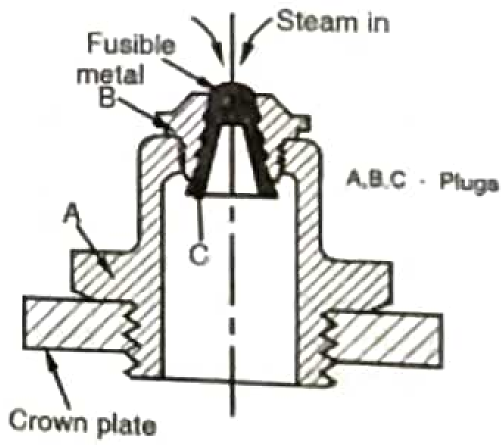


Fig. 6.9 Fusible plug

Working :

Under the normal water level conditions in boiler, upper surface of fusible plug is covered by water while the other end of plug is exposed to fire or hot gases. The low melting metal does not melt till the upper surface of plug is submerged in water.

When the level of water in boiler falls low enough to uncover plug, its temperature rises. The fusible metal between 'B' and 'C' quickly melts and plug 'C' drops out. This allows the steam to rush into the furnace and extinguish the fire. This prevents further overheating.

6.6.7 Safety Valves :

Safety valves are used to maintain safe pressure inside the boiler. When the pressure of steam inside the boiler increases beyond the safe value, the valve opens and blows–off excess steam. All boilers should have at least two safety valves and they are mounted directly over the boiler. Dead weight safety valve, lever safety valve, spring loaded safety valve and high steam–low water safety valve are the different types of safety valves.

(1) Dead Weight Safety Valve :

Construction :

The valve has a flange at the end of a long pipe. This flange is fixed at the top of a boiler. A valve sits on the valve seat at the top of the pipe. A weight carrier carries dead weights. These weights act upon the valve through pin in downward direction.

Working :

When the pressure in the boiler exceeds the normal limit, the upward force on valve exceeds the downward force on it due to the weights. So the valve is lifted from its seat and excess steam escaps through the pipe to the outside.

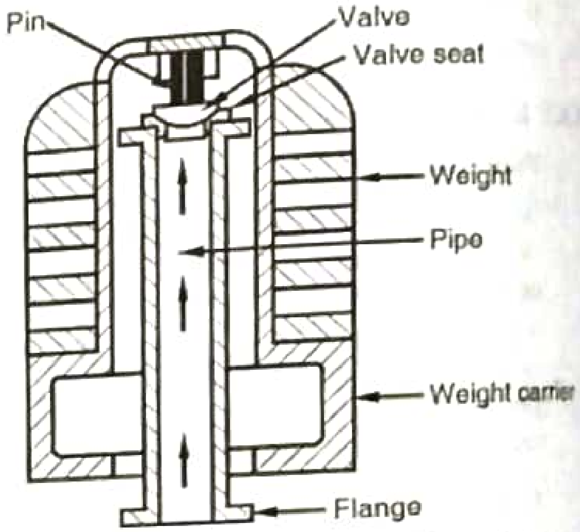


Fig. 6.10 Dead weight safety valve

Merits and Demerits :

The construction of the valve is simple and gives satisfactory operation for low pressure and stationary boilers. This valve is not suitable for moving boilers as the force of the weights should always work vertically downward. It is also not suitable for high pressure boilers as the weight becomes too large. This disadvantage is overcome in lever safety valve.

(2) Lever Safety Valve :

Construction :

The valve is placed over a valve seat which is fixed over a mounting block. The mounting block is fitted over the boiler shell with the help of studs. One end of the lever is hinged to a rod of the mounting block at the fulcrum. The weight hangs at the other end. A short strut of lever is placed over the valve. A guide limits the maximum angular movement of the lever.

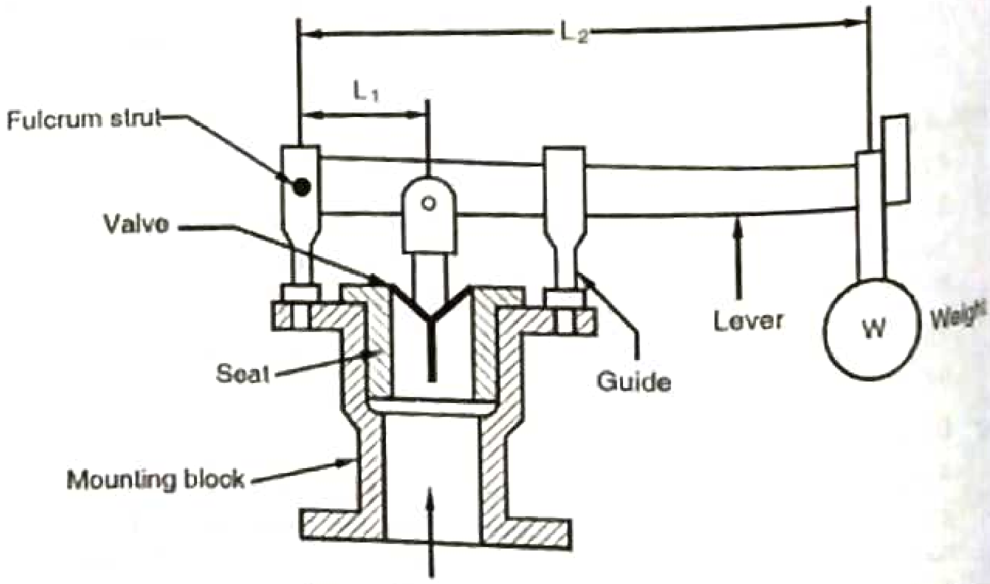


Fig. 6.11 Lever safety valve

Working :

When pressure of steam exceeds the safe limit, the upward force on the valve become greater than downward force on it applied through strut. The valve is lifted from its seat and steam is allowed to escape till pressure falls back to safe value.

If we apply moment balance at the fulcrum.

$$F \cdot L_1 = W \cdot L_2$$

Where F = downward force on valve through strut

W = Weight suspended at the end of the lever

As, L_2 is much larger than L_1, F is much larger than W. Thus, using the leverage, a large force on valve can be produced.

Use and Limitations :

This type of valve can be used at a pressures higher than that of dead weight safety valve. But this valve also can be used only for stationary boilers.

(3) **Spring-loaded Safety Valve :**

Different types of spring loaded safety valves are used on different boilers. Here we will describe Ramsbottom safety valve used on locomotive boilers.

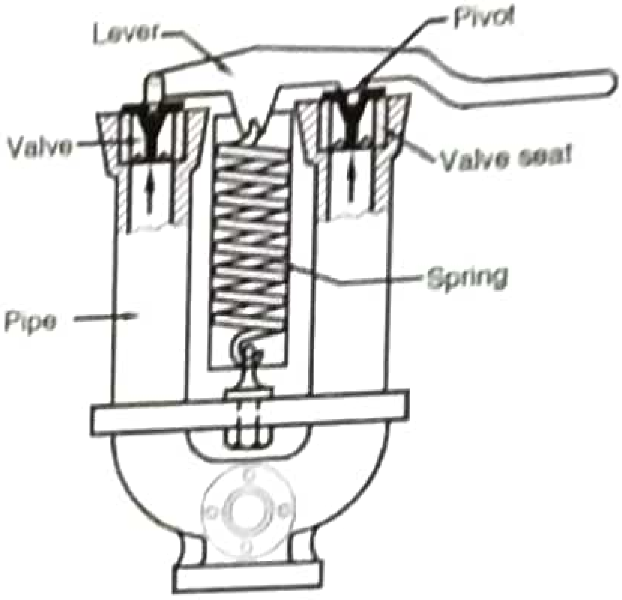


Fig. 6.12 Ramsbottom safety valve

Construction :

This valve consists of a cast iron body having two branch pipes. Two valves sit on corresponding valve seats at the end of the pipes. The lever is placed over the valves by means of two pivots. The lever is held tight at its position by means of a compression spring. One end of this spring is connected with the lever while the other end with the body of the valve.

Working :

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

Merits and Use :

Spring loaded saftety valve operation is not affected by jerks and vibration. So it can be used on portable boilers such as locomotive and marine boilers.

(4) **High Steam and Low Water Safety Valve :**

Function :

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

Construction and Working :

There are two valves in this equipment, V and U. Valve V (high steam valve, actuated by high steam pressure) rests on valve seat. Valve U is loaded by weight W_2 through a long rod. It rests on valve V. When steam pressure exceeds the normal limit, the valve V alongwith valve U rises up against downward force applied by strut of the lever. The excess steam is released to atmosphere.

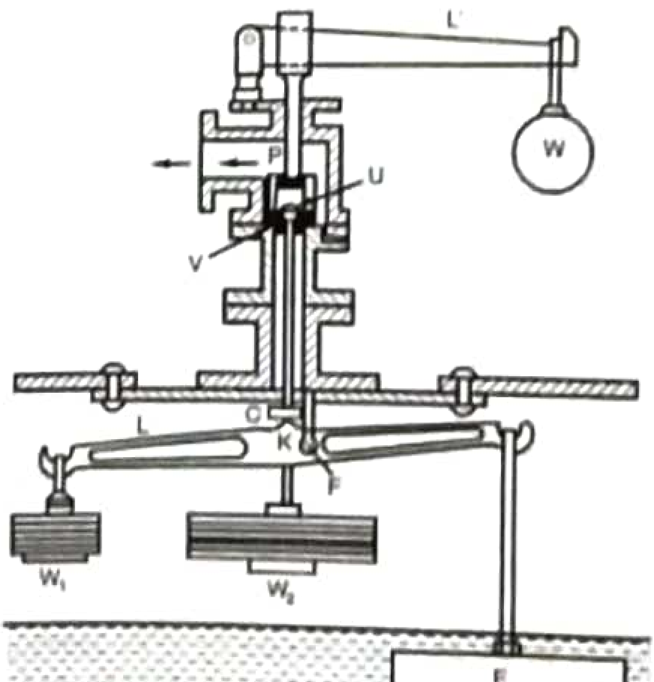


Fig. 6.13 High steam and low water safety valve

Inside the boiler, a lever L is hinged at the point F. One end of the lever carries a weight W_1 on one side and float E on the other side. The lever is balanced when the weight E is under water. But when the water level falls such that the float is out of water, the lever gets unbalanced, moving weight E downward. Due to this the knife-edge K pushes the collar C upward. Collar C is mounted on a rod connecting the weight W_2 and valve U. So when collar moves up, valve U is also lifted. This causes the steam inside the boiler to escape through a narrow passage causing a loud noise. This alerts the operator to start the feed water pump to increase the level of water in boiler.

Use : This valve is generally used in the Cornish or Lancashire boiler.

6.7 BOILERS :

We will describe here different types of boilers like, Cochran boiler, Lancashire boiler, and Babcock and Wilcox boiler.

6.7.1 Vertical Multitubular Boiler (Cochran Boiler) :

Cochran boiler is a vertical, multifire-tube boiler used for low rate steam generation. It is made in different sizes with steam evaporation capacity ranging from 150 to 3000 kg per hour and working pressure upto 20 bar.

Construction and Working :

The boiler consists of a cylindrical shell with hemispherical shaped crown. The fire-box is also hemispherical in shape. The hemispherical crown of boiler gives good strength to withstand pressure of steam inside the boiler. The hemispherical shape of furnace can withstand intense heat and is also advantageous for absorption of radiant heat from the furnace. The grate is placed at the bottom of furnace and ash-pit is located below the grate. The coal is fed to the grate through the fire door and ash formed is collected in ash-pit. The furnace and the combustion chamber are connected by short flue pipe. The back of the combustion chamber is lined with fire bricks.

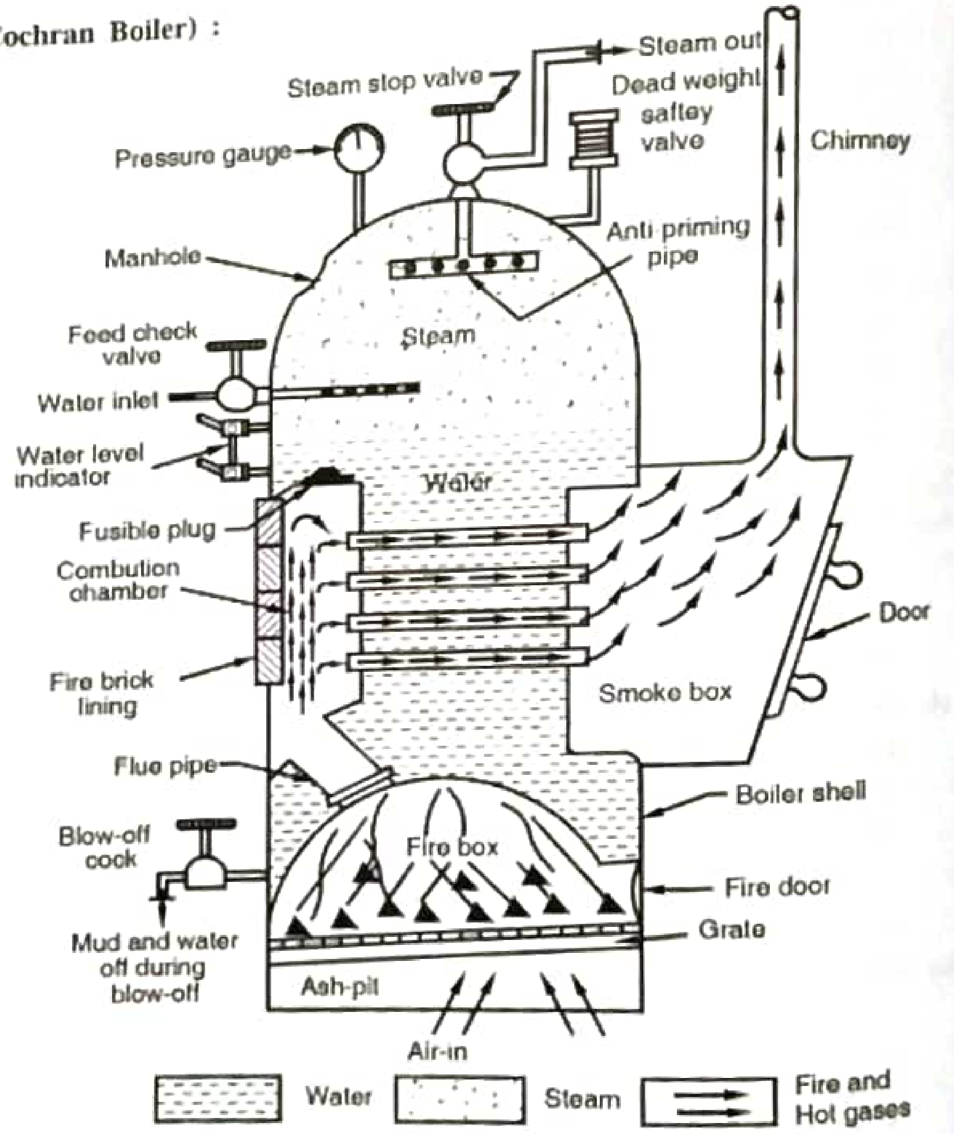


Fig. 6.14 Cochran boiler

The hot gases enter combustion chamber through flue pipe with considerable velocity. The hot gases in the combustion chamber flow through the nest of horizontal fire-tubes (generally 62.5 mm external diameter and 165 – 170 in number). The gases passing through the fire tubes transfer a large portion of heat to the water by convection mode of heat transfer. The flue gases coming out of fire tubes enter smoke box. They are then discharged to atmosphere through a chimney.

A man-hole is provided near the top of the crown of shell for cleaning. A number of hand holes are also provided around the outer shell for cleaning purposes (not shown in figure). The smoke box is provided with doors for cleaning of the interior of the fire tubes.

The air flow through the grate is caused by means of the draught produced by the chimney. A damper is placed inside the chimney to control the discharge of hot gases and thus the flow of air through grate. Oil is also used in some boiler as fuel in place of coal.

The boiler contain the standard mountings as shown in figure.

Advantages :

(1) Compactness and portability
(2) Low first cost
(3) Little floor space required per unit power produced
(4) Quick and easy installation

Disadvantages :

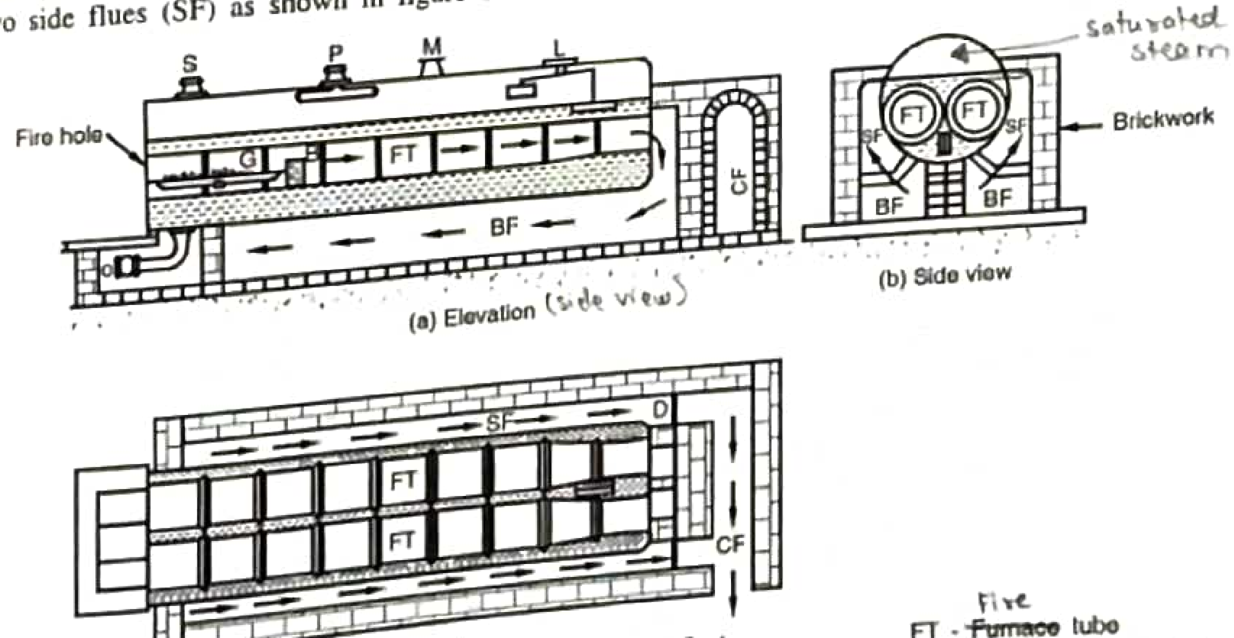
(1) The interior is not easily accessible for cleaning, inspection and repair.
(2) Water capacity is small, making it difficult to keep a steady steam pressure.
(3) Water alongwith steam may enter the steam pipe under heavy loads due to small steam space.
(4) Efficiency is low in smaller sizes.

6.7.2 Lancashire Boiler :

Construction and Working :

Lancashire boiler is one of the most commonly used stationary boilers. The boiler is internally fired and flue gases have three passes–one from inside of boiler, second from below and third from the sides of boiler shell. The boiler has good steaming quality as it is heated from three sides. It can burn inferior quality coal also. The boilers have a cylindrical shell of 2 m diameter and length of 8 m to 10 m.

The cylindrical shell is placed over the brick structure. The brick work also forms one bottom flue (BF) and two side flues (SF) as shown in figure 6.15. (A flue is a channel for flow of gases).



M - Man hole
BF - Bottom flue
L - Low water safety valve
B - Brick bridge
SF - Side flue
S - Safety valve
G - Grate
CF - Chimney flue
C - Blow-off cock
FT - Furnace tube (Fire)
P - Steam collecting pipe
D - Damper

Fig. 6.15 Lancashire boiler

The grates G are provided at the front end of the two main flue tubes (FT) inside the boiler. A fire brick bridge B is provided at the end of the grate to prevent coal and ash particles entering into the interior of the furnace tubes. The hot gases leaving the grate pass upto the back end of the tubes and then in the downward direction (see Elevation). They move by the bottom flue to the front of the boiler where they are divided into two streams and pass into the side flues (see Side view). They move along two side flues and enter the chimney flue (see Plan). Ultimately they are discharged to atmosphere from chimney.

The water-level in the boiler shell is always above the main flue tubes. The water in the shell is also heated from bottom by the bottom flue and from sides by side flue. When provided, the superheater is at the end of the main flue tubes in the passage of flue gases. While an economiser is at the end of the side flues, before exhausting the gases to chimney. Dampers D in the form of sliding door are placed at the end of the side flues to control the flow of gases. This regulates the fuel combustion rate as well as steam generation rate. These dampers are operated by chains passing over a pulley outside the boiler.

Mountings :

The steam collecting pipe P, safety valve S, Low water and high steam safety valve L and manhole M are provided on the top of boiler shell. The pressure gauge and water level indicator and Feed check valve are provided at front of the boiler (not shown in figure). The blow off cock C is at the bottom of shell on front side. The fusible plugs are mounted on the top of the main flues just over the grates (not hown in figure).

Advantages :

(1) The heating surface area per unit volume of the boiler is considerably large.

(2) Its maintenance is easy.

(3) Load fluctuation can be easily met by this boiler due to large reserve capacity for water.

(4) By incorporating economiser or and superheater, the efficiency of the boiler can be increased.

Limitations :

(1) It occupies large floor space due to brick work.

(2) It takes more time to deliver steam at required pressure and rate.

(3) The grates are inside the flue tubes. So their area is restricted.

(4) The maximum pressure is limited to around 15 bar due to shell construction.

6.7.3 Babcock and Wilcox Boiler :

This is a water tube boiler i.e. water flows inside the tubes and hot gases flow over the tubes.

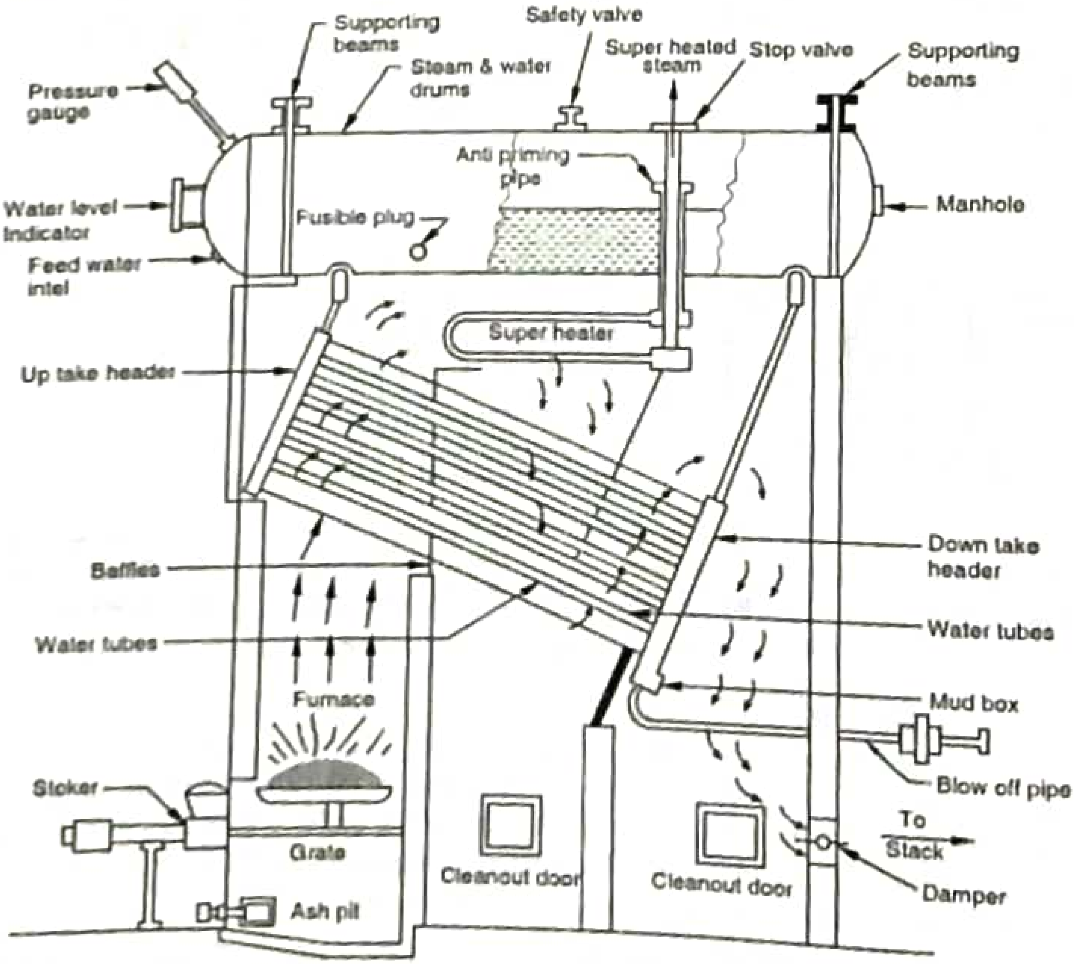


Fig. 6.16 Badcock and Wilcox boiler

Construction and Working :

The steam and water drum (boiler shell) run from front to rear of boiler. It is made of high quality steel. The inclined steel tubes of around 4 inch diameter are connected with pressed steel headers on either side. A short pipe (riser) connect the front header while a longer pipe (down comer) connect the back header with the drum. The headers are provided with hand holes which are covered with caps. The hand holes are useful to clean the tubes. The mud box collects sediments which are blown away frequently through blowoff valve.

The furnace is kept below the front header. Coal is fed to grate through fire hole. The fire brick baffles are oriented such that the hot gases from furnace are first forced to move up, then down and again upward over the water tubes. The damper control the flow of air into the furnace.

Water in the drum comes down through downcomer and enter the tubes. They get heat from the gases. The water of decreased density and part of water converted to steam enter the drum through riser. Thus a continuous circulation of water from drum to water tubes and water tubes to drum is maintained. Saturated steam from the upper part of drum passes downward to the superheater. The superheater is a set of U-tubes and is situated below the drum. The superheated steam is taken from main stop valve through superheater header.

The access to the interior of boiler is provided by the cleanout doors. The water tubes are cleaned by removing soot from their surface. The boiler contains the standard mounting like steam gauge, water level indicator, feed check valve, safety valve etc.

The advantages or outstanding features of the boiler are as follows :

(1) The steam generation capacity of the boiler is very high (20000 to 40000 kg/hr) as compared to other boilers.

(2) The defective tubes can be easily replaced.

(3) The boiler rests over an iron structure, independant of brickwork. So it can expand or contract freely.

(4) The draught loss (pressure drop of gases) is much less.

Babcock and Wilcox boiler can generate high quality steam in large amount. So it is used in power stations. It occupies less space per unit power generation and offers greater operational safety.

6.8 STEAM GENERATOR OF A POWER PLANT

Fig. 6.17 shows steam generator (boiler) of a steam power plant. The steam drum is located at the top of a tall tower, which is lined with water tubes. Water comes down from the steam drum to bottom of the tower by downcomer. It is distributed into multiple tubes lining the furnace through bottom headers. The pulverized coal (coal in dust form) is burnt inside the furnace using ambient air which is heated in air preheater first. Some hot air is used to carry coal, which is called primary air and the air which is introduced into the furnace directly is called secondary air. A fan takes ambient air and supplies it to the furnace at a pressure enough to overcome all heat exchanger resistances.

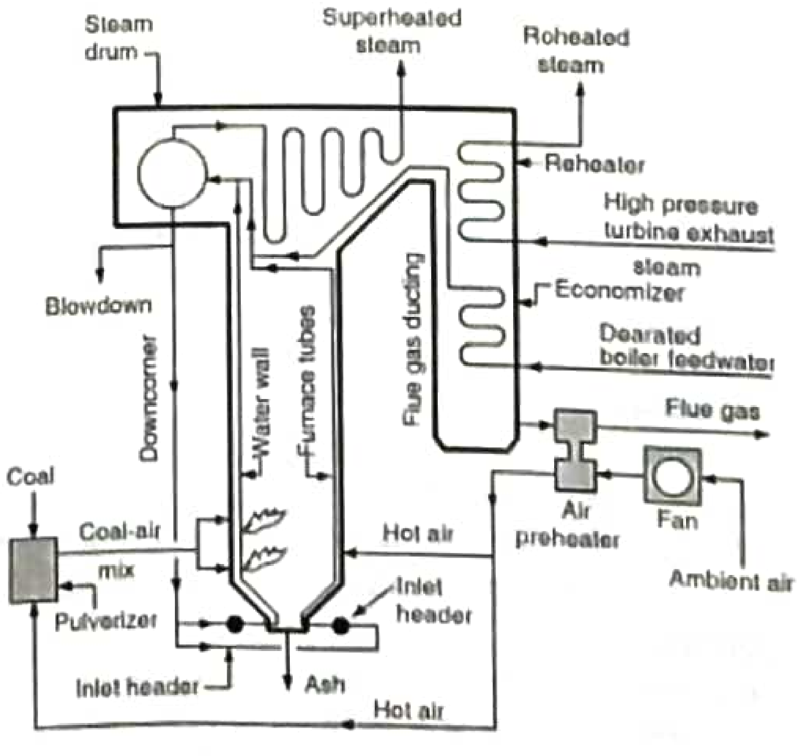


Fig. 6.17 : Steam Generator of a Modern Power Plant

The water in the waterwall is heated by hot combustion products (flue gases). A small fraction of water gets converted to steam and rises up into top of steam drum. Cold water from drum takes its place in waterwall and the cycle continues. Steam collected at top of steam drum is passed through a superheater to produce superheated steam used in steam turbine to produce power. There may be two stages of turbine, high pressure and low pressure. Steam coming out from high pressure turbine is reheated using heat available in flue gases after superheater. The reheater and economiser are located inside the flue gas ducting. The water pumped into steam drum is first heated in economiser using hot flue gases. The flue gases coming out of economiser are still hot enough to heat the air taking part in combustion in air preheater. The ash generated due to combustion of coal is collected at the bottom of the furnace and taken out from there.

6.9 BOILER ACCESSORIES :

Boiler accessories are auxiliary parts required for the smooth operation of the boiler and to increase its efficiency. Water feeding equipments (injector and feed pump), Feed water heater, Economiser, Superheater, Air preheater, Steam separator and Steam trap are some of essensial accessories of the boiler.

6.9.1 Water Feeding Equipments :

Principal devices to feed water into steam boilers are injectors and pumps.

(1) Injector :

The injector is a very simple device used to supply water in a boiler. The water is forced into the boiler by the pressure of the steam. The steam is taken from boiler. The injector is used in small stationary boilers and locomotive boilers.

The injector consists of a spindle P, having a collar L, a steam cone S, a combining cone K, a delivery cone D and a handle H having a pointer T. The upper end of the spindle is fitted with a handle while the lower end serves to act as a valve. The spindle can only rotate, the axial motion being prevented by collar L. The lower part of the spindle has a screw which moves in a nut which is in one piece with the steam cone S. The rotation of steam cone is prevented by the key E. Any rotation of the handle will cause an upward or downward movement of the steam cone. This makes the value V to control the flow of steam through the steam cone. The steam is supplied through the steam pipe A, while the water through another pipe B and the supply of water is also controlled by the movement of steam cone. The water is mixed up with the steam at the combining cone K and it is condensed. It is then forced into the boiler through a divergent cone D. The excess water is allowed to flow by an overflow pipe C.

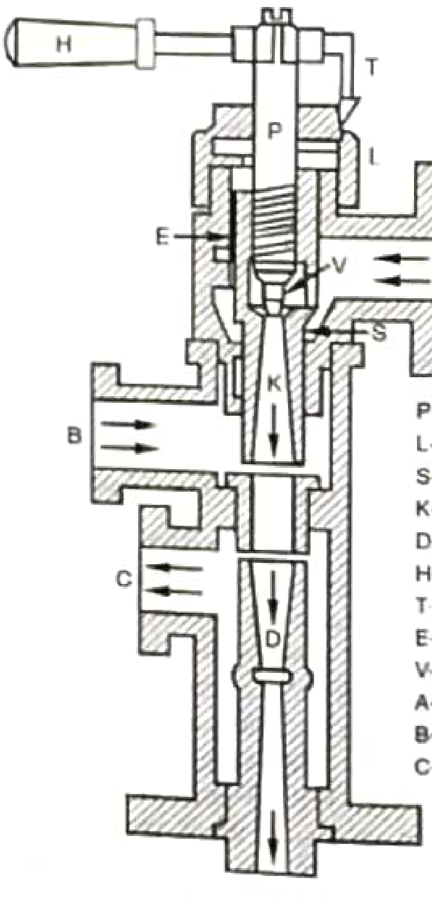


Fig. 6.18 Injector

Advantages :

(1) It is small and very compact.

(2) Its first cost as well as upkeep and repair costs are low.

(3) There are very less chances of its failure, because of simple construction.

(4) It has high thermal efficiency, practically, all heat contained by steam is utilized to heat feed water.

Disadvantages :

(1) With varying load on boiler, the injector must be started and stopped frequenty. So there is danger that water level may drop below the safe level when injector is not in operation.

(2) It does not operate efficiently on superheated steam and hot feed water.

(3) It has low mechanical (pumping) efficiency as compared to feed pump.

(2) **Feed Pump :**

Advantages Over an Injector :

(1) It can be adjusted to feed continuously at steady or varying rate and does not have to start and stop at frequent intervals.

(2) It uses much less steam.

(3) It can handle hotter water.

(4) It permits the economical use of exhaust steam or bled steam for feed-water heating.

Because of these advantages, feed pumps are installed in all large steam boiler plants as well as small plants. Injectors are confined to a very small stationary plants and portable and locomotive boiler.

Classification :

The pumps can be classified as :

(1) **Reciprocating Pumps :** Power driven (simplex, duplex or triplex); Direct acting, steam driven (simplex and duplex). The simplex pump has one steam and water cylinders each. The duplex and triplex have two and three steam and water cylinders each respectively.

Reciprocating pumps are capable of producing very high pressures but are too bulky for moving large volumes of water.

(2) **Centrifugal Pumps :** (Steam turbine, electric motor or belt driven) · Single stage or multistage. Multistaging is used to produce higher pressures.

(3) **Rotary Pumps :** (Turbine, motor or belt driven) The impellers are in the form of gears, lobes or vanes.

Reciprocating and rotary pumps are used to some extent in smaller power plants and heating plants. Centrifugal pumps are used in small as well as large plants.

We will describe here Duplex steam driven reciprocating pump which is used for medium pressure boilers.

6.9.2 Feed Water Heater :

Function :

Feed water heater and economiser increase the temperature of water fed to the boiler. A 50°C temperature increase saves about 5 percent of fuel. Feed water heater are of two types : Open feed-water heater and closed feed water heater.

(1) **Open Feed-Water Heater :**

In this type of feed water heater, the steam and water are mixed intimately in a chamber. As the steam carries more heat, the outcoming feed water has higher temperature.

(2) **Closed Feed-Water Heater :**

It consists of a cylindrical shell and a series of bent U-tubes which are placed inside the shell. The exhaust steam enters into the chamber A and passes through U-tubes and finally discharged from the chamber B. The feedwater enter into the shell through the pipe P, comes into contact with U-tubes and gets heated. The hot water is supplied to boiler through pipe Q. A safety valve V is fitted over the shell. Any impurities deposited inside the shell is discharged through the pipe D.

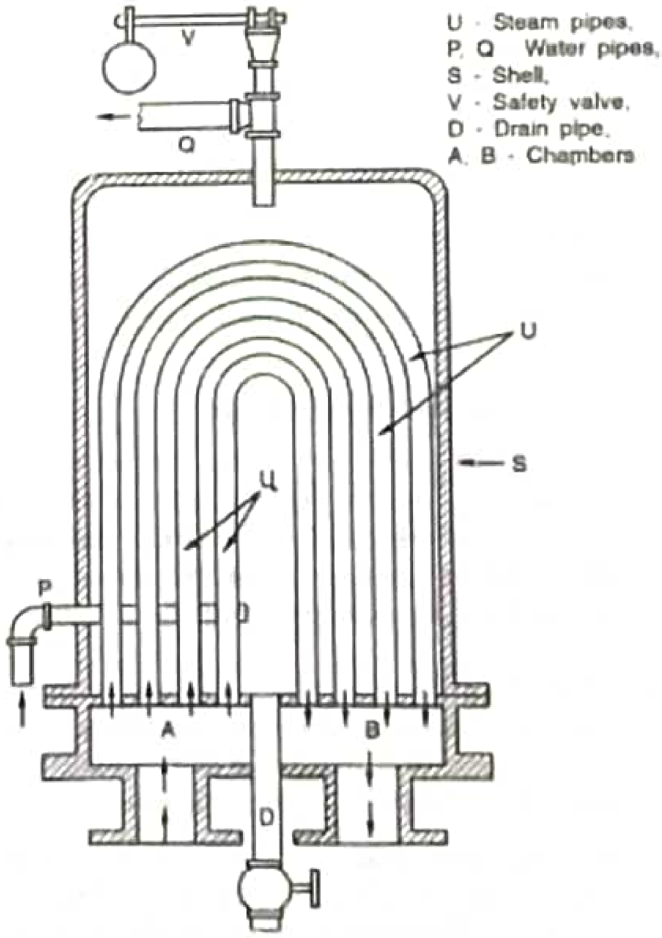


Fig. 6.19 Exhaust steam feed water heater

Advantages :

(1) As feedwater is preheated, there is less consumption of fuel to supply heat in boiler.
(2) As water needs less heat per unit mass, in boiler evaporation rate is faster.
(3) The dissolved gases such as air, CO_2 are liberated and salts are decomposed as the feedwaters heats.
(4) There is a smaller temperature difference between feedwater and boiler. This reduces temperature stress in boiler.

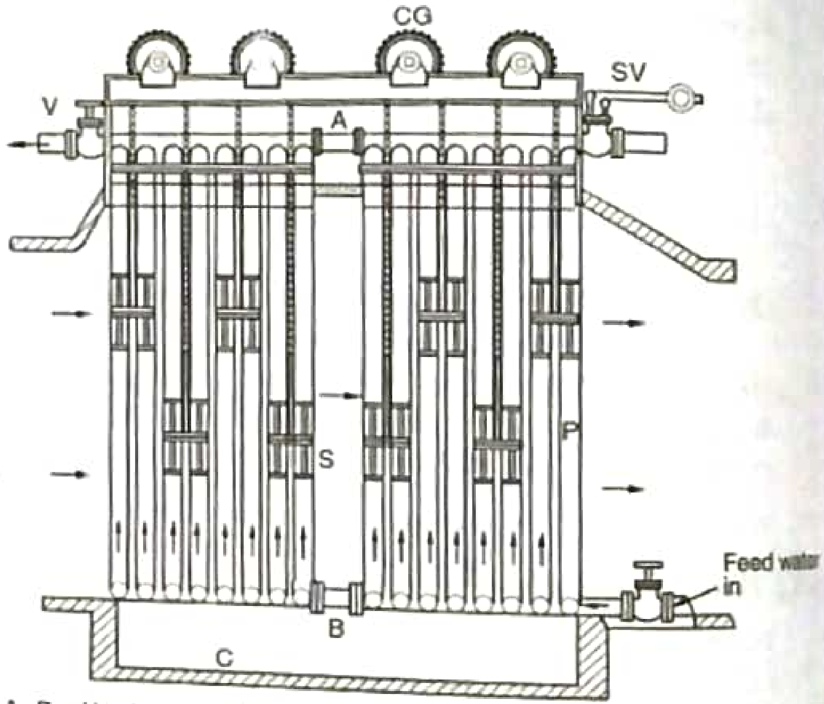
The water passing through the closed heater is under a pressure higher than the boiler pressure. Its temperature can be raised much higher than that in an open heater.

Most plants use an open heater as well as a closed heater (or several closed heaters in series).

6.9.3 Economiser :

The economiser consists of a large number of vertical cast iron or steel pipes P, which are connected with two horizontal pipes (header), A and B, one at top and the other at bottom. The feed water is pumped into the economiser through the bottom pipe B. From the bottom pipe, the water comes into the top pipe A through the vertical pipes and finally goes to boiler. The exhaust gas flow is shown by horizontal arrows. Indirect heat transfer occure from these gases to feedwater.

At the rear end of the vertical pipes, a blow off valve (not shown in figure) is fitted through which any mud or sediment deposited in the bottom boxes may be discharged. The soot of the flue gases deposits on the outer surface of the vertical pipes and this reduces efficiency of the economiser. A system of scrapers S is, therefore, adopted to clean the outer surface of the vertical pipes. Each vertical pipe is fitted with a scraper which moves up and down automatically and continuously by means of a chain and gear arrangement. A safety valve SV is also provided at the end of the pipe A for the safety of pipes.



A, B - Headers S - Scraper P - Pipes C - Soot Chamber
SV - Safety valve V - Stop valve CG - Chain and Gear arrangement

Fig. 6.20 Economiser

Advantage and Disadvantage :

Economisers offer considerable resistance to the passage of flue gas and therefore some form of mechanical drought (e.g. induced draught fan) must be installed when they are used. They take up space, add to the initial cost of installation and involve extra maintenance cost for cleaning and repair. On the other hand they may effect quite a large saving in fuel consumption. Higher feedwater temperature tend to reduce boiler stresses and increase evapourative capacity of boiler.

6.9.4 Superheater :

The steam leaves the water surface and pass into 'steam space' in boiler drum. Steam formed above the surface of water is always wet, i.e. it carries some minute droplets of water. If wet steam is all that is required, then steam is piped directly from the steam space to steam main.

But if superheated steam is required, the wet steam is removed from the steam space and piped into a 'Superheater'. This consists of a long tube or series of tubes which are suspended across the path of the hot gases from the furnace. As the wet steam progresses through the tube or tubes, it is gradually dried out and eventually superheated.

Following are the advantages of superheated steam

(1) Superheated steam is at high temperature. So it increases overall efficiency of steam plant.

(2) It reduces steam consumption for same power produced.

(3) It reduces condensation losses in pipes and engine cylinder of steam engine.

(4) When superheated steam is supplied to turbine, the steam is drier at later stages. Drier the steam, lesser the water particles and turbine blade erosion.

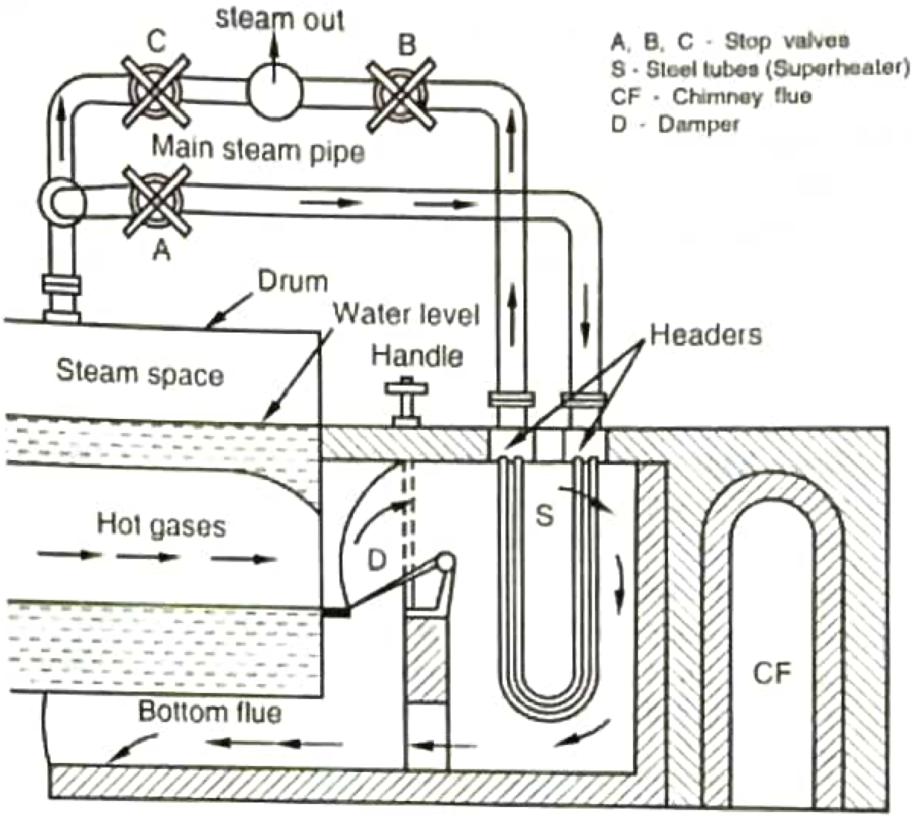


Fig 6.21 Superheater

A superheater commonly used in Lancashire boiler is shown in Fig. 6.22. This superheater consists of two headers and a set of superheater tubes made of high quality steel in form of U-tubes. Superheater is located in the path of furnace gases where the temperature of the gases is not less than 550°C. The superheater is located just before the entry of hot gases to bottom flue.

The amount of hot gases passed over the superheater tubes should be in proportion to the steam passing through tubes and degree of superheat required. To avoid overheating, some amount of hot gases may be diverted with the help of the damper. The superheater may be bypassed by bringing the damper in vertical position and thus passing flue gases directly to bottom flue. The damper may be partially closed to control the degree of superheat irrespective of steam flow rate.

The figure shows valves A, B and C at top. The valve, A and B control the passage of steam entering and coming out of superheater respectively. When valve A and B are open and C is closed, wet steam pass through superheater and enter the steam main. When valve A and B are closed and valve C is open, wet steam directly enter the steam main.

6.9.5 Steam Separator :

Function :

A steam separator is an apparatus for separating out moisture that may be carried in suspension by steam flowing in pipe lines. It prevents this moisture from reaching and probably damaging engines, turbines or any other machinery that may be driven by steam.

Steam separator is located near the engine to remove water particles from the steam as completely as possible.

Construction and Working :

The steam enters at A and moves down. It strikes the baffle at bottom and suddenly changes its direction of motion. The dry steam gets deflected, but the heavy water particles stay on the baffles because of its weight and inertia. It falls to the bottom of the steam separator from baffles. The dry steam moves up and is taken out from pipe B. The water collected at the bottom of the

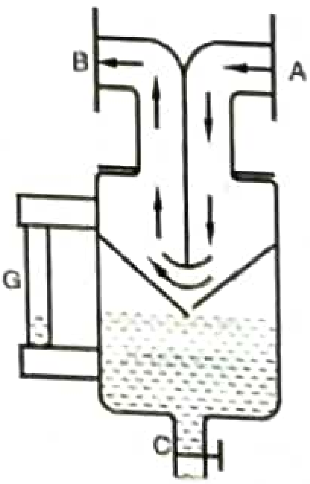


Fig. 6.22 Steam separator

separator is discharged through a cock C from time to time. A gauge glass G exhibits the level of water in the separator.

6.9.6 Steam Traps :

Function :

The steam trap automatically drains away the condensed steam from steam pipes, steam jackets and steam separators without allowing any steam to escape.

There are various types of steam traps of which bucket type is described here.

Construction and Working :

Steam traps consists of a bucket which is fitted with a spindle S at its centre. The upper end of spindle act as valve. A pipe P is fitted inside the chamber which has an outlet at its top.

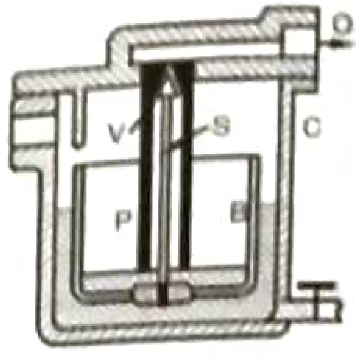


Fig. 6.23 Steam trap

At normal condition, the bucket B floats over the water and the outlet is closed by the valve. When water level increase in chamber, it enters the bucket to fill it. This causes the bucket to come down, opening the valve. Due to pressure of steam, the water is discharged through the outlet till the bucket is nearly empty. Then the valve comes down and closes the outlet.

6.9.7 Air Preheater :

Air for combustion purposes may be preheated before it enters the boiler furnace by passing it through banks of tubes placed in flue leading from boiler to the chimney. It thus uses some heat of leaving flue gases, that would otherwise pass to waste.

Advantages of Air Preheating :

(1) Due to higher combustion air temperature, combustion improves and fuel is used efficiently.

(2) Steam generation capacity of boiler increases.

(3) Boiler efficiency increases by 1% for every 20°C rise of preheated air temperature.

(4) Low grade, high ash coal can be utilized.

Disadvantages of Air Preheating :

(1) If there is clogging in air preheater, entire steam generation may be critically hampered.

(2) An forced draft fan for air circulation and an Induced draft fan for flue gas circulation are required to overcome the resistance offered by air preheater.

(3) Low temperature flue gases cause corrosion on heat exchanger tubes.

(4) Maintenance and power costs are involved in their operation.

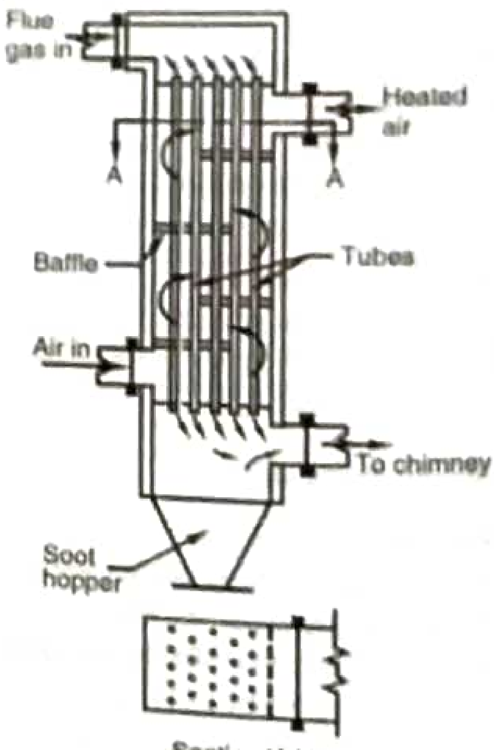


Fig. 6.24 Air preheater

There are mainly two types of air preheaters. Recuperative air heaters and Regenerative air heaters. We will describe here the first one only.

Recuperative Air Heaters :

They are mostly tubular heat exchangers in which heat is continuously transferred from flue gases to air. Air is passed through shell side and flue gases through tube side. The tubes are welded at both ends to tube plates. The tubes are arranged in a staggered configuration, as seen in plan in figure.

A number of baffles are placed in air path. This increases the total path length of air and thus increase heat transfer. A forced draft fan pushes the air through air preheater. The soot hopper provided at the bottom is used to remove soot after cleaning operation of the tubes.

EXERCISES

1. What is boiler ?
2. Mention at least six essential requirement of a good boiler.
3. Draw neat sketch of water level indicotol state its function and location.
4. Write shortnotes :
   (i) Fusible plug. (ii) Lever loaded safety valve. (iii) Pressure gauge. (iv) Blow-off cock.
5. Compare fire-tube boilers and water-tube boilers.
6. Explain with neat sketches : Natural circulation and forced circulation.
7. Explain the method and describe the device used for separating water particles from wet steam.
8. Describe with neat sketches :
   (i) Steam stop valve. (ii) Feedcheck valve.
   (iii) Dead weight safety valve. (iv) High steam law water safety valve.
9. Which safety valve can be used on locomotive and marine boilers ? Why ? Describe the valve with neat sketch.
10. Draw neat sketch of cochran boiler.
11. Describe the working of a Lancashire boiler. Draw only simple (line sketch). Where it is used ? State its advantages.
12. Explain with neat sketch the working of Babcock and Wilcox boiler.
13. With a neat simple sketch of cochran boiler. State its limitations also.
14. What is economiser ? What are the advantages of using an economiser in a boiler ? What are disadvantages?
15. What is air preheaters ? Where is it placed in a boiler ?
16. Explain difference between mountings and accessories. Also mention function of Blow off cock, Safety valve, Fusible plug, Superheater and Economiser.
17. Give advantages and disadvantages of an injector as a water feeding equipment.
18. Give advantages of a feedwater heater.
19. Explain construction of superheater with a neat sketch and give advantages of superheated steam.
20. Explain following with a neat sketch in short :
    (i) Steam trap (ii) Steam separator (iii) Recuperative air heaters

OBJECTIVES TYPE QUESTIONS

1. Which one of the following is not requirement of good boiler?
   (a) It should have high efficiency.
   (b) It should be able to meet large load fluctuations.
   (c) It should occupy more space.
   (d) It should be light and simple in construction.
2. Which one of the following is vertical boiler?
   (a) Lancashire (b) Cochran (c) Babcock and Wilcox

3. Which one of the following is Externally fired boiler?
   (a) Babcock and Wilcox (b) Lancashire (c) Cochran (d) All of above
4. The plateform on which the fuel is burn is called
   (a) Fire box (b) Grate (c) Fire hole (d) Ash pan
5. The hole through which coal is added to the furnace is called
   (a) Man hole (b) Hand hole (c) Fire hole (d) Ash pan
6. A siphon is used with pressure gauge
   (a) to facilitate mounting of pressure gauge (b) to prevent steam from entering a pressure gauge
   (c) to prevent steam escaping from pressure gauge
   (d) so that uniform steam pressure will act on bourden tube
7. Function of two balls in Water level indicator is
   (a) To safeguard the glass tube against breakage
   (b) To prevent water and steam flow in case of breakage of glass tube
   (c) To drain water from the indicator
   (d) To avoid mixing of steam and water
8. The function of Steam stop valve is
   (a) to control flow of water from pump to boiler (b) to empty boiler periodically
   (c) to control flow of steam from boiler (d) All of above
9. The function of Feed check valve is
   (a) to control flow of water from pump to boiler (b) to empty boiler periodically
   (c) to control flow of steam from boiler (d) All of above
10. The function of Blow-off cock is
    (a) to control flow of water from pump to boiler (b) to empty boiler periodically
    (c) to control flow of steam from boiler (d) All of above
11. The function of Fusible plug is
    (a) to put off the fire in boiler (b) to maintain safe pressure inside the boiler
    (c) to maintain constant water level in the boiler (d) All of above
12. The Fusible plug uses ____ which melts when water level falls below safe level.
    (a) mild steel (b) copper (c) aluminium (d) lead or tin
13. The function of Safety valves is
    (a) to put off the fire in boiler (b) to maintain safe pressure inside the boiler
    (c) to maintain constant water level in the boiler (d) All of above
14. _______ safety valves are used with locomotive and marine boiler.
    (a) dead weight (b) lever loaded (c) spring loaded (d) any one of the above
15. Steam evaporation capacity of Cochran Boiler ranges from.
    (a) 150 to 3000 kg/hr (b) 100 to 2000 kg/hr (c) 20000 to 40000 kg/hr (d) 10,000 to 20,000 kg/hr
16. Lancashire boiler is a _______ boiler.
    (a) single pass (b) two pass (c) three pass (d) four pass
17. Which one of the following is not true for Cochran boiler?
    (a) Compactness (b) Low initial cost (c) Less floor space (d) ease of cleaning

18. Which is the correct sequence of flue gas path in Lancashire boiler?
(a) FT → BF → SF → CF (b) BF → FT → SF → CF (c) FT → SF → BF → CF (d) BF → SF → FT → CF
19. Which one of the following is false for Lancashire boiler?
(a) Large heating surface area per unit volume
(b) ease of maintenance
(c) Less floor space
(d) Meet load fluctuation easily
20. In Babcock and Wilcox boiler, the superheater is a set of
(a) straight tubes (b) U-tubes (c) L-tubes (d) C-tubes
21. _____ is used as water feeding equipment in modern power plants.
(a) Injectors (b) Reciprocating pumps (c) Centrifugal pumps (d) rotary pumps
22. Function of feed water heater is to
(a) To increase temperature of steam above saturation temperature
(b) To increase the feed water temperature
(c) To separate water droplets from wet steam
(d) To drain condensed steam automatically
23. Function of superheater is
(a) To increase temperature of steam above saturation temperature
(b) To increase the feed water temperature
(c) To separate water droplets from wet steam
(d) To preheat air before it enters the boiler for combustion
24. Function of air preheater is
(a) To increase temperature of steam above saturation temperature
(b) To increase the feed water temperature
(c) To separate water droplets from wet steam
(d) To preheat air before it enters the boiler for combustion
25. The purpose of providing baffles in between water tubes in Babcock - Wilcox boiler is
(a) to regulate water flow
(b) to regulate steam flow
(c) to have better contact of flue gases with water tubes
(d) to prevent bucking of water tubes
26. Which of the following is a boiler accessory?
(a) stop valve (b) feed water pump (c) fusible plug (d) blow off cock
27. Which of the following is a boiler mounting?
(a) superheater (b) economiser (c) feed check valve (d) air preheater
28. Which of the following is fitted to boiler to improve the boiler efficiency?
(a) safety valve (b) steam trap (c) economiser (d) blow down cock
(Jan. 2013)
29. Which one is the accessory of the boiler?
(a) Steam Injector (b) Fusible plug (c) Pressure Gauge (d) Blow of cock
(Jan. 2013)
30. Which one is the water tube boiler?
(a) Cochran Boiler (b) Lancashire Boiler (c) Babcock Wilcox boiler (d) None of these
(June 2015)
31. The correct location of economizer is
(a) Between furnace and preheater
(b) between airpreheater and chimney
(c) between forced draft fan and furnace
(d) near the superheater

32. Water after being pumped into a boiler cannot come out because of **(June 2015)**
    (a) Steam stop valve (b) Feed check valve (c) Safety valve (d) Blow off valve
33. Which of the following statement is correct? **(Winter 2016)**
    (a) A fire tube boiler occupies less space than a water tube boiler, for a given power.
    (b) Steam at a high pressure and in large quantities can be produced with a simple vertical boiler.
    (c) A simple vertical boiler has one fire tube.
    (d) All of the above
34. Which one of the following is vertical boiler? **(Summer 2017)**
    (a) Lancashire (b) Cochran (c) Cornish (d) Locomotive
35. Which of the following is boiler mounting **(Winter 2017)**
    (a) Super heater (b) Air preheater (c) Economizer (d) Blow off cock
36. Which of the following are boiler mountings? **(Summer 2018)**
    (a) Super heater (b) Air preheater (c) Fusible Plug (d) Economiser
37. Which of the following is not correct for water tube boiler when compared to fire tube boiler
    (a) They are externally fired boilers (b) The skill required to operate is less
    (c) It can withstand higher pressures (d) Various parts are easily accessible for maintenance
38. Following mounting is not connected with steam side of a boiler
    (a) Feed check valve (b) Bourden pressure gauge
    (c) Fusible plug (d) Safety valve
39. The following is not true about Lancashire boiler
    (a) It can use inferior quality coal (b) It occupies less floor space
    (c) Load fluctuations can be easily met (d) The grate area has restriction
40. An uptake header is available in following boiler
    (a) Babcock and Wilcox (b) Lancashire (c) Cochran (d) All of above
41. The following accessory will not be seen in boilers now as it operates manually
    (a) Feed water heater (b) Economiser (c) Feed pump (d) Injector
42. The primary function of the following component is not saving of fuel
    (a) Feed water heater (b) Economiser (c) Superheater (d) None of above
43. The following is not an accessory for boiler
    (a) Steam traps (b) Air preheater (c) Feed pump (d) Water level indicator
44. The following component comes first in boiler if air circuit is considered
    (a) Air preheater (b) Economiser (c) Feed water heater (d) Superheater

: ANSWERS :

1. (c)	2. (b)	3. (a)	4. (b)	5. (c)	6. (b)	7. (b)	8. (c)	9. (a)	10. (b)
11. (a)	12. (d)	13. (b)	14. (c)	15. (a)	16. (c)	17. (d)	18. (a)	19. (c)	20. (b)
21. (c)	22. (b)	23. (a)	24. (d)	25. (c)	26. (b)	27. (c)	28. (c)	29. (a)	30. (c)
31. (d)	32. (b)	33. (c)	34. (b)	35. (d)	36. (c)	37. (b)	38. (a)	39. (b)	40. (a)
41. (d)	42. (c)	43. (d)	44. (a)						

❖ ❖ ❖

7

INTERNAL COMBUSTION ENGINES

As we have seen in chapter 5, heat engine converts heat energy in to mechanical work. Heat engines are classified in two catogories 1. Internal combustion engines (I.C. engines) 2. External combustion engines. Steam turbine, steam engine fall under catagory of external combustion engines in which combustion of fuel take place outside the engine. In I.C. engines combustion of fuel takes place inside the engine cylinder. They are used in scooters, motorcycles, cars, trucks, buses, ship locomotives, power generation and many industrial applications.

7.1 CLASSIFICATION OF I.C. ENGINES :

I.C. Engines are classified as follows.

(1) **According to Type of Fuel Used :** One this basis, they are classified as Petrol engine, Diesel engine and Gas engine.

(2) **According to Number of Strokes required to Complete the Cycle :** On this basis, they are classified as two stroke engines and four stroke engines. In two stroke engine there is one power stroke in every two stroke i.e. during each revolution of the crank shaft. In four stroke engine, there is one power stroke in every four stroke i.e. during two revolutions of the crank shaft. Petrol, Diesel or Gas engine may be operated on two stroke cycle or four stroke cycle.

(3) **According to the Cycle of Operation :** On this basis, they are classified mainly as Otto cycle and Diesel cycle engines. In Otto cycle, combustion of fuel takes place at constant volume. Petrol and gas engines are mostly operated on Otto cycle. In Diesel cycle, combustion of fuel takes place at constant pressure. Diesel engines are mostly operated on Diesel cycle.

(4) **According to Method of Ignition :** On this basis, they are classified as Spark Ignition (S.I.) engines or Compression Ignition (C.I.) engines. In S.I. engine, the air fuel mixture is ignited by an electric spark. Petrol engines work on this system. In C.I. engines the fuel is ignited by hot air in the cylinder due to high compression ratio. Diesel engines work on this system.

(5) **According to Cooling Method :** On this basis, they are classified as air cooled or water cooled engines. Small capacity engines are air cooled (Ex. scooter, motorcycle). Large capacity engines are water cooled. (Ex. cars, buses, trucks etc).

(6) **According to Method of Governing :** On this basis, they are classified as quantity governing and quality governing. In quantity governing method, the quantity of air fuel mixture changes with load maintaining air-fuel ratio constant. Petrol engines are governed by this method. In quality governing method, the quantity of fuel supplied changes with load keeping mass of air constant. Hence air fuel ratio (quality of mixture) changes with load. Diesel engines are governed by this method.

(7) **According to Speed of Engine :** On this basis, they are classified as low, medium and high speed engine. Petrol engines are generally high speed engines while Diesel engines are low or medium speed engines.

(8) **According to Number of Working Cylinder :** On this basis, they are classified as single cylinder or multi cylinder engine.

(9) **According to the Arrangement of Cylinder :** On this basis, they are classified as inline, V-type opposite piston and radial engines. Scooters and motorcycles use horizontal, vertical or inclined engines. Multicylinder engines are generally inline. Ex. car, bus, truck. Earlier aeroplane engines were of radial type. They required less space.

(10) **According to Combustion of Fuel takes place on One or Both Side of Piston :** They are classified as single acting or double acting engines. Almost all I.C. Engines are single acting.

(11) **According to Application :** They are classified as stationary, automobile, air craft, marine or locomotive engines.

(12) **According to Location of Valve :** They are classified as overhead valve engines and side valve engines.

Following are some engines which falls in special category.

(1) Gas Turbine (2) Stirling engines (3) Free piston engine (4) Wankel engine

7.2 ENGINE PARTS AND THEIR FUNCTIONS :

Figure 7.1 shows sectional view of I.C. Engine.

(1) **Frame :** It consists of bed plate, crank case and it also supports the different moving parts. The bed plates are rigidly fixed with foundations. Lower part of crank case containes oil for lubricating purpose.

(2) **Cylinder and Cylinder Block :** Single cylinder engine has a single cylinder while multi cylinder engine has cylinder block. It contains cylindrical bores, and passage for cooling water known as water jackets. Cylinder liner are provided in the cylindrical bore. A separate cylinder head is fitted over the cylinder block with studs and nuts. Cylinder block is made from cast iron.

(3) **Cylinder Head :** The top of the engine cylinder is closed by means of a cover known as cylinder head. It contains inlet and exhaust valves. The two valves are kept closed by springs and opened by means of rocker arm, push rod and cam.

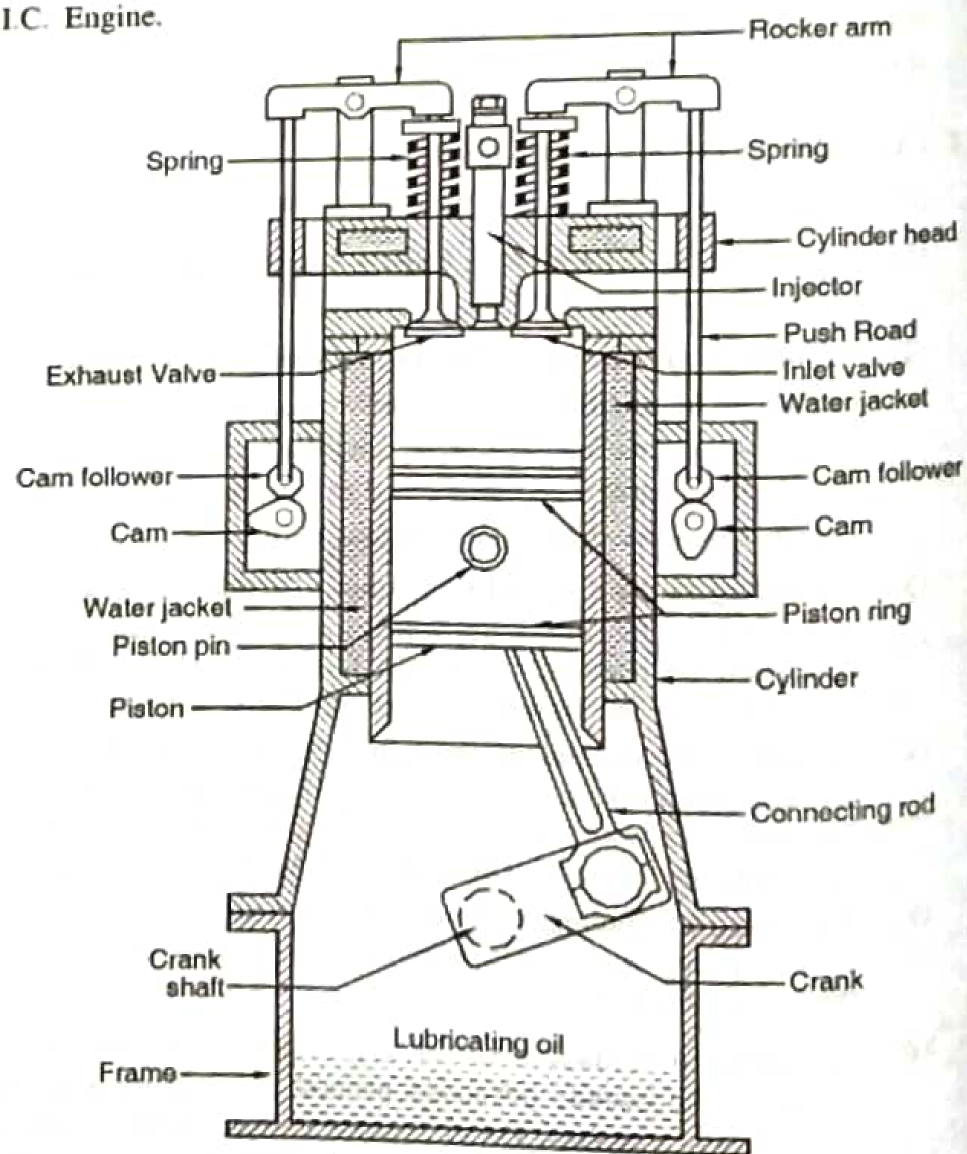


Fig. 7.1 I. C. Engine

(4) **Piston :** It is a gas tight movable cylindrical part which reciprocates in cylinder. Hot gases acts on it which cause rotation of crank shaft through connecting rod. Piston rings are provided around the piston to prevent leakage of hot high pressure gases. It is generally made from aluminium alloys.

(5) **Connecting Rod :** It connects piston and crank. Small end of the connecting rod is fitted with piston by piston pin or gudgeon pin. The other end is connected to crank shaft by crank pin. It helps to convert reciprocating motion of piston in rotary motion of crank shaft. It is made from forged steel.

(6) **Crank Shaft :** It is principal rotating part of engine. The shaft is supported on main bearings. Mechanical work is available at the crank shaft of I.C. engines. It drives various accessories of I.C. engine like lubricating oil pump, cooling water pump, fuel pump, alternator, cam shaft, spark distributor etc. Fly wheel is mounted on crank shaft. It is made from forged steel.

(7) **Valve Gear :** The combination of parts which control the admission of fresh charge into cylinder and discharge of exhaust gases from cylinder is termed as valve gear. It consists of cam shaft, cams, followers, push rods, rocker arms, springs and valves. Inlet valve controls the admission of fresh charge and exhaust valve controls discharge of exhaust gases. Valves are made from nickel steel or chrome steel.

(8) **Cam Shaft :** It operates the valve gear mechanism. It is driven by crank shaft through timing gear. It rotates at half of the crank shaft speed. This is because *each valve needs to be operated once in two revolution of crank shaft*. It also carries a cam which operates distributor or fuel pump. It is made from forged steel.

(9) **Fly Wheel :** It is a heavy wheel which is fitted on crank shaft. It minimizes the fluctuation of cyclic variation in speed by storing the energy during expansion stroke (also known as power stroke), and the same is used during other strokes.

(10) **Carburettor :** It is provided in petrol engine for proper mixing of air and petrol.

(11) **Spark Plug :** It is provided in petrol engine to provide spark to ignite air–fuel mixture. It is fitted in cylinder head.

(12) **Fuel Injector :** It is provided in diesel engines. It is used to inject diesel in form of fine atomized spray under pressure.

(13) **Fuel Pump :** In diesel engine it pumps the fuel from storage tank to injector at high pressure. In petrol engine it is used to pump the petrol from storage tank to carburettor if storage tank is below the carburettor level.

7.3 IMPORTANT TERMS :

(1) **Dead Centre :** It is defined as positions occupied by piston at the end of stroke. It may also be defined as position of the piston, at the moment when the direction of the piston motion is reversed at either end of the stroke.

(2) **Top Dead Centre (T.D.C.) :** It is top most position of piston on cylinder head side in vertical engines.

(3) **Bottom Dead Centre (B.D.C.) :** It is bottom most position of piston on crank shaft side in vertical engines.

(4) **Inner Dead Centre (I.D.C.) :** It is inner most position of piston on cylinder head side in horizontal engines.

(5) **Outer Dead Centre (O.D.C.) :** It is outer most position of piston on crank shaft side in horizontal engine.

(6) **Stroke :** Travel of piston from one dead centre to other dead centre is termed as stroke.

(7) **Swept Volume :** It is volume swept away by piston in one stroke. If 'D' is diameter of cylinder or bore and 'L' is stroke length then, swept volume 'V_s' can be written as

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

$V_s = A \times L$

(8) **Clearance Volume :** Volume entraped between piston and cylinder head when piston is at T.D.C. or I.D.C. is known as clearance volume. It is denoted by V_c.

(9) **Stroke Length :** It is distance travelled by piston from one dead centre to other dead centre. It is equal to twice the crank radius or crank throw.

Stroke length (L) = 2 × crank radius

(10) Piston Speed : It is average piston speed. Since during one stroke piston travels a distance equal to stroke length and in one revolution of crank shaft piston completes two stroke, piston speed is written as

Piston speed = 2LN

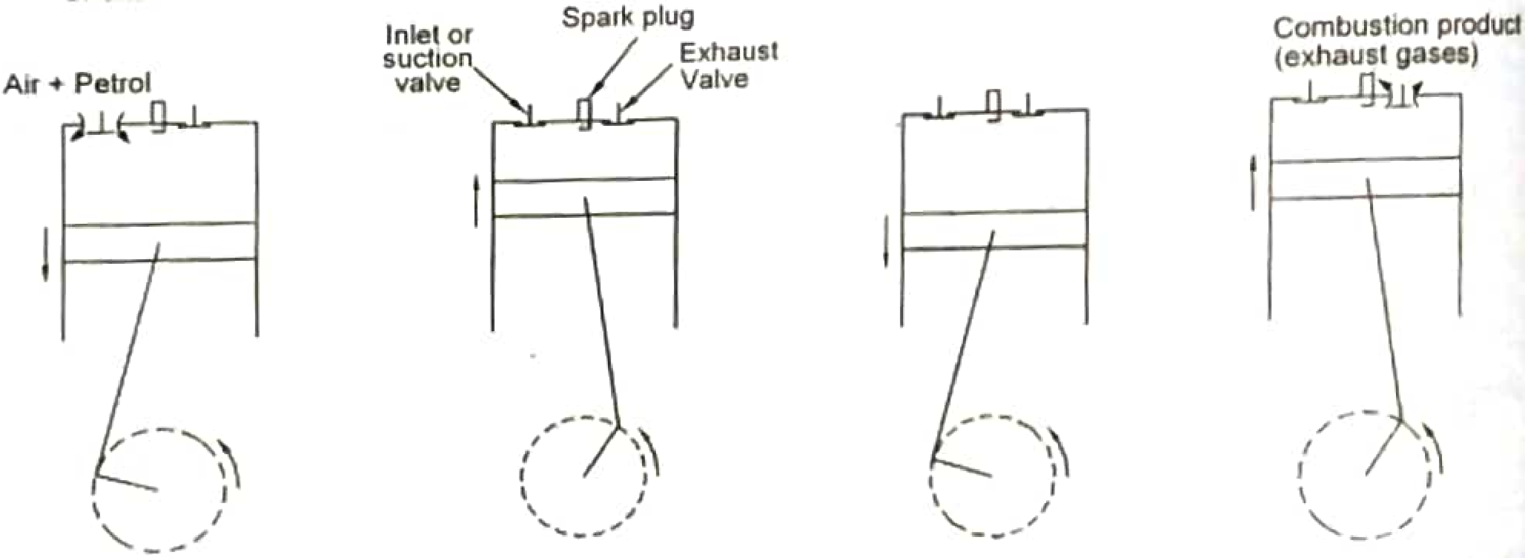
Where N is speed of engine.

(11) Compression Ratio : It is a ratio of volume at the beginning of compression stroke to volume at the end of the stroke. Volume at the beginning will be $V_s + V_c$ and at the end it will be V_c so compression ratio $r = \dfrac{V_s + V_c}{V_c}$.

For petrol engine its value varies from 6 to 12 while for diesel engine it is 16 to 22.

7.4 WORKING OF FOUR STROKE PETROL ENGINE :

Petrol engines works on Otto cycle. It uses spark to ignite the air fuel mixture so they are S.I. engines. The four strokes are (1) Suction stroke (2) Compression stroke (3) Expansion or power or working stroke (4) Exhaust stroke.



(a) Suction stroke (b) Compression stroke (c) Expansion stroke (d) Exhaust stroke

Fig. 7.2 Working of four stroke Petrol engine

(1) Suction Stroke : As shown in Fig. 7.2(a) during this stroke inlet valve remains open and exhaust valve remains closed. Piston moves from TDC to BDC. Since pressure inside the cylinder reduces below atmospheric pressure during downward motion of piston and inlet valve opens, air–fuel mixture (charge) sucks in during this stroke. When piston reaches at BDC, inlet valve is closed.

(2) Compression Stroke : As shown in Fig. 7.2(b) both valves remain closed during this stroke. Piston moves from BDC to TDC. Since both the valves are closed during upward motion of piston, air fuel mixture is compressed. Pressure and temperature of it will increase. When piston reaches to TDC, spark is produced by spark plug and it will ignite air–fuel mixture. This combustion is almost instantaneous. So it is referred as constant volume combustion. Pressure and temperature rapidly increases due to the combustion.

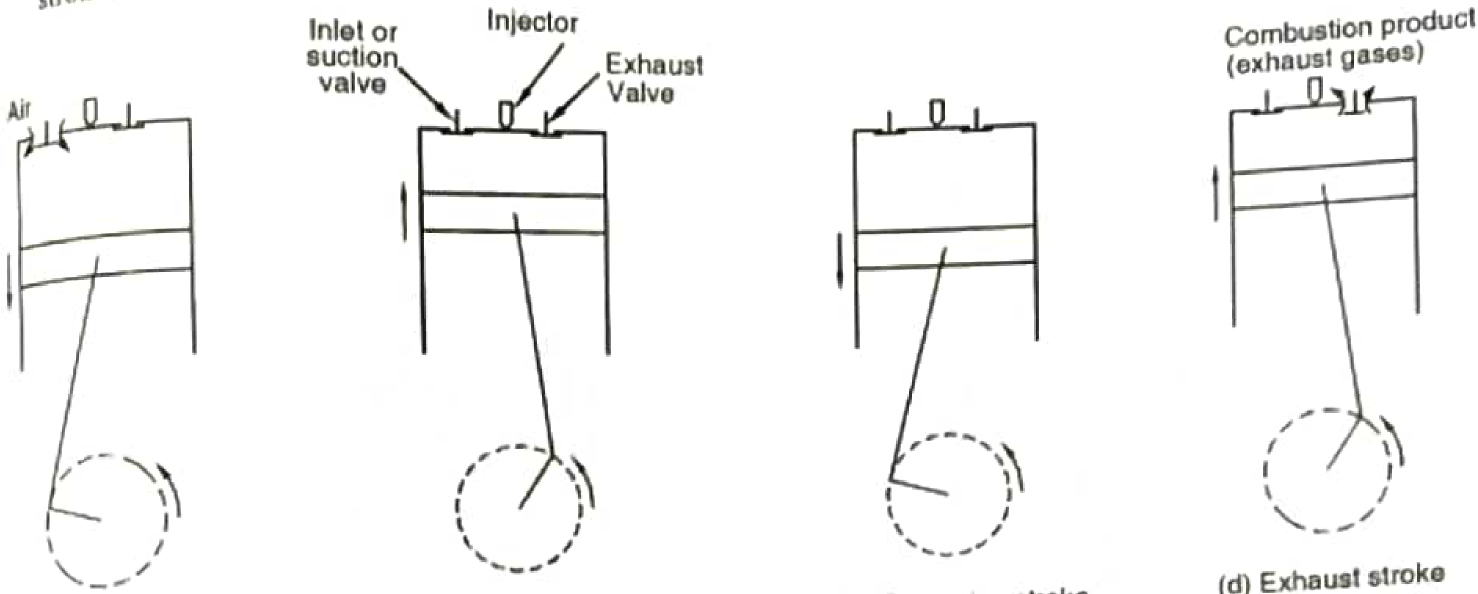
(3) Expansion or Power Stroke : As shown in Fig. 7.2(c) both inlet and exhaust valves remain closed. Piston moves from TDC to BDC. High pressure combustion product acts on piston and piston moves downward. This is working stroke because during this stroke work is done by the engine.

(4) Exhaust Stroke : As shown in Fig. 7.2(d) inlet valve remains closed and exhaust valve remains open during this stroke. Piston moves from BDC to TDC. During upward motion of piston, it pushes the exhaust gases (combustion product) out of the cylinder.

At the end of exhaust stroke exhaust valve is closed and inlet valve is opened and thus cycle is repeated.

7.5 WORKING OF FOUR STROKE DIESEL ENGINE :

Diesel engine works on diesel cycle. It uses compressed air to ignite fuel so it is Compression Ingnition (C.I.) engine. The four strokes are (1) Suction stroke (2) Compression stroke (3) Expansion or power stroke (4) Exhaust stroke.



(a) Suction stroke (b) Compression stroke (c) Expansion stroke (d) Exhaust stroke

Fig. 7.3 Working of four stroke Diesel engine

(1) **Suction Stroke :** During this stroke piston moves from TDC to BDC. Inlet valve remains open and exhaust valve is closed. Due to downward motion of the piston, pressure inside the cylinder decreases below atmospheric and air is sucked in to the cylinder. When piston reaches to BDC, inlet valve is closed.

(2) **Compression Stroke :** During this stroke both inlet and exhaust valves remain closed. Piston moves from BDC to TDC. since both valves are closed during upward motion of the piston, air is compressed. Pressure and temperature of the air increase. When piston reaches to TDC, diesel is injected in to the cylinder by fuel injector. Compression ratio of diesel engines is higher than petrol engine (around 16 to 22), so temperature of air at the end of compression is very high. This high temperature air causes the combustion of injected fuel. This combustion is nearly at constant pressure.

(3) **Expansion or Power Stroke :** During this stroke both valve remain closed. Piston moves from TDC to BDC. Due to combustion of fuel, pressure and temperature of combustion gases are high. This high pressure high temperature gases act on the piston and push it downward. This is the working stroke because during this stroke work is done by the engine.

(4) **Exhaust Stroke :** During this stroke inlet valve remains closed and exhaust valve is opened. Piston moves from BDC to TDC. During upward motion of the piston, it pushes the exhaust gases out of the cylinder.

At the end of exhaust stroke, exhaust valve is closed and inlet valve is opened and thus the cycle is repeated.

7.6 WORKING OF TWO STROKE PETROL ENGINE :

The two stroke engine requires two strokes of the piston or one revolution of the crankshaft to complete the cycle. Ports are used instead of valves in two stroke engines. The exhaust gases are expelled out from the engine cylinder by fresh charge of the fuel entering the cylinder. This is known as scavenging. Fig. 7.4 shows the working principle of two stroke petrol engine.

(1) **First Stroke :** At the beginning of stroke assume that the piston is at BDC. During this stroke, the piston moves from BDC to TDC. During upward motion, piston covers the transfer port and exhaust port. The air–petrol mixture (charge) which is already there in the cylinder is compressed. Pressure and temperature of air–petrol mixture increases. During upward movement, piston uncover the inlet port. Also partial vacuum is created in the crank case and fresh mixture of air–petrol is sucked into the crank case through inlet port. Stroke completes when piston reaches to TDC.

(2) **Second Stroke :** During this stroke piston moves from TDC to BDC. The compressed charge is ignited by spark provided by spark plug. Due to combustion of fuel pressure and temperature of combustion product increases rapidly. Due to this high pressure and temperature, combustion product acts on piston. It pushes the piston downward and produces useful work. During downward motion, piston covers the inlet port and fresh charge is compressed in the crank case. Further downward motion of piston uncovers the exhaust port and then the transfer port.

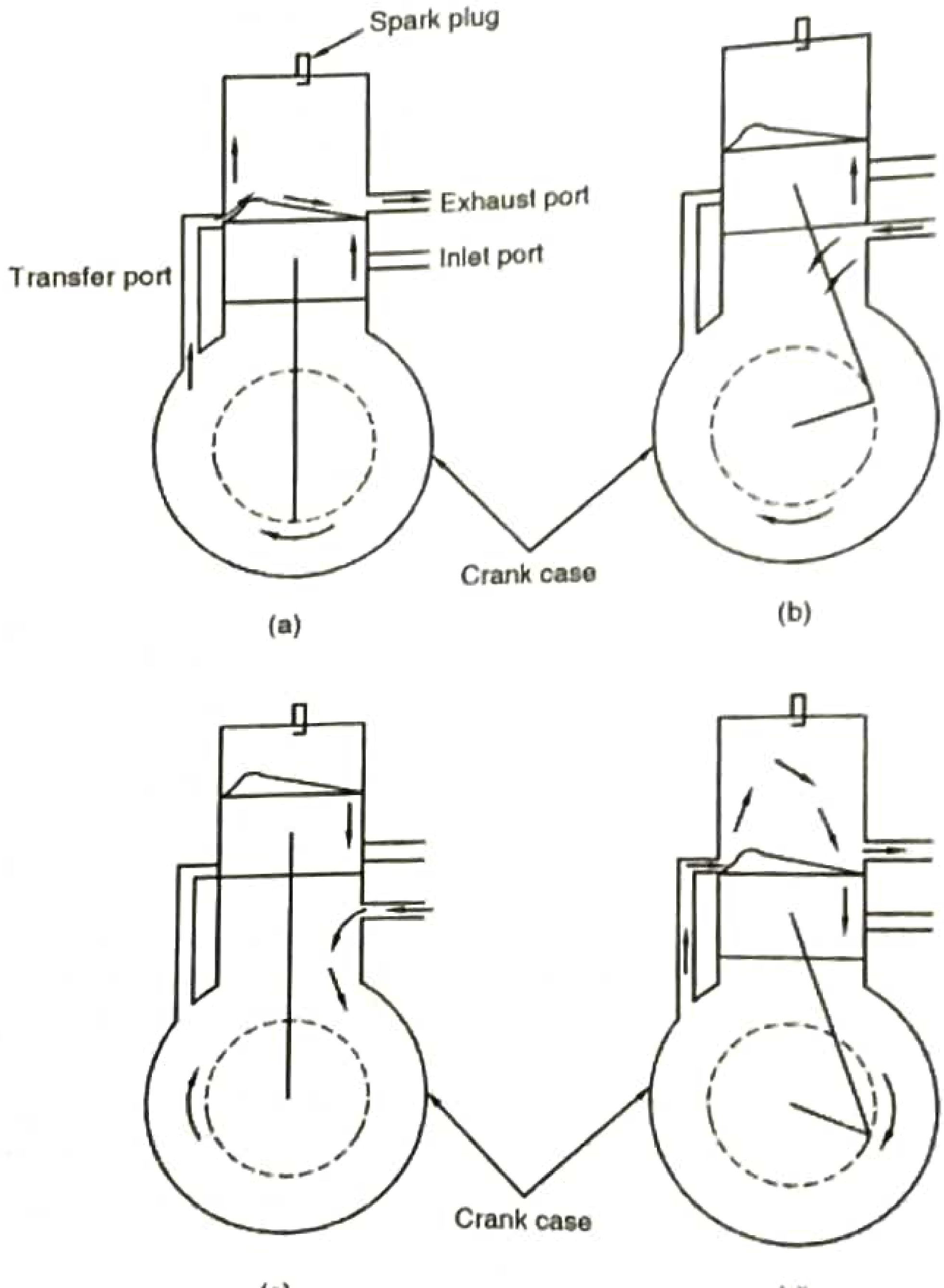


Fig. 7.4 Working of two stroke Petrol engine

The exhaust gases start escaping through the exhaust port. At the same time fresh charge compressed in crank case is forced into cylinder through transfer port. The charge strikes the deflector on the piston crown, rises to the top of the cylinder and pushes out the exhaust gases. When piston reaches BDC, the cylinder is completely filled with fresh charge and thus the cycle is completed. The cycle of events is then repeated.

7.7 WORKING OF TWO STROKE DIESEL ENGINE :

Fig. 7.5 shows working principle of two stroke diesel engine.

(1) **First stroke :** At the beginning of this stroke assume that piston is at BDC. During upward movement of the piston, first it cover the transfer port and then the exhaust port. Now air is compressed in cylinder, increases its pressure and temperature. At the same time piston uncover the inlet port. Partial vacuum is created in the crank case and fresh air is sucked into the crank case.

(2) **Second Stroke :** During this stroke, piston moves from TDC to BDC. At the end of first stroke air is present in the cylinder with high pressure and temperature. Just before end of first stroke diesel is injected by injector into the cylinder. At this moment, the temperature of the compressed air is high enough to ignite the fuel. The rate of fuel injection is such as to maintain constant pressure during the combustion. Combustion product acts on the piston pushing it downward producing useful work. Later on the stroke piston covers the inlet port and fresh air is compressed in crank case. Further downward motion of piston uncovers the exhaust port and then transfer post. The exhaust gases start escaping through exhaust port. At the same time fresh air compressed in crank case is forced into cylinder through transfer port. The air strikes the deflecter provided on piston. Due to this air rises up into cylinder and pushes exhaust gases out. When piston reaches BDC, the cylinder is completely filled with fresh air and thus the cycle is completed.

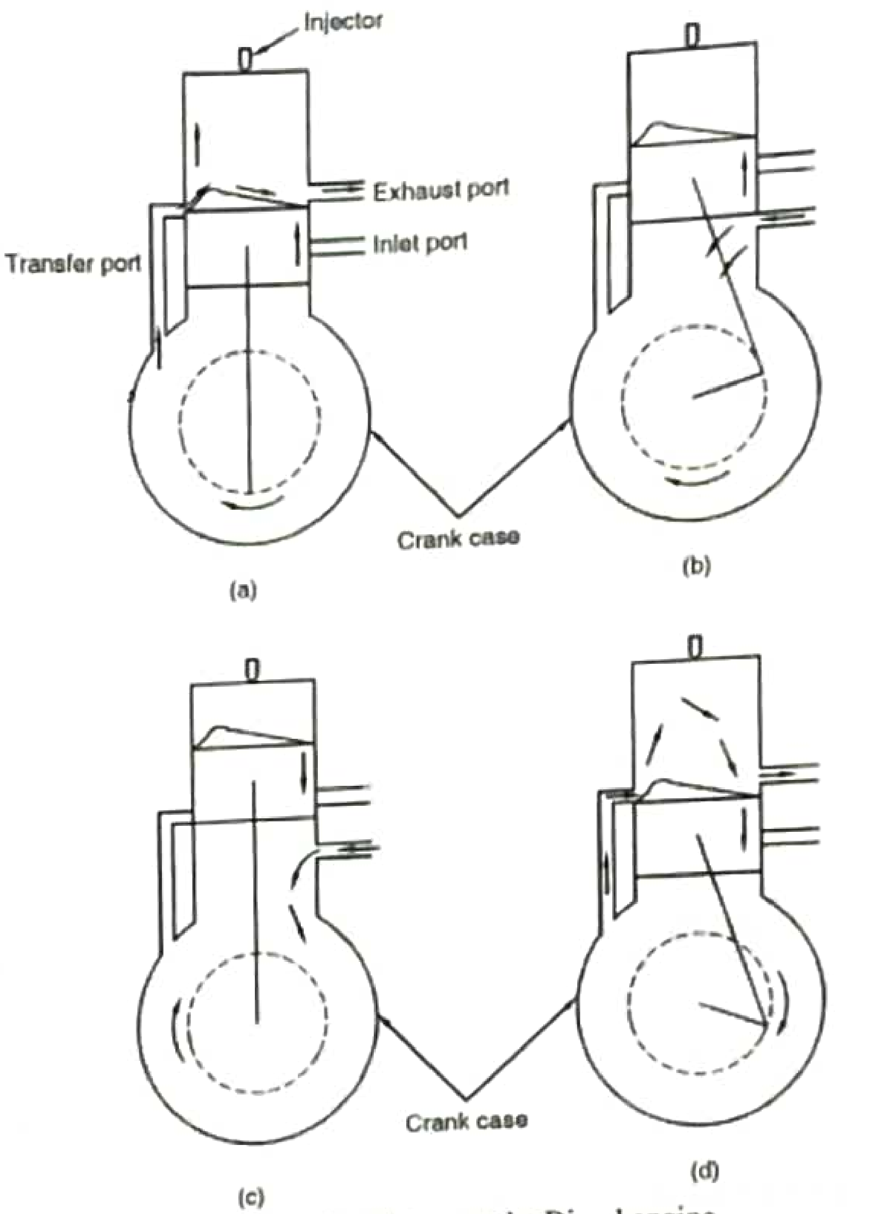


Fig. 7.5 Working of two stroke Diesel engine

7.8 ADVANTAGES OF TWO STROKE ENGINES OVER FOUR STROKE :

(1) The two stroke engine has one power stroke for each revolution. Four stroke engine has one power stroke for every two revolution of crank shaft. So theoretically power developed by two stroke engine is twice of that is developed by four stroke engine for same engine speed and cylinder volume. Actually it develops 1.7 to 1.8 times the power developed by four stroke engines.

(2) Due to even torque distribution, lighter flywheel is required.

(3) For same power, two stroke engine is more compact, light and require less space than four stroke engine. So it was more suitable for scooters and motorcycles.

(4) Due to absence of valve and valve mechanism, two stroke engines are simpler in construction and mechanism. Ports are used in two stroke engines which are opened and closed by piston movement. This makes them cheaper also.

(5) High mechanical efficiency due to less moving parts.

(6) Starting of two stroke engine is easier than four stroke engine.

7.9 DISADVANTAGE OF TWO STROKE ENGINE OVER FOUR STROKE ENGINE :

(1) Thermodynamic efficiency of two stroke engine is less than four stroke engine because compression ra of the two stroke engine is less than that of four stroke engine.

(2) The overall efficiency of two stroke engine is less as portion of fresh air petrol mixture in case of S engine always escapes through exhaust port. So specific fuel consumption is higher.

(3) More effective cooling system is required as there is one power stroke in each revolution in case of tw stroke engine.

(4) Consumption of lubricating oil is more as it is subjected to higher temperature.

(5) The exhaust is more noisy due to sudden release of the burnt gases.

(6) The fresh charge is polluted by burnt gases due to incomplete scavenging.

(7) There is a greater wear and tear of moving parts.

7.10 COMPARISON BETWEEN PETROL AND DIESEL ENGINES :

Petrol Engines	Diesel Engines
(1) During suction stroke air petrol mixture is sucked into cylinder.	(1) During suction stroke only air is sucked into cylinder.
(2) They work on Otto cycle.	(2) They work on Diesel cycle.
(3) Air petrol mixture is ignited by spark provided by spark plug. So they are S.I. engines.	(3) Fuel is ignited by high temperature compressed air. So they are C.I. engines.
(4) Petrol engines have carburettor for proper mixing of air and petrol before they sucked into cylinder.	(4) Diesel engine have injecter to inject fuel at the end of compression stroke.
(5) Compression ratio : 6 to 12.	(5) Compression ratio : 16 to 22.
(6) Due to lower compression ratio engines are lighter in weight.	(6) Due to high compression ratio they are heavier and stroger than petrol engines.
(7) Thermal efficiency is lower due to lower compression ratio.	(7) Higher thermal efficiency due to higher compression ratio.
(8) Initial cost is less but running cost is higher because cost of petrol is more than diesel.	(8) Initial cost is higher but running cost is lower.
(9) Starting torque is lower.	(9) Starting torque is higher.
(10) Examples : cars, scooters, motorcycles engines.	(10) Examples : trucks, buses and locomotive engines.

7.11 PERFORMANCE PARAMETERS :

Engine performance parameters like power, efficiency and specific fuel consumption are described in this section.

7.11.1 Indicated Power (IP) : It is power developed by engine. It is given by

$$IP = \frac{p_m ALn}{60} \quad (7.1)$$

Where, IP = indicated power, W

p_m = indicated mean effective pressure, N/m^2

A = cross section area of piston, m^2

L = stroke length, m

n = number of working stroke per minutes

For four stroke engine $n = \frac{N}{2}$ where N is speed of engine in rpm.

$$\therefore \quad IP = \frac{p_m ALN}{60 \times 2} \quad (7.2)$$

For two stroke engine n = N

$$\therefore \quad IP = \frac{p_m ALN}{60} \tag{7.3}$$

7.11.2 **Brake Power (BP) :** It is power available at the engine shaft. It is less than indicated power because of friction of various moving engine parts. Generally brake arrengements are used to measure it hence named as brake power.

$$BP = \frac{2\pi NT}{60} = \frac{p_{mb} ALn}{60} \tag{7.4}$$

Where, N = speed of engine in rpm

T = resisting torque or torque available at engine shaft N.m

p_{mb} = brake mean effective pressure

7.11.3 **Friction Power :** It is power lost due to friction FP = IP – BP.

7.11.4 **Mechanical Efficiency :** It is ratio of power available at crank shaft (BP) to the power developed by engine cylinder (IP). It is denoted by η_{mech}.

$$\eta_m = \frac{BP}{IP} \tag{7.5}$$

7.11.5 **Thermal Efficiency :** It is ratio of work output of the engine to heat supplied by fuel.

Indicated Thermal Efficiency : It is ratio of indicated power to heat supplied by fuel per second. It is denoted by η_{ith}.

$$\eta_{ith} = \frac{\text{Indicated power, kW}}{\text{Fuel supplied, kg/sec} \times \text{C.V., kJ/kg}} \tag{7.6}$$

Brake Thermal Efficiency : It is ratio of brake power to heat supplied by fuel per second. It is denoted by η_{bth}.

$$\eta_{bth} = \frac{\text{Brake power, kW}}{\text{Fuel supplied, kg/sec} \times \text{C.V., kJ/kg}} \tag{7.7}$$

From equation 7.6 and 7.7 we can write

$$\eta_m = \frac{\eta_{bth}}{\eta_{ith}} \tag{7.8}$$

7.11.6 **Relative Efficiency :** It is ratio of actual thermal efficiency to its corresponding air standard efficiency. It is denoted by η_r

$$\eta_r = \frac{\text{Actual thermal efficiency}}{\text{Air standard efficiency}} \tag{7.9}$$

7.11.7 **Brake specific fuel consumption :** It is generally expressed as fuel consumption in kg per kWh of brake power. It indicates how good the engine performance is

$$BSFC = \frac{\text{Fuel consumption per unit time}}{\text{brake power}} \tag{7.10}$$

EXERCISES

1. With neat sketch explain working of :
   (a) Four stroke petrol engine (b) Four stroke diesel engine
   (c) Two stroke petrol engine (d) Two stroke diesel engine.
2. Differentiate between :
   (a) Two stroke engine and Four stroke engine
   (b) Petrol engine and diesel engine
3. Define :
   (a) Indicated power (b) Brake power (c) Friction power
   (d) Mechanical efficiency (e) Indicated thermal efficiency (f) Brake thermal efficiency
   (g) Relative efficiency
4. Justify :
   (a) Heavier flywheel is required for four stroke engine compared to two stroke engine.
   (b) For same power output two stroke engines are compact/smaller in size compared to four stroke engines.
   (c) Two stroke engine has higher pickup
   (d) Two stroke engines are cheaper than four stroke engines.
   (e) Cam shaft rotates at a speed of half of that of crank shaft.
   (f) Fins are provided on surface of the cylinder
   (g) Piston head of two stroke engine is provided with deflecter.
   (h) Two stroke engine has higher specific fuel consumption.
5. State function of following components :
   (a) piston (b) cylinder (c) piston rings (d) gudgeon pin
   (e) connecting rod (f) crank shaft (g) cam shaft (h) spark plug
   (i) injector (j) carburettor

PROBLEMS

1. A four stroke four cylinder petrol engine has bore of 65 mm and stroke of 95 mm. It develop torque of 64 N.m while running at 3000 rpm. If clearance volume in each cylinder is 63 cm^3, relative efficiency based on brake thermal efficiency is 0.5 and calorific value of petrol is 42,000 kJ/kg, calculate fuel consumption in kg/hr and p_{mb}.
   [Ans. 6.726 kg/hr, 6.279 bar]

2. A four cylinder two stroke cycle petrol engine develops 30 kW at 2500 rpm. The indicated mean effective pressure in each cylinder is 8 bar and mechanical efficiency is 80%. Storke to bore ratio is 1.5, brake thermal efficiency is 28% and C.V. of fuel is 44,000 kJ/kg. Calculate (a) bore and stroke of each cylinder (b) brake specific fuel consumption.
   [Ans. D = 62 mm, L = 93 mm, BSFC = 0.2922 kg/kWh]

3. The following data available for two stroke diesel engine : bore = 10 cm, stroke = 15 cm, piston speed = 300 m/min, torque developed = 58 Nm, mechanical efficiency = 80%, indicated thermal efficiency = 40%, calorific value of fuel used = 44000 kJ/kg. Calculate (a) indicated power (b) p_m (c) BSFC.
   [Ans. 7.59 kW, 3.87 bar, 0.2557 kg]

4. The following data available for four stroke petrol engine : bore = 20 cm stroke to bore ratio = 1.5, speed = 350 rpm, p_m = 2.75 bar, net brake load = 610 N, effective diameter of brake drum = 1 m, petrol consumption = 4.25 kg/hr, C.V. of pertrol = 44 MJ/kg. Determine : (a) IP (b) BP (c) η_{mech} (4) η_{ith} (5) η_{bth}
   [Ans. 15.2 kW, 11.2 kW, 73.93%, 29.1%, 21.5%]

5. A four stroke six cylinder engine with stroke volume of 1.75 litres develops 26.25 kW. The mean effective pressure is 6 bar. Find speed of the engine.
   [Ans. 500 rpm]

6. A six cylinder four stroke I.C. engine is to develop 100 kW IP at 800 rpm. The stroke to bore ratio is 1.25. Assuming mechanical efficiency of 80% and brake mean effective pressure of 5 bar, find out the diameter and stroke of the engine.
   [Ans. D = 16 cm, L = 20 cm]

7. A six cylinder four stroke petrol engine develops 300 kW (BP) at 2500 rpm. The stroke to bore ratio is 1.25. The mean effective pressure on each piston is 9 bar and mechanical efficiency of the engine is 80%. Indicated thermal efficiency is 30%. Calculate (a) stroke and bore of the engine. (b) fuel consumption. Take C.V. of petrol equals to 41900 kJ/kg. [**Ans.** L = 189 mm, D = 151 mm, m_f = 107.4 kg/h]

8. During a trial on single cylinder four stroke IC engine, the following observations were taken : Mean effective pressure = 4 bar, speed = 200 RPM, Brake power = 7.5 kW, L/D ratio of pistion = 1.5. If mechanical efficiency is 70% find the dimensions of the engine. [**Ans.** D = 240 mm, L = 360 mm]

9. Following data refers to a test on a petrol engine. Indicated power = 30 kW, Brake power = 26 kW, Engine speed = 1800 RPM, Brake specific fuel consumption = 0.35 kg/kWh, C.V. of fuel = 44,000 kJ/kg

   Calculate : (1) η_m (2) η_{ith} (3) η_{bth} [**Ans.** 86.67%, 26.97%, 23.37%]

10. An engine is used on a job requiring 110 kW BP. The mechanical efficiency of the engine is 80% and engine consumes 50 kg/hr of fuel. A design improvement is made which reduces the engine friction by 5 kW. If indicated thermal efficiency remains the same, how many kg of fuel per hour will be saved ? [**Ans.** 1.8 kg/h]

11. The following data refer to single cylinder four stroke Diesel engine.

    BP = 100 kW, N = 400 rpm, bmep = 850 kPa, C.V. of fuel = 43000 kJ/kg, L/D = 1.25, η_m = 80%, BSFC = 0.335 kg/kWh. Calculate bore and stroke of the engine, indicated mean effective pressure, brake thermal efficiency and indicated thermal efficiency.

    [**Ans.** D = 330 mm, L = 412.5 mm, IP = 125 kW, p_m = 1062.5 kPa, η_{bth} = 25%, η_{ith} = 31.25%]

12. A petrol engine is working on four stroke cycle. It has bore and stroke equal to 150 mm and 175 mm respectively and clearance volume of 5×10^5 mm^3. The indicated thermal efficiency is 28%. Find the relative efficiency of the engine. If the mean effective pressure is 4.6 bar and engine speed is 1900 rpm find indicated power of the engine. [**Ans.** 51.3%, IP = 22.58 kW]

OBJECTIVE TYPE QUESTIONS

1. Four stroke engine has one power stroke for ______ of crank shaft
   (a) each revolution (b) every two revolutions (c) every half revoluton (d) every four revolutions
2. Petrol engines work on ______ system
   (a) spark ignition (b) compression ignition (c) either spark or compression ignition
3. Diesel engines are ______ governed
   (a) quality (b) quantity (c) either of the two
4. Cars have generally ______ engine
   (a) V-type (b) radial (c) horizontal (d) inline
5. Piston is generally made from
   (a) mild steel (b) aluminium alloys (c) bronze (d) brass
6. Crankshaft rotates at ______ of the camshaft speed
   (a) same (b) half (c) twice (d) four times
7. Swept volume equals to
   (a) $\pi D^2 L$ (b) $\frac{\pi}{4} D^2 L$ (c) $\pi D L^2$ (d) $\frac{\pi}{4} D L^2$
8. Piston speed equals to
   (a) 2LN (b) LN (c) DN (d) 2DN
9. Compression ratio equals to
   (a) $\frac{V_s}{V_s + V_c}$ (b) $\frac{V_s + V_c}{V_s}$ (c) $\frac{V_s + V_c}{V_c}$ (d) $\frac{V_c}{V_s + V_c}$
10. In four stroke petrol engine spark is product at the end of ______ stroke
    (a) suction (b) compression (c) expansion (d) exhaust
11. Which one of the following is not a standard component of Diesel engine ?
    (a) spark plug (b) fuel injector (c) fuel pump (d) air filter

12. In four stroke Diesel engine _______ is sucked during suction stroke
(a) only air (b) air-fuel mixture (c) air and 50% of fuel (d) fuel and 50% of air

13. During expansion stroke in four stroke engine
(a) inlet valve remains open and exhaust valve remains closed
(b) inlet valve remains closed and exhaust valve remains open
(c) both valves remain closed
(d) both valves remain open

14. In two stroke engines ports are operated by _______ movement
(a) crank (b) piston (c) connecting rod (d) piston pin

15. Mechanical efficiency of two stroke engine is _______ four stroke engine
(a) higher than (b) lower than (c) comparable to

16. Specific fuel consumption of two stroke engine is _______ four stroke engine
(a) higher than (b) lower than (c) comparable to

17. Choose the false statement
(a) Thermal efficiency of Petrol engines is lower than that of Diesel engine
(b) Starting torque of Petrol engines is lower than that of Diesel engine
(c) Petrol engines are lighter than Diesel engines
(d) Petrol engines are CI engines

18. Mechanical efficiency of IC engines is defined by the equation
(a) $\eta_m = \frac{BP}{m_f \times CV}$ (b) $\eta_m = \frac{IP}{m_f \times CV}$ (c) $\eta_m = \frac{BP}{IP}$ (d) $\eta_m = \frac{FP}{BP}$

19. Travel of piston from one dead centre to other dead centre is termed as _______. **(Jan. 2011)**
(a) stroke length (b) swept volume (c) clearance volume (d) compression ratio

20. Two stroke Diesel cycle is completed in _______ revolution of crank shaft. **(Jan. 2013)**
(a) One (b) Two (c) Three (d) Four

21. Carburetor is used to supply **(Jan. 2013)**
(a) Diesel and Air Mixture (b) Petrol and Air mixture
(c) Diesel only (d) Petrol only

22. The compression ratio for petrol engine is _______ **(Winter 2016)**
(a) 3 to 6 (b) 5 to 8 (c) 15 to 20 (d) 20 to 30

23. Petrol engine work on _______ system. **(Summer 2017)**
(a) either spark or compression ignition (b) spark ignition
(c) compression ignition (d) all of the above

24. In a two stroke engine ports are operated by movement of **(Winter 2017)**
(a) Crank (b) Piston (c) Connecting rod (d) Piston pin

25. The unit of specific fuel consumption is _______ **(Winter 2017)**
(a) Kg/sec (b) kg/kWh (c) kg/kW (d) none of the above

26. In a IC engine which energy is converted into mechanical energy? **(Summer 2018)**
(a) Heat energy (b) Potential energy (c) Kinetic energy (D) Chemical energy of fuel

: ANSWERS :

1. (b)	2. (a)	3. (a)	4. (d)	5. (b)	6. (c)	7. (b)	8. (a)	9. (c)	10. (b)
11. (a)	12. (a)	13. (c)	14. (b)	15. (a)	16. (a)	17. (d)	18. (c)	19. (a)	20. (a)
21. (b)	22. (b)	23. (b)	24. (b)	25. (b)	26. (d)				

❖ ❖ ❖

8

AIR COMPRESSORS

A *compressor* is a device which take in gas or vapour, increases its pressure and deliver it at a high pressure.

8.1 USES OF COMPRESSED AIR :

(1) Operating pneumatic drills, hammers, spanner

(2) Operating hoist, lift gates and pneumatic tools in mines

(3) Operating blast furnaces and sand blasting

(4) Spray painting

(5) Air brakes used in buses and trucks

(6) To drive air motors

(7) Filling air in automobile tyres

(8) Glass blowing

(9) Air compression is a major factor in performance of I.C. engines and gas turbines

8.2 CLASSIFICATION OF AIR COMPRESSORS :

Air compressors are classified based on various catagories.

(a) According to Principle of Working :

(1) Positive displacement

(2) Dynamic

(b) According to Number of Stages :

(1) Single stage – upto pressure ratio 5 to 6

(2) Multi stage – pressure ratio more than 6

(c) According to Acting of Piston :

(1) Single acting

(2) Double acting

(d) According to Number of Cylinder :

(1) Single cylinder

(2) Multi cylinder

(e) According to Pressure Ratio :

(1) Fan – pressure ratio up to 1.1

(2) Blower – pressure ratio 1.1 to 2.5

(3) Compressor – pressure ratio more than 2.5

(f) According to the Arrangement of Cylinder :

(1) Vertical

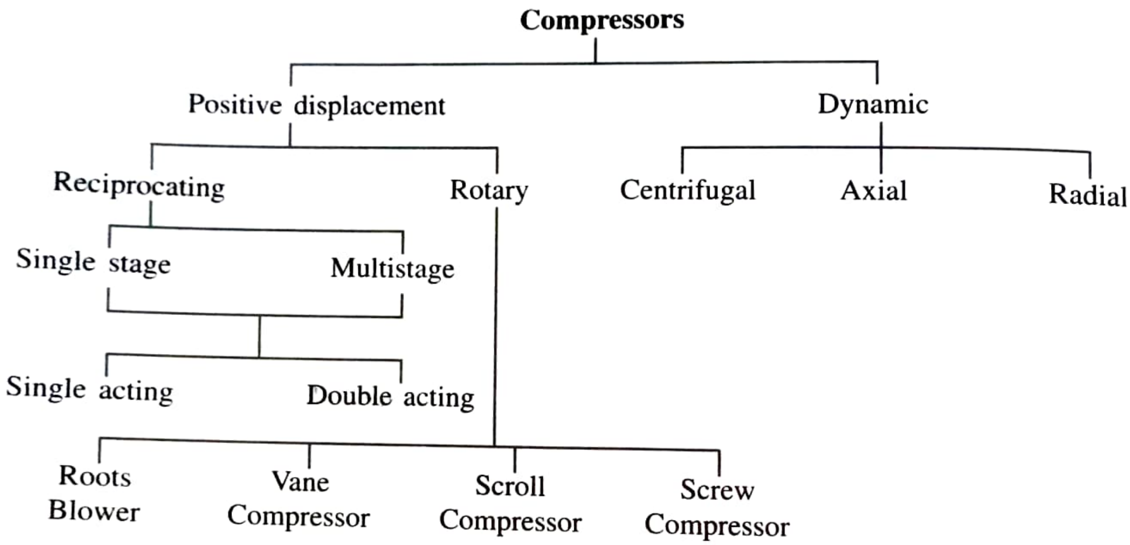
(2) Horizontal

(3) V–type

(4) Radial

(g) According to Method of Cooling :

(1) Air cooled (2) Water cooled



As seen from Fig. 8.1 below, centrifugal compressors in general are used for low pressure applications, while rotary and reciprocating compressor can produce medium and high pressures.

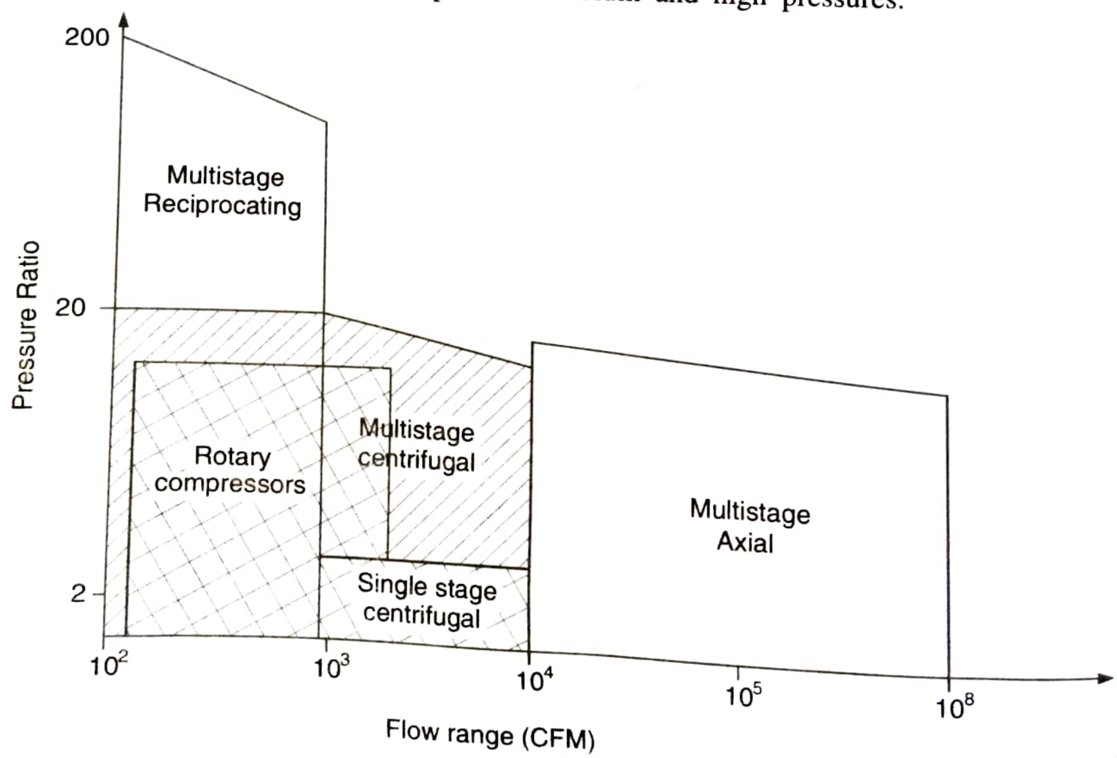


Fig. 8.1

8.3 AIR COMPRESSOR TERMINOLOGY :

(1) **Single Acting Compressor :** Compressor in which suction, compression and delivery of air takes place only on one side of piston is called single acting compressor.

(2) **Double Acting Compressor :** Compressor in which suction, compression and delivery of air takes place on both sides of piston is called double acting compressor.

(3) **Single Stage Compressor :** Compressor in which compression of air from suction pressure to delivery pressure takes place only in one cylinder is called single stage compressor.

(4) **Multi Stage Compressor :** Compressor in which compression of air from suction pressure to delivery pressure takes place in more than one cylinder is called multi stage compressor.

(5) **Compression Ratio :** It is defined as ratio of absolute discharge pressure to absolute suction pressure.

(6) **Volumetric Efficiency :** It is defined as ratio of actual volume of air taken in the compressor to the swept volume of the compressor.

(7) **Compressor Capacity :** It is volume of air delivered by the compressor. It is expressed in m^3/min or m^3/s.

(8) **Free Air Delivery :** It is actual volume of air delivered by a compressor when reduced to the normal temperature and pressure condition. The capacity of a compressor is generally given in terms of free air delivery.

(9) **Swept Volume :** Swept volume or displacement volume of a single acting air compressor is given by

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

D = diameter of cylinder

L = stroke length

8.4 WORKING OF SINGLE STAGE RECIPROCATING AIR COMPRESSOR :

As shown in Fig. 8.2 a single stage reciprocating air compressor consists of piston which reciprocates in a cylinder, driven through connecting rod and crank. It also consists of inlet (suction) valve (I.V.) and delivery valve (D.V.). These valves are pressure differential type. They operate due to pressure difference across it.

When piston moves downward during suction stroke, the compressed air left in the cylinder expands. Due to expansion of air, pressure inside the cylinder falls below atmospheric pressure. As result of this pressure difference the inlet valve opens and fresh air is sucked into the cylinder. During this stroke the delivery valve remain closed since the compressed air on outside of the valve (in the reciever) is at a higher pressure.

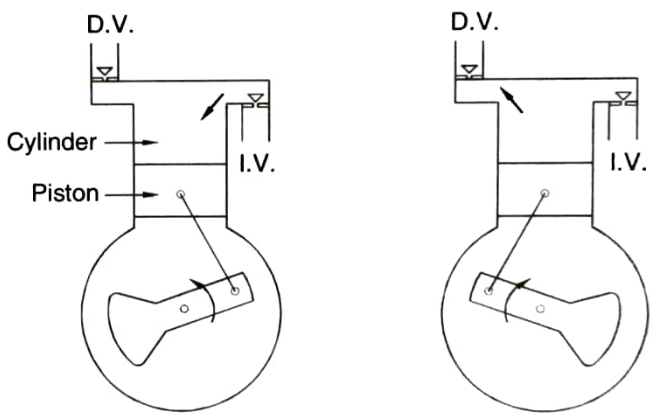


Fig. 8.2 Single stage reciprocating air compressor

At the beginning of the upward stroke, slight increase in pressure will close the inlet valve. Now both inlet and delivery valves are closed and hence pressure of air increases rapidly. When pressure inside the cylinder increases slightly above the compressed air pressure on outside of delivery valve, the delivery valve opens and compressed air is delivered into the reciever. At the end of this stroke piston once again moves downward and as pressure decreases delivery valve will be closed. When pressure falls below atmospheric once again inlet valve opens and thus the cycle is repeated.

8.5 NEED FOR MULTI STAGING :

(1) As shown in Fig. 8.3 if delivery pressure is too high, then only clearance volume will be compressed and expanded and there will be no delivery of air.

(2) Also temperature is very high. If high temperature is not required it is loss of energy.

(3) Heavier parts are required due to high pressure. This will lead to balancing problems.

(4) Due to high temperature lubricating oil looses its lubricating properties and friction increases.

(5) The size of cylinder will be too large.

Due to above problems maximum pressure compression ratio in single stage is generally limited to 7.

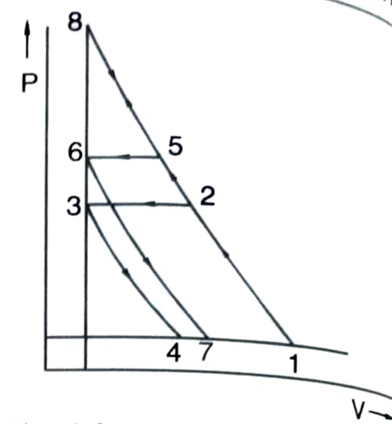


Fig. 8.3 Multistage compression

Advantages of Multistage Compression :

(1) Due to intercooling between two stages work required per kg of air reduces.

(2) For a given pressure ratio volumetric efficiency increases.

(3) It reduces the leakage loss considerably.

(4) It gives more uniform torque and so a smaller size flywheel is required.

(5) Lubrication is more effective due to lower temperature range.

(6) It reduces the cost of compressor.

8.6 CENTRIFUGAL COMPRESSOR :

A centrifugal compressor consists of an impeller (rotor) usually rotates at high speed (some time at 20,000 to 30,000 rpm) in an air tight volute casing (Refer Fig. 8.4). The impeller consists of disc to which a number of curved vanes are fitted symmetrically. The vanes breaks up air into cells. When the impeller is rotated the cells of air will also rotate. Due to centrifugal force, the air in the cell moves out from the outside edge of the impeller. This will create partial vacuum at the centre of the impeller (which is also known as eye of impeller).

This cause more air to move into centre of the impeller. The air move away from the outside edge of impeller passes into a diffuser which helps to direct the air into volute casing. Also in the diffuser the air is decceleraled due to which pressure of air will increase. The volute casing is a collecting device for the compressor. It has increased cross section area round the compressor. This is because a greater section is required to pass the increasing quantity of air round the volute. Also increase in cross section area helps to convert kinetic energy of air into pressure energy before it leaves the casing. Centrifugal compressor is a steady flow device and we can have continuous flow of air. It deals with large quantity of air with moderate pressure range. Pressure ratio acheived by such compressor ranges 4 to 6.

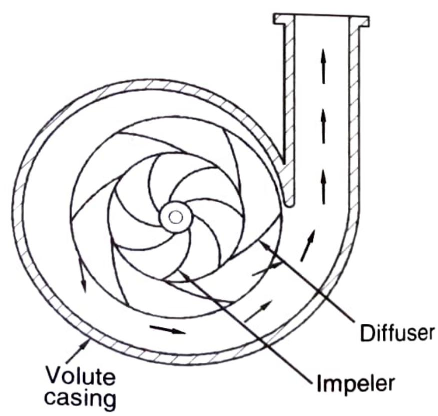


Fig. 8.4 Centrifugal compressor

8.7 AXIAL FLOW COMPRESSOR :

In axial flow compressor there are alternate rows of fixed and moving blades. The fixed blades are attached to inner side of outer casing. The moving blades are attached to a central drum which is rotated by external means. The moving blades are seen as a set of fans in series. When mechanical energy is provided to the rotating shaft, the drum will rotate. The air enters the compressor as shown in Fig. 8.5. As the drum rotates, the air flows through the alternately arranged fixed and moving blades. As the air flows from one set of fixed and moving blade to another, it gets compressed. Thus there is a succesive compression of air in all sets of fixed and moving blades. The air passes axially along the compressor hence it is named. The high pressure air is removed by suitable duct at the end of the compressor. This type of compressor are high speed and deals with large quantity of air. Pressure ratio upto 10 is obtained by such compressors. This type of compressor is generally used in air craft gas turbines.

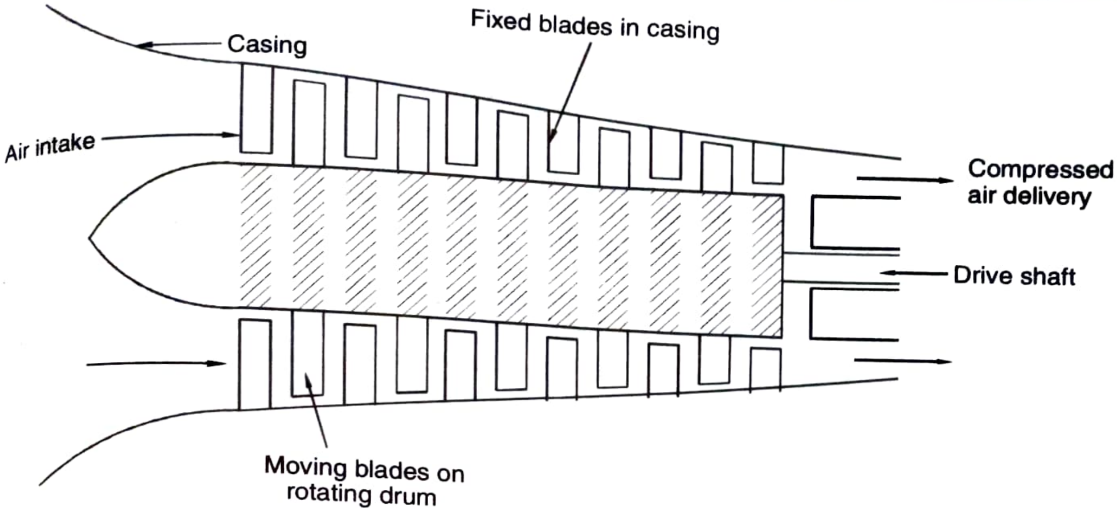


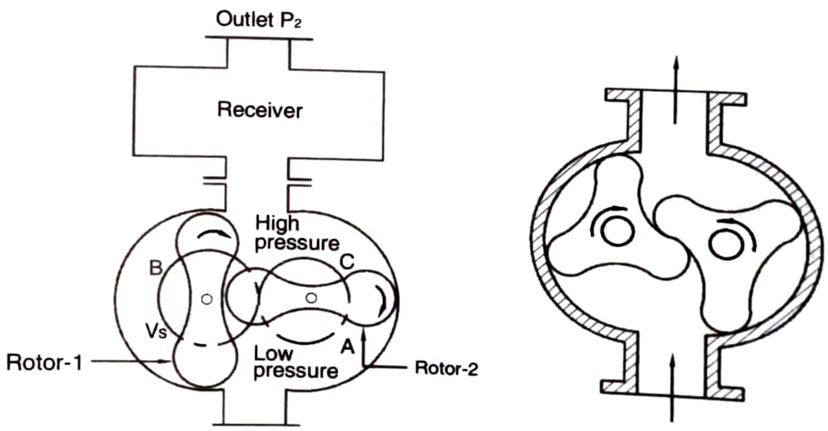
Fig. 8.5 Axial flow compressor

Difference between Centrifugal and Axial Flow Compressors :

Centrifugal Compressor	Axial Flow Compressor
(1) The flow of air is perpendicular to the axis of compressor.	(1) The flow of air is parallel to axis of compressor.
(2) It requires low starting torque.	(2) It requires high starting torque.
(3) It has low manufacturing and running cost.	(3) It has high manufacturing and running cost.
(4) It is not suitable for multi staging.	(4) It is suitable for multi staging.
(5) It requires large frontal area.	(5) It requires less frontal area.

ROOTS BLOWER :

A roots blower consists of two rotors with lobes rotating in a air tight casing. The casing has inlet and outlet ports on opposite sides. Roots blower has generally two or three lobes as shown in Fig. 8.6. The lobes are so designed that they provide an air tight joint at the point of their contact.



(a) (b)

Fig. 8.6 Roots blower compressor

One of the rotors is rotated by external means. The other is gear driven by the first one. When the rotors rotate, the air at atmospheric pressure is trapped in the pockets formed between rotor and casing. The rotory motion of the lobes deliver the entrapped air into the receiver. Thus more and more air is delivered in to the receiver. This increases the pressure of air in the receiver. Finally the air is used at required pressure from the receiver.

When rotating lobes uncovers the outlet port, some high pressure air flows back into pocket from receiver. This process is known as backflow process. The back flow of air from receiver to pocket continues untill the pressure in the pocket and receiver become equal. Thus the pressure of entrapped air in the pocket increases at constant volume by the backflow of air.

8.9 VANE BLOWER :

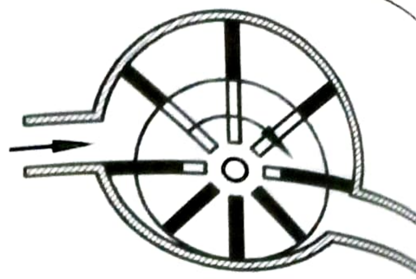


Fig. 8.7 Vane blower compress

A vane blower consists of a rotor rotating eccentrically in an air tight casing (Refer fig. 8.7). The casing has inlet and outlet ports on opposite sides. The rotor has 4 to 8 slots. The slots contain vanes which can reciprocate in the slots. The vanes are generally made from non–metallic material like fibre. When the rotor rotates, the vanes are pressed against the casing due to centrifugal force and form air tight pockets.

When the rotor is rotated by external source, the air is trapped between vanes and casing. Rotary motion of the rotor causes reduction of the volume between the vanes and casing. Thus the initial compression of air is due to reduction in volume. W rotating vanes uncovers the outlet port high pressure air from the receiver flows back in to the space betw vanes and casing. Thus further increase in pressure is due to back flow. Finally the air is delivered to the rece This compressed air is used from the receiver.

8.10 COMPARISON BETWEEN RECIPROCATING AND ROTARY AIR COMPRESSOR :

Reciprocating Compressor	Rotary compressor
(1) Maximum delivery pressure may be as high as 1000 bar.	(1) Maximum delivery pressure is 10 bar only.
(2) Maximum air discharge is around 300 m^3/min.	(2) Maximum air discharge is round 3000 m^3/min
(3) Used for low discharge–high pressure applications.	(3) Used for high discharge–low pressure applicat
(4) Rotates at low speed.	(4) Rotates at high speed.
(5) Air discharge is intermittent.	(5) Air discharge is continuous.
(6) For given discharge, size is larger than rotory compressor.	(6) For given discharge, size is smaller than reciproc compressor.
(7) Balancing is main problem due to reciprocating mass.	(7) No or less balancing problem due to rotory r
(8) lubrication system is complicated.	(8) Lubrication system is simple.
(9) As air comes in contact with lubricating oil, it is less clean.	(9) As air does not come in contact with lubricatin it is more clean.
(10) For calculation, Isothermal process is taken as ideal process.	(10) For calculation, isentropic process is taken as process.

EXERCISES

1. Define air compressor.
2. What are the uses of compressed air ?
3. Classify air compressor.
4. With neat sketch explain (a) centrifugal compressor (b) axial flow compressor (c) roots blower (d) vane

OBJECTIVE TYPE QUESTIONS

1. Compressor in which compression of air from suction pressure to delivery pressure takes place in more one cylinder is called _______ compressor.
   (a) single acting (b) double acting (c) single stage (d) multi stage
2. Compressor in which compression of air takes place on both sides of piston is called _______ compr
   (a) single acting (b) double acting (c) single stage (d) multi stage
3. Scroll compressor is a _______ compressor.
   (a) reciproacting (b) rotary (c) dynamic (d) radial

A device is called compressor if pressure ratio is
(a) up to 1.1 (b) between 1.1 and 2.5 (c) > 1.5 (d) > 2.5

Which type of valves are used in reciprocating air compressor ?
(a) cam operated (b) pressure differential (c) crank operated (d) piston operated

Due to multi staging volumetric efficiency of a compressor
(a) increases (b) decreases (c) remain unaffected (d) can't say

Advantage of using multi stage compression is
(a) work input increases
(b) small size flywheel is required
(c) leakage loss increases
(d) amount of lubricant required increases

With increase in pressure ratio volumetric efficiency of a compressor
(a) increases (b) remains constant (c) decreases (d) can't say

Volute casing has ________ cross section area
(a) increased (b) decreased (c) same

Pressure ratio acheived by axial flow compressor is upto
(a) 6 (b) 10 (c) 20 (d) 30

An axial flow compressor is a ________ compressor.
(a) positive displacement
(b) radial flow dynamic
(c) axial flow dynamic
(d) positive displacement rotary

Roots blower is a ________ compressor.
(a) positive displacement reciprocating
(b) radial flow dynamic
(c) axial flow dynamic
(d) positive displacement rotary

In a rotary compressor, maximum delivery pressure may be around ________. **(Jan. 2011)**
(a) 1000 bar (b) 100 bar (c) 2 bar (d) 10 bar

The volume of air delivered by compressor is called ________. **(Jan. 2013)**
(a) Swept Volume
(b) Free Air Delivery
(c) Compressor Capacity
(d) Efficiency

Centrifugal compressor is suitable for producing? **(Winter 2015)**
(a) High pressure (b) medium pressure (c) low pressure (d) all of the above

The work done on compressor is least when the compression is ________. **(Summer 2016)**
(a) Isothermal (b) Adiabatic (c) Polytropic (d) None of the above

Intercooling in multi-stage compression is used to ________. **(Summer 2016)**
(a) cool air
(b) minimize the work done
(c) reduce volume of air
(d) none of the above.

The maximum delivery pressure in a rotary air compressor is ________. **(Winter 2016)**
(a) 10 bar (b) 20 bar (c) 30 bar (d) 50 bar

Scroll compressor is a ________ compressor. **(Summer 2017)**
(a) reciprocating (b) rotary (c) dynamic (d) radial

The compressor used in aircrafts is ________. **(Winter 2017)**
(a) Axial flow (b) Roots blower (c) Vane blower (d) Reciprocating compressor

ANSWERS

1. (d)	**2.** (b)	**3.** (b)	**4.** (d)	**5.** (b)	**6.** (a)	**7.** (b)	**8.** (c)	**9.** (a)	**10.** (b)
11. (c)	**12.** (d)	**13.** (d)	**14.** (a)	**15.** (c)	**16.** (a)	**17.** (b)	**18.** (a)	**19.** (b)	**20.** (a)

❖ ❖ ❖

9

PUMPS

9.1 INTRODUCTION :

Pump has been used to lift water for a long time. Today also it is used to lift water in our houses, in water works and agricultural purpose. The application of pump has now diversified to different fields and industries. It is an indispensable part of power plants, steel and mining industry, fertilizer and chemical industries, cement and paper industries. The pump basically increases the energy level of the fluid which it handles. This energy can be used to increase potential energy as in water pumping, create a water jet (convert to kinetic energy) in fire–fighting pumps or supply fluid on high pressure side as in power plants. The pump may be driven by an electric motor, an I.C. engine, a gas or steam turbine or a wind mill.

9.1.1 Terminology for Pumps :

(1) Head (H) : In case of pumps, different forms of energy are expressed in terms of height (in meter), which is called 'Head'. The pump imparts energy to the liquid which is the sum of (1) Energy required to lift the liquid from sump to pump (Suction Head). (2) Energy required to lift the liquid from pump to end of delivery pipe with required delivery pressure (Delivery Head). (3) Kinetic energy carried by the liquid at the end of delivery pipe (Velocity Head). (4) Energy consumed to overcome friction in pipes and within the pump.

Static head is the sum of suction and delivery heads ($H_s = h_s + h_d$), refer Fig. 9.1.

Manometric Head is the total head developed by the pump.

$$H_m = h_s + h_d + h_{fd} + h_{fs} + h_{fp} + h_v \quad (9.1)$$

Here, h_s = suction head, h_d = derivery head, h_{fd} = friction head loss in delivery pipe, h_{fs} = friction head loss in suction pipe, h_{fp} = friction head loss inside the pump, h_v = velocity head = $\frac{V^2}{2g}$, where V = velocity of fluid in pipe.

(2) Efficiency : The efficiency of a pump can be determined if its power output (Power delivered to liquid) hydraulic power P_h and the power input (Power supplied to pump shaft) P_s are known. Thus,

$$\eta_p = \frac{P_h}{P_s} \times 100\% \quad (9.2)$$

The overall efficiency, η_o of an installation consisting of a pump, a prime mover (say a motor) and an intermediate drive (say a coupling) can be expressed as

$$\eta_o = \eta_p \times \eta_{motor} \times \eta_{coupling}$$

$$= \frac{\text{Hydraulic power}}{\text{Power input to motor}} \times 100\%$$

$$= \frac{\varrho g Q H_m}{\text{Power input to motor}} \times 100\% \quad (9.3)$$

Here ϱ = density of liquid (kg/m^3)

g = gravitational acceleration (m/s^2)

Q = discharge (m^3/s)

H_m = Manometric head (in m)

Power input to motor is measured in Watts (W).

2 CLASSIFICATION OF PUMPS :

Pumps may be classified as shown in the chart below :

Pumps
- Positive Displacement pumps
  - Reciprocating pumps
    - Piston pump
    - Plunger pump
    - Diaphragm pump
  - Rotary pump
    - Gear pump
    - Vane pump
    - Cam pump
    - Screw pump
- Rotodynamic pumps
  - Radial (Centrifugal)
    - Single stage
    - Multi stage
  - Mixed flow type
  - Axial flow (Propeller type)
- Impulse pump
  - Hydraulic pump
  - Hand pump

3 CENTRIFUGAL PUMPS :

Fig. 9.1 shows typical installation of a centrifugal pump and other components in pipe–line. The foot valve and non–return valves are used to prevent reverse flow when the pump is idle and to protect the pump from excessive pressure on delivery side when the pump is running. A Gate valve is opened before or after starting the pump as per requirement or characterstic of pump.

The centrifugal pump has an impeller revolving at high speed in a casing. An impeller is a circular metallic disc with passages for the flow of fluid. (Refer Fig. 9.5)

Liquid enters the impeller axially through the 'eye' of casing. It is caught up in the impeller blades and is whirled tangentially and radially outward. The liquid leaves the impeller at its circumference and enters into the diffuser port of casing. The liquid gains both pressure and velocity while passing through the impeller. The cross

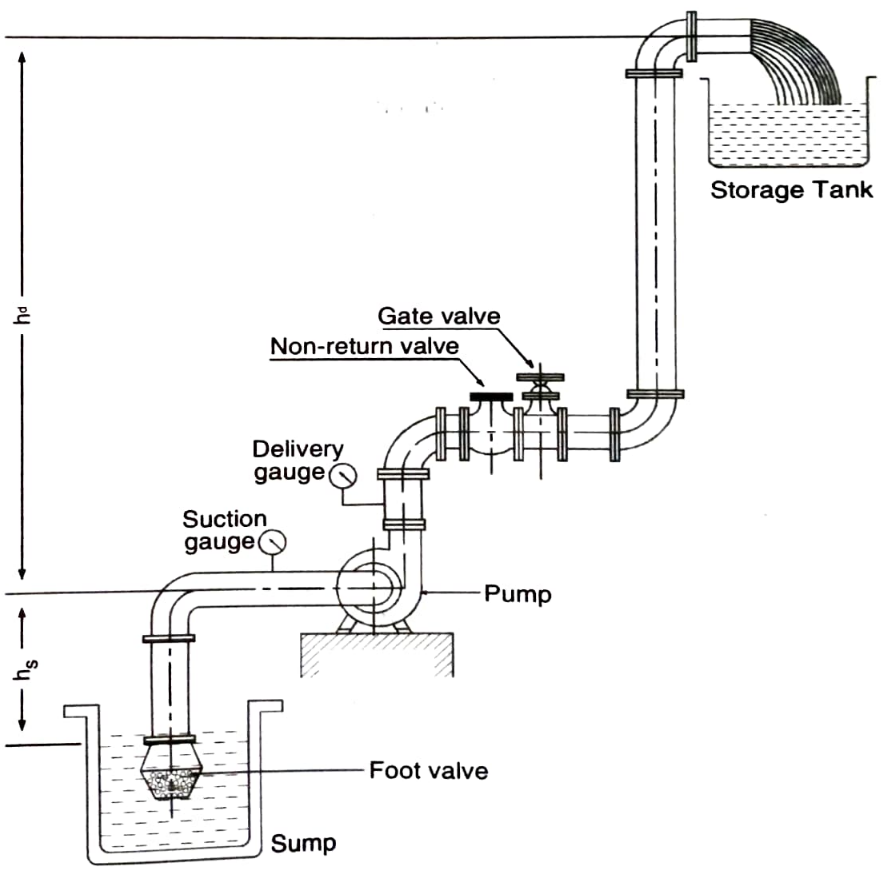


Fig. 9.1 Installation of centrifugal pump

sectional area of casing increases along the direction of flow of liquid. This decelarates the flow and further increases pressure.

The conversion of kinetic energy imparted by rotating impeller is dynamically converted to pressure energy as the liquid passes through the blade passages in the impeller as well as through the expanding area casing. Therefore this type of pump is also called 'rotodynamic pump'.

9.3.1 Priming of Centrifugal Pumps :

When a centrifugal pump stops, there is a tendency for the liquid to run out of the suction pipe. If this occurs and the pump has to restart under this condition, it has to handle the air pocket in the suction line. The pump is not able to suck and push air out to bring liquid back in suction line and pump casing. **The entrapped air is vented out through a valve by filling suction line, casing and a part of delivery line. This process is called priming**.

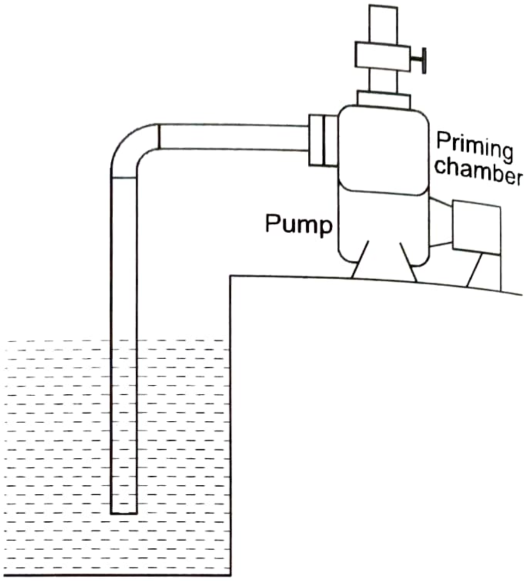


Fig. 9.2 Centrifugal pump with priming chamber

A positive displacement pump works on the principle of trapping certain amount of liquid and pushing it out by reducing the volume inside the pump. So, it is able to prime itself and no external priming process is required. Centrifugal pumps can also be **self-priming**. These pumps have a suction reservoir cast integrally with the pump casing to retain a certain volume of liquid even when suction line is drained by gravity. When the pump restarts, it recirculates that same liquid through the priming chamber until all the air has been passed through and normal pumping is reestablished (Refer Fig. 9.2). This arrangement usually locates a foot valve at the bottom end of suction line to prevent the liquid draining back into the sump. Unfortunately, the simple design of these foot valves is susceptible to sticking in the open position and allowing the pipe to empty.

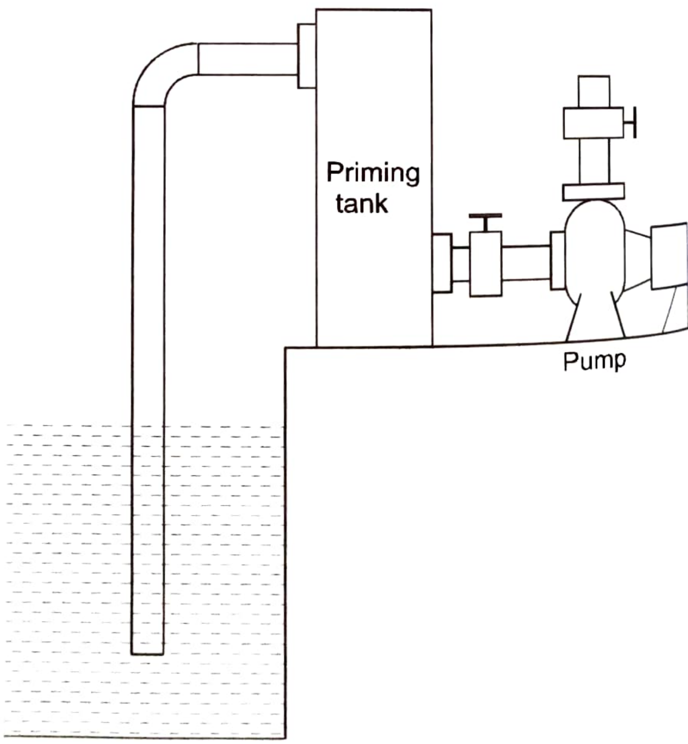


Fig. 9.3 Centrifugal pump with priming tank

Sometimes a **priming tank** is put on upstream of pump. When the pump starts and the tank is emptied, vacuum is created, which draws liquid in suction line. The suction line becomes full of liquid before the priming tank is emptied.

An **air ejector system** can be used to automate priming operation (Refer Fig. 9.4). Compressed air is used to create vacuum in the pump to draw the liquid in suction line before the pump starts. Thus, the pump starts in fully primed condition.

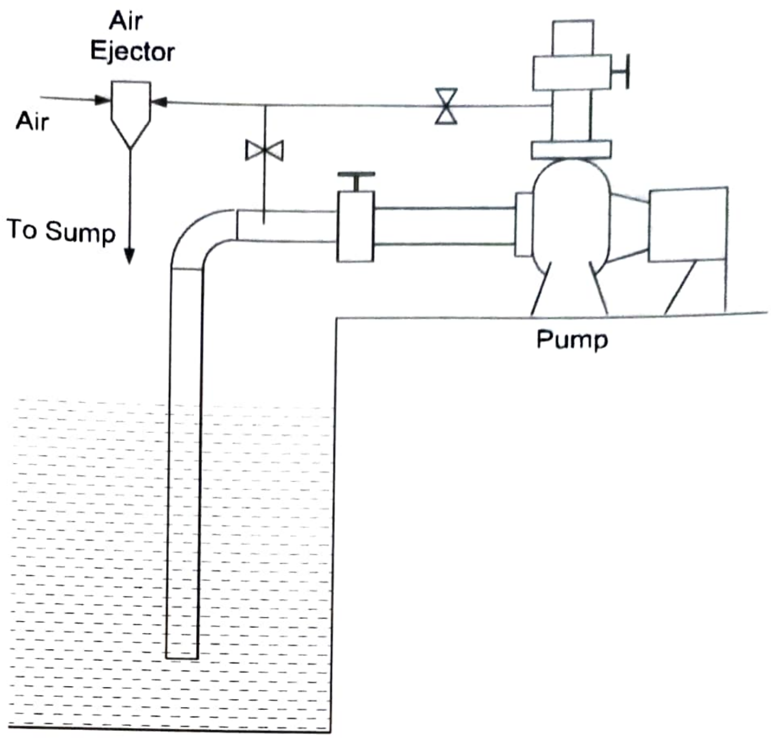


Fig. 9.4 Air ejector priming system

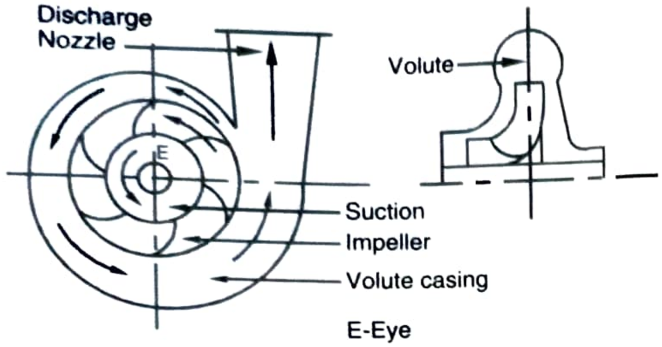
Classification based on the Type of Casing :

The primary purpose of providing a casing over the impeller is to contain the liquid coming out of the impeller and to convert its kinetic energy (energy associated with velocity) into pressure energy. The casing may be volute, vortex or diffuser type. (Fig. 9.5)

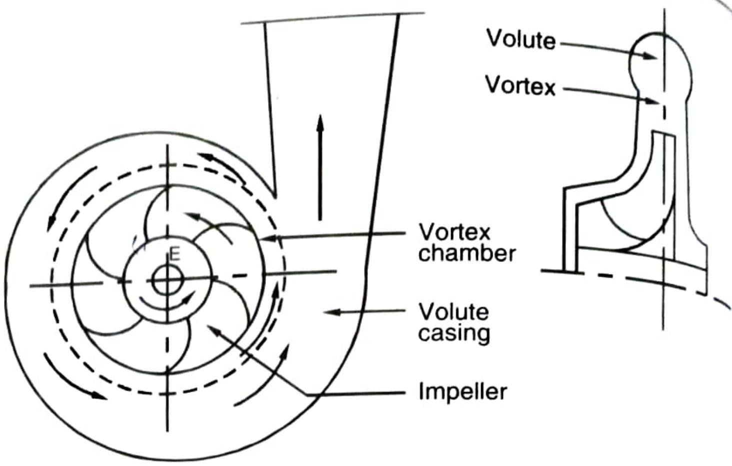
1) **Volute Casing :** This is used very commonly due to the simplicity in construction. The spiral shaped casing is called volute chamber. The sectional area of flow of discharged water gradually increases from its throat to the discharge pipe. This is necessary for effective conversion of kinetic energy of water coming out of impeller into pressure energy. The main drawback of the pump is that the water coming out of impeller gets choked and whirls are formed.

2) **Vortex (Whirlpool) Chamber :** In this pump, a vortex chamber is provided in form of an annular ring. The annular ring behaves as a diffuser without guide vanes. This is an improved design of pump which gives higher efficiency.

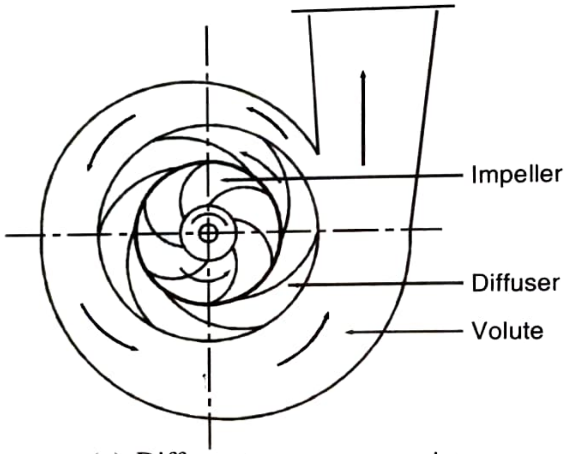
3) **Turbine (Diffuser) Pump :** Like water–turbines, these pumps are provided with a stationary diffuser ring around the impeller for flow–guidance and conversion of kinetic energy into pressure energy. The liquid, after leaving the impeller, passes through the guide vanes which have gradually enlarging passages. The velocity of water gets reduced and pressure increases. After passing through the vanes the liquid diffuses out in the casing and then discharges out.



(a) Volute type pump casing



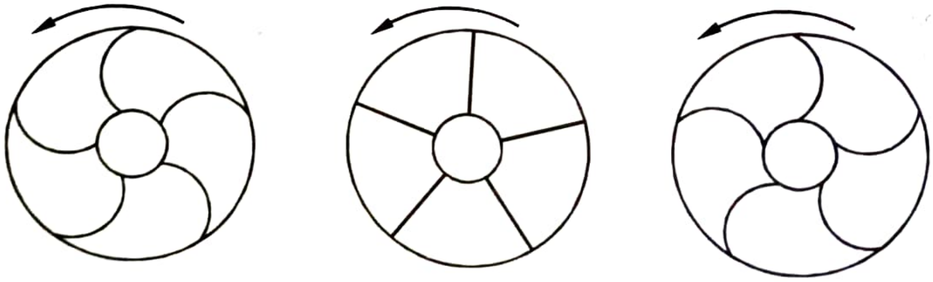
(b) Vortex chamber type pump casing



(c) Diffuser type pump casing

Fig. 9.5 Various type of pump casing

9.3.3 Classification based on Type of Blade :



(a) Backward curved blades (b) Radial blades (c) Forward curves blades

Fig. 9.6 Types of impeller blades of centrifugal pump

Fig. 9.6 shows impeller of centrifugal pump with blades curved in different fashion. The direction of rotation of impellers is also shown.

If the blades are curved in direction opposite to the direction of rotation of impeller, they are called 'backward curved'. If the blades are curved in the direction of rotation of impeller, they are called 'forward curved' blades. The 'radial blades' are without curvature.

erformance Curves for Centrifugal Pump :

r a centrifugal pump, the head developed is maximum 'shut off' (no flow) and decreases continuously as flow e increases. (Refer Fig. 9.7). Input shaft power is inimum at no flow and increases as delivered flow reases.

mp efficiency increases with capacity until the 'best ficiency point' (BEP) is reached, then decreases as flow e is increased. For optimum power consumption, it is esirable to operate as close to BEP as possible.

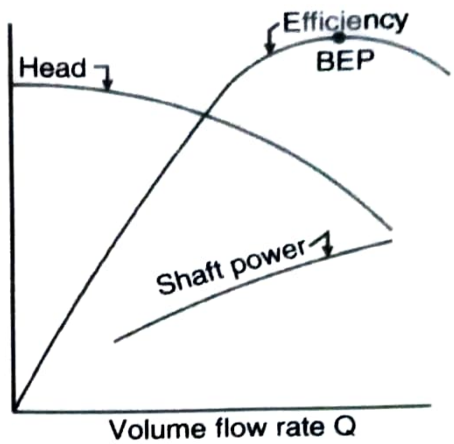


Fig. 9.7 Performance curves of a centrifugal pump

urging and Cavitation :

urging occurs predominantly in forward curved blade pumps at low flow rate. The pump 'hunts' for proper perating point which leads to unstable (rough) operation of the pump.

f the static pressure of liquid of any point in pump falls below its vapour pressure, it flashes into vapour locally. The flow may become unsteady causing the entire flow to oscillate and machine to vibrate. Cavitation not only educes pump efficiency but causes damage to the impeller. To avoid cavitation, some Net Positive Suction Head NPSH) is recommended at pump suction.

Multistage Pumps :

Multi-staging is done by adding impellers of identical construction in series on the same shaft. They run at the same speed and deals the same quantity of liquid per unit time, The exit of one impeller is fed directly into the eye of next impeller. The pressure in each stage gets multiplied of its previous value and thus very high heads can be produced.

RECIPROCATING PUMPS :

Reciprocating pump is a positive displacement type of pump. In this pump, all the amount of liquid sucked in first half of cycle of operation is completely displaced to discharge side in the next half of cycle. Reciprocating pumps have to and fro motion (backward and forward motion) as distinguished from circular motion of centrifugal and rotary pumps.

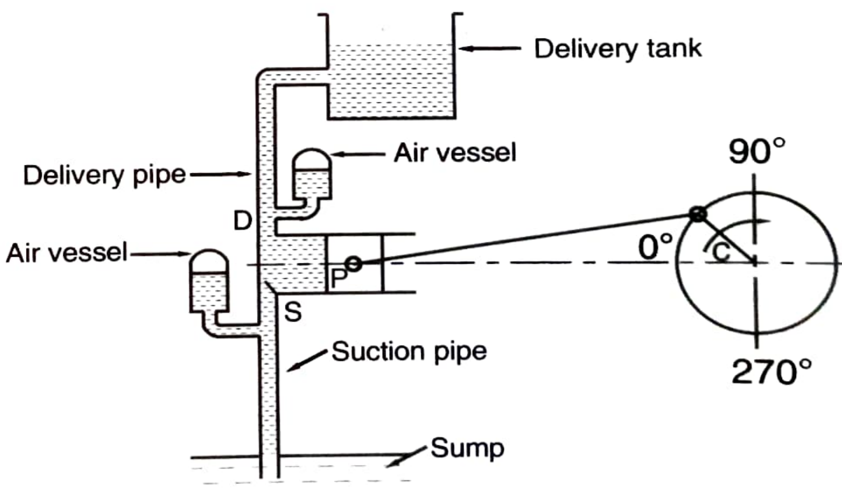


Fig. 9.8 Single acting reciprocating pump

Single Acting Piston Pump :

In single acting pump, any one side of piston act upon the fluid. In its simplest form, reciprocating pump consists of the following parts :

(1) **Piston** is the component, which reciprocates inside the cylinder.

(2) The **suction pipe** is a connecting passage between the source of fluid and the cylinder. It contains a hinged suction valve.

(3) The fluid is discharged into the **delivery pipe** through delivery valve.

(4) **Air Vessel (Air Chamber) :** For a single acting pump, the flow in the delivery pipe as well as suction pipe is not continous (Refer Fig. 9.8). For double acting or multi–cylinder pump, the flow is continuous but still velocity vary in suction as well as delivery pipe.

To obtain continuous supply of flow and uniform velocity in pipes, a large air vessel is fitted to suction as well as delivery pipe, at a point very close to cylinder (as shown in Fig. 9.8). This vessel (chamber) has an opening at its base through which, the liquid may flow into or out of it. It contains compressed air at top, which will be compressed further when the liquid enters and expands when the liquid flows out.

The air vessels store water from the supply or delivery pipe when the velocity in the pipes are more than mean velocity and deliver water when the velocity is less than the mean value.

During the suction stroke, the piston P moves towards right (Crank moves from 0° to 180°, Refer Fig. 9.8). This creates vacuum in the cylinder on the left side of piston causing the suction valve to open. The fluid enters the cylinder and fills it. During the reverse stroke (delivery stroke), the piston moves towards left (Crank moves from 180° to 360°). This causes increase of pressure in the cylinder. The delivery valve D opens and the fluid is forced to delivery pipe.

9.4.2 Double Acting Piston Pump :

Here, suction and delivery take place simultaneously on opposite sides of piston. When piston moves towards right side of cylinder, the liquid is sucked from sump through suction valve S_A. (as shown in Fig. 9.9) At this moment, the fluid on right side of piston is compressed, the delivery valve D_B opens and liquid is discharged through this valve. During the reverse stroke, fluid is sucked from valve S_B. The fluid on left side of piston is compressed and delivered through valve D_A. The double acting pump give more uniform discharge than single acting pump, as fluid is delivered in both strokes of piston.

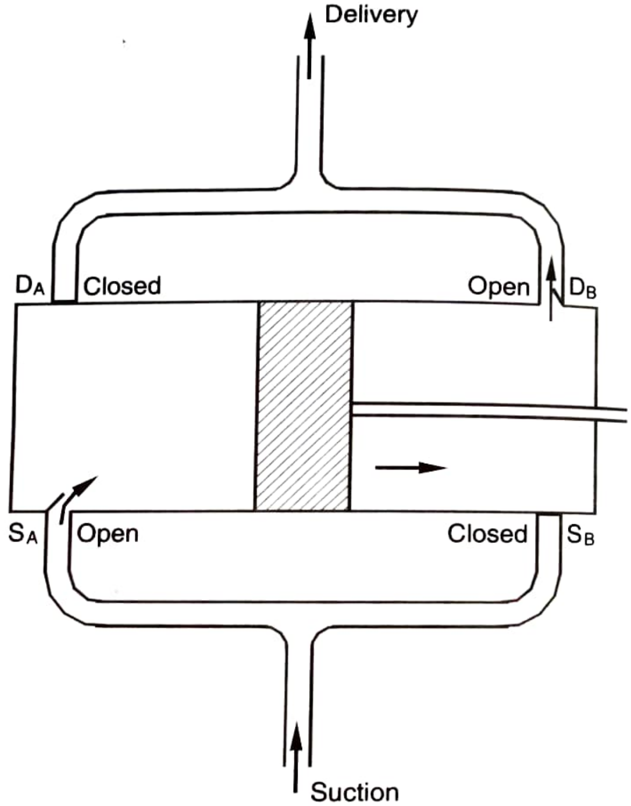
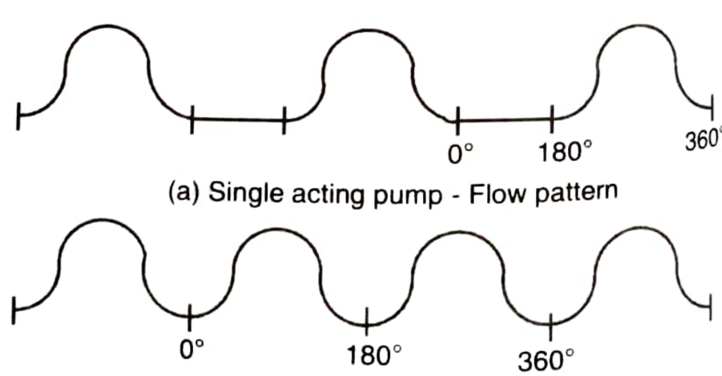


Fig. 9.9 Double acting reciprocating pump



(a) Single acting pump - Flow pattern

(b) Double acting pump - Flow pattern

Fig. 9.10 Flow patterns of single and double acting pumps

Calculations for Piston Pumps :

Discharge and Power :

(a) Single Acting Pump :

This type of pump has one suction and one delivery stroke during one cycle of crank.

Volume flow rate (Discharge rate) through pump,

Q = Volume displaced in delivery stroke × No. of cycles (delivery strokes) per second.

$$= (LA) \times \left(\frac{N}{60}\right)$$

Here.
L = Length of stroke
A = Cross sectional area of piston
N = Speed of pump (in r.p.m.)

Power required to drive the pump (in Watt),

P = discharge rate × pressure to be developed

$= Q \times \rho g H_m$

Here.
ρ = density of fluid (in kg/m³)
g = gravitational accelaration (in m/s²)
H_m = Manometric head

H_m is approximately equal to $h_d + h_s$, neglecting frictional losses and velocity head.

On account of frictional losses and leakage losses, the power required by pump will be more. If η_p is the efficiency of pump,

$$P = \frac{\rho g Q H_m}{\eta_p \times 1000} \text{ (P in kW)}$$

Power required to drive pump motor

$$P = \frac{\rho g Q H_m}{\eta_o \times 1000}$$

where η_o = overall efficiency

$= \eta_p \times \eta_{coupling} \times \eta_{motor}$

Let us say a pump has to lift water from a sump 4 m below it and lift it to delivery heat of 25 m. In that case, total (menometric) head would be 29 m ($H_m = h_s + h_d$ = = 4 + 25 = 29 m). If this pump gives a flow rate of 227 m³/h (0.063 m³/s), the ideal power consumption (hydraulic power) would be $P_h = \rho g Q H_m$ = 1000 × 9.81 × 0.063 × 29 = 17923 W or 17.923 kW.

If a motor with 25 kW rating is employed and it has 90% efficiency, then the motor provides 0.9 × 25 = 22.5 kW power to pump shaft. So, pump efficiency would be

$\eta_p = P_h/P_s$ = 17.923 / 22.5 = 0.7964 or 79.64%

(b) Double Acting Pump :

There are two delivery strokes per cycle. So discharge will be double.

i.e., $Q = \frac{2LAN}{60}$

Further calculations will be similar to single acting pump.

Slip : It is the measure of return of liquid through valves and leakage.

$$\text{Percentage slip} = \frac{Q - Q_a}{Q} \times 100$$

Where, Q = theoritical discharge, Q_a = actual discharge

Coefficient of Discharge : It is the ratio of actual volume or mass discharged to theoritical value.

$$C_d = \frac{Q_a}{Q}.$$

9.4.4 Diaphragm Pump :

A diaphragm pump is a positive displacement pump that uses a combination of the reciprocating action of a rubber, thermoplastic or teflon diaphragm and suitable non–return check valves to pump a fluid. Sometimes this type of pump is also called a membrane pump.

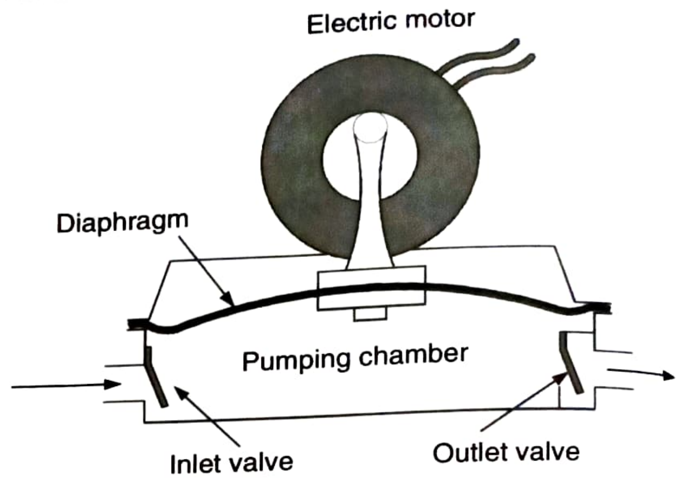


Fig. 9.11 A diaphragm pump

Fig. 9.11 shows the schematic diagram of the diaphragm type pump. The motor shaft is coupled with an eccentric rotor. When the rotor rotates, the diaphragm moves up and down. When the volume of a chamber of a diaphragm type of pump is increased (the diaphragm moving up), the pressure decreases and fluid is drawn into the chamber. When the chamber pressure increases from decreased volume (the diaphragm moving down), the fluid previously drawn in is forced out. Finally, the diaphragm moving up once again draws fluid into the chamber, completing the cycle. This action is similar to that of the piston moving in a cylinder.

9.4.5 Plunger Pump :

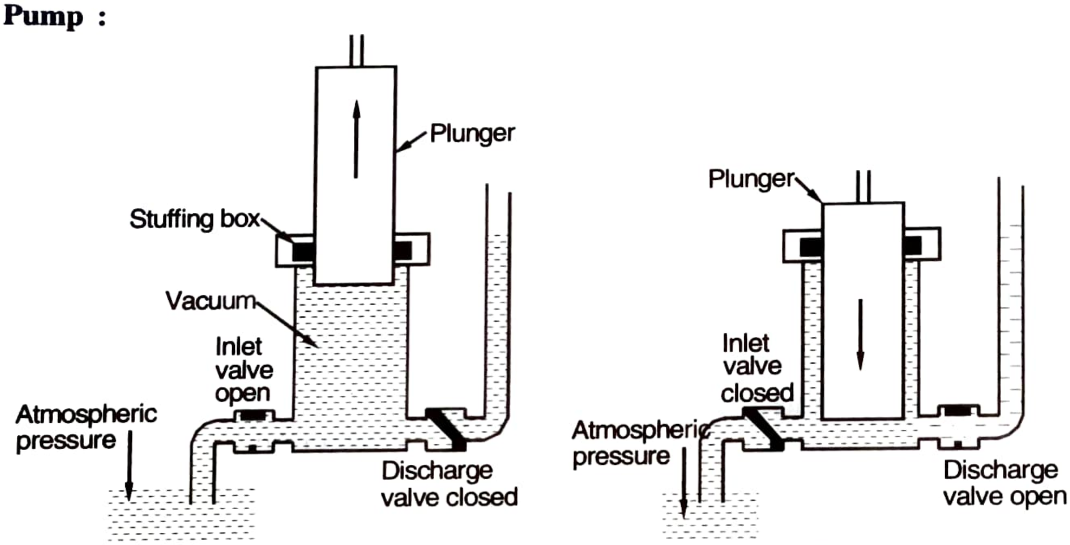


Fig. 9.12 Two stroke working cycle of a single acting plunger type pump

It consists of an inlet valve, a discharge valve and a plunger. When the plunger moves up, vacuum is created in the cylinder. So the atmospheric pressure forces water into the cylinder through inlet valve. This is called intake stroke. During the downward (discharge) stroke, the plunger forces the discharge valve to open. The water flows out of the cylinder. The stuffing box prevent leakage from the pump.

9.4.6 Bucket pump :

A bucket pump consists of an open cylinder and a piston with bucket type valve. (Refer Fig. 9.13) This pump is used to lift water. When the piston moves down, the bucket valve opens and when the piston moves up the valve closes.

When the pump is put into operation, and the piston moves down for the first time, the air below piston moves above it. The bucket valve is open during this stroke. In the next stroke, the piston moves up, the air above it is pushed out of cylinder and water is sucked from suction pipe.

In the third stroke, the piston moves down. During this stroke (transfer stroke) the bucket valve is open while inlet valve is closed. The water below the piston is transferred above it. In the fourth stroke (discharge stroke) the piston moves up. The bucket valve is closed and the water above the piston is lifted and delivered out of cylinder from the opening. At this time, inlet valve is open and volume below piston is filled with water. After the pump has been primed and it is in operation, the working cycle is completed in two strokes-transfer stroke and discharge stroke.

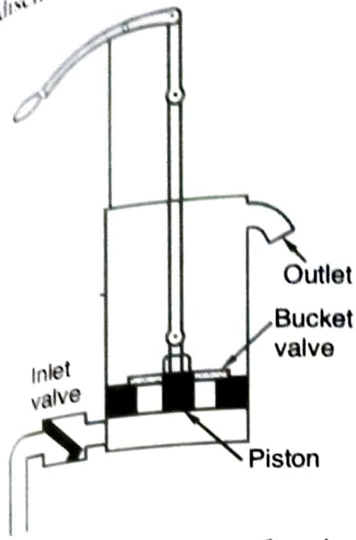


Fig. 9.13 Basic construction of a single acting lift pump

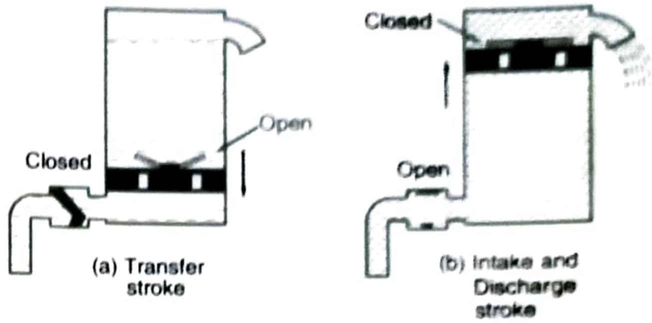


Fig. 9.14 Two stroke working cycle (after priming) for a single acting lift pump

COMPARISON BETWEEN RECIPROCATING PUMPS AND CENTRIFUGAL PUMPS :

Reciprocating Pump	Centrifugal Pump
They run at slow speed. They are often run by steam, petrol or diesel engines.	(1) They can be directly coupled to high speed diesel engines and electric motors.
The discharge quantity does not vary with variation in delivery head. The delivery head may rise dangerously if the delivery pipe is choked.	(2) The discharge decreases with increase in delivery head. They can develop definite maximum head for perticular speed.
Losses due to slip or leakage in passages may occure.	(3) No losses due to slip or leakage in passage.
The water flow is pulsating.	(4) The flow of liquid is continuous.
The initial and maintenance cost is high.	(5) Low initial and maintenance cost.
They can produce high heads but low flow rates.	(6) They are efficient for heads upto 60 m in single stage.
They are effective in handling viscous fluids.	(7) Their efficiency reduces as visco-sity of fluid handled increases.

ROTARY PUMPS :

Rotary pumps consist of a fixed casing with a rotor which may be in the form of gears, vanes, lobes, screws, cams etc. Both rotodynamic and rotary pumps have circular motion of their rotors, but the rotary pumps are positive displacement pumps. A rotodynamic pump causes the increase in the velocity and pressure of liquid by throwing it out centrifugally where as the rotary pump traps the liquid and pushes it around a closed casing. The flow is continuous and smooth unlike a reciprocating positive displacement pump.

Rotary pumps can handle visuous fluids like vegetable oil, lubricating oil, alcohol etc. Rotary pumps develop more losses with increasing delivery pressure. They are much more restricted in practical sizes and flow rates as compared to centrifugal pumps.

We will now study here some of the rotary pumps.

9.6.1 Gear Pump :

Two gears of the same size and form, mounted on separate shafts are housed in a closed fitting casing as shown in Fig. 9.15. One gear shaft is driven in the direction of arrow as shown. It moves the other in opposite direction.

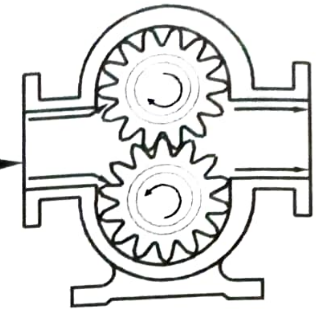


Fig. 9.15 Gear pump

A negative pressure is created on the suction side due to rotation of gears. So atmospheric pressure in fluid tank causes the fluid to run from tank to pump. This is how suction in this pump takes place.

The fluid fills the gear spaces, forming closed chambers with the housing. During further movement, the entrapped fluid is pushed to pressure side and then ultimately out of gear chambers.

9.6.2 Vane Pump :

These pumps have a slotted rotor mounted on drive shaft. The rotor rotates inside a cam ring in pump casing. Vanes are fitted to the rotor slots and are radially movable. (Fig. 9.16)

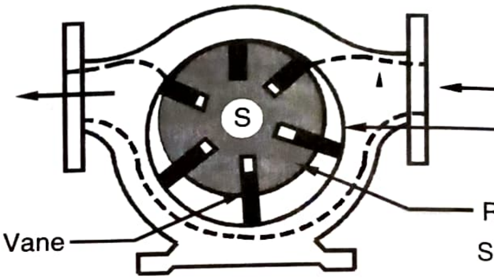


Fig. 9.16 Vane pump

During the rotation of the rotor, the centrifugal force pushes vanes towards outside. Thus the external edge of the vanes is always touching the internal area of cam ring. Pumping chambers are thus formed between the vanes. At the suction side, negative pressure is created as the space between the rotor and ring increases. Liquid entering at inlet is trapped in pumping chambers and then pushed to the outlet as the space decreases.

9.6.3 Screw Pump :

Screw pump are a special type of rotary positive displacement pump in which flow through the pumping element is truely axial.

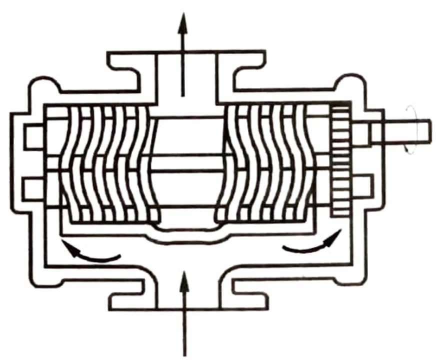


Fig. 9.17 Screw pump

There are two rotors – male and female, as shown in Fig. 9.17. The male rotor shown on the right drives the female rotor in a stationary housing. At the suction position of the pump, a void is created into which the inlet fluid flows. The fluid is trapped in cavity and moved circumferentially around the housing of the pump. Further rotation results in meshing of lobe and the female gully, decreasing volume in the cavity and compressing the fluid. Then the discharge part is uncovered and compressed fluid is discharged.

Low internal velocity and axial flow have number of advantages in many applications where liquid churning is objectionable. Screw pump is used in chemical industries, oil handling etc.

EXERCISES

1. Classify the pumps, based on their principle of working construction and fluid flow direction in pump.
2. Explain with neat sketch, the working of C.F. pump. What are various methods of increasing efficiency of C.F. pump ?

   (**Hint** : Vortex and Diffuser type casings have more efficiency than the simple volute type C.F. pump.)
3. What is the function of a pump ? Classify the centrifugal pumps and describe with a neat sketch the working of a volute type of centrifugal pump.

Explain the following terms for pumps :
(i) Manometeric head
(ii) Pump efficiency
(iii) Overall efficiency
(iv) Slip
(v) Coefficient of discharge.

Explain with neat sketch the working of single acting piston pump.

What is priming ? Why is it required for a centrifugal pump ?

Write in short about the construction and working of a double acting piston type reciprocating pump.

Explain single acting plunger pump.

Describe in short : A bucket pump.

What is the effect of air vessels on the flow rate of liquid from reciprocating pump ? Show the location of the air vessels in the delivery and suction line of the pump.

Compare the performance of a reciprocating pump and a centrifugal pump.

Differentiate between rotary positive displacement pump and rotodynamic pumps. Name the different type of rotary pumps.

Explain with a neat sketch : Vane pump.

Describe in short :

(1) Gear pump (2) Screw pump

OBJECTIVE TYPE QUESTIONS

Pump can not be driven by _______ . **(Summer 2017)**

(a) electric motor (b) I.C. Engine (b) steam turbine (d) compressor

Vane pump is a _______ of pump.

(a) positive displacement type (b) Rotodynamic type (c) Impulse type (d) Reciprocations type

Function of foot valve is

(a) to prevent reverse flow when pump is stopped
(b) to protect pump from excessive pressure
(c) to control flow rate through pump
(d) to increase pressure of liquid

The process of filling liquid up to delivery valve in casing of pump is called **(Winter 2017)**

(a) idling (b) pre-starting (c) priming (d) charging

Function of volute casing is to

(a) convert pressure energy of water in to kinetic energy
(b) convert kinetic energy of water in to pressure energy
(c) convert mechanical work in to kinetic energy of water
(d) convert mechanical work in to pressure energy of water

6. Based on the type of blade pumps can be classified as
   (a) Backward curved blade
   (b) Radial blade
   (c) Forward curved blade
   (d) all of above
7. To get almost continuous supply from reciprocating pump ______ is provided.
   (a) foot valve
   (b) pressure gauge
   (c) air chamber
   (d) fly wheel
8. Priming is necessary in (Jan. 201
   (a) Centrifugal pump
   (b) Vapour Compression refrigeration system
   (c) 4-Stroke Diesel Engine
   (d) Babcock Wilcox boiler
9. Which of the following part of centrifugal pump converts kinetic energy of pump into pressure energy? (June 201
   (a) Foot valve
   (b) Casing
   (c) Suction pipe
   (d) Impeller
10. Bucket pump is a type of ________ pump.
    (a) rotaty
    (b) Centrifugal
    (c) reciprocating
    (d) axial
11. The operation of filling passage-ways with liquid from outside source before staring pumps is known
    (a) cavitation
    (b) cleaning
    (c) priming
    (d) chocking
12. Gear pump and Vane pump are types of
    (a) Rotary pump
    (b) Reciprocating pump
    (c) Centrifugal pump
    (d) None of the above.
13. The impeller of a centrifugal pump may have ________. (Winter 201
    (a) volute casing
    (b) volute casing with guide blades
    (c) vortex casing
    (d) any one of these

: ANSWERS :

1. (d)	2. (a)	3. (a)	4. (c)	5. (b)	6. (d)	7. (c)	8. (a)	9. (b).	10. (c)
11. (c)	12. (a)	13. (d)							

❖ ❖ ❖

10

REFRIGERATION AND AIR CONDITIONING

10.1 REFRIGERATION :

Refrigeration may be defined as producing and maintaining temperature below surrounding temperature. The system maintained at the lower temperature is known as *refrigerated system* while equipment used to maintain this lower temperature is known as *refrigerating equipment*. To transfer heat from low temperature body to high temperature body external work must be supplied.

Amount of heat removed by refrigerating equipment from refrigerated system is know as refrigerating effect. It's unit is kJ/s.

The effectiveness of refrigerating equipment is given by the term coefficient of performance (COP). It is defined as ratio of refrigerating effect to external work required by refrigerating equipment.

$$COP = \frac{\text{Refrigerating effect}}{\text{Work supplied}}$$

Applications :

(1) Comfort air conditioning of auditoriums, hospitals, residences, offices, hotels etc.
(2) Manufacturing and preservation of medicine.
(3) Storage and transportation of food stuffs such as dairy products, fruits, vegetables, meat, fish etc.
(4) Processing of textiles, printing work and photographic materials.
(5) Manufacturing of ice.
(6) Cooling of concrete for dam.
(7) Treatment of air for blast furnace.
(8) Processing of petroleum and other chemical products.
(9) Production of Rocket fuel.
(10) Computer functioning

10.2 REFRIGERANT :

The working substance used in refrigerating equipment is known as *refrigerant*. Refrigerant under goes various processes of refrigeration cycles which are used to produce refrigeration. Analysis of refrigeration cycles involve calculations of changes of properties of the refrigerant during various processes of the cycles. Some desirable properties of refrigerants are listed below.

(1) It should have high latent heat of evaporation and low specific volume.
(2) It should have good thermal conductivity for rapid heat transfer.
(3) It should be non-toxic, non-flamable and non-corrosive.
(4) It should have low saturation pressure.

(5) It should have reasonable cost and should be available easily.

(6) It should be stable and should not decompose under any condition.

(7) It should have high critical pressure.

(8) It should have high COP.

Commonly used refrigerants are R12, R22, R134a, NH_3 and air.

R12 (CCl_2F_2) is chloroflouro carbon (CFC). When it release in atmosphere, the Cl atom react with ozone layer and deplete it. In presence of sunlight CFCs under goes following reactions :

$$CCl_2F_2 \xrightarrow{\text{sunlight}} CClF_2 + Cl$$

$$O_3 + Cl \xrightarrow{\text{sunlight}} ClO + O_2$$

Thus O_3 is depleted to O_2.

The ozone layer is required to absorb ultraviolet rays of the sun. These rays can cause skin cancer. The Montreal protocol had been signed by most of the countries and manufacturing and use of CFCs had been stoped since 2000.

10.3 UNIT OF REFRIGERATION :

Due to the fact that in early stages refrigeration was produced by ice, the rate of removal of heat is expressed in terms of tons of ice required per unit time. The unit of refrigeration is ton of refrigeration or simply ton denoted by TR.

One ton of refrigeration is defined as amount of heat required to be removed from one short ton of water at 0°C to produce ice at 0°C in 24 hours. The latent heat of ice is 334.9 kJ/kg and one short ton equals to 907.18 kg therefore 1 ton of refrigeration equals to

$$1 \text{ TR} = \frac{334.9 \times 907.18}{24 \times 3600} = 3.516 \text{ kW}$$

10.4 TYPES OF REFRIGERATORS (REFRIGERATION EQUIPMENTS) :

Refrigerators can be classified in two catagories. Natural refrigerators and mechanical refrigerators. In natural refrigerator, cooling effect is produced by evaporation, by sublimation of solid etc. While in mechanical refrigerator cooling effect is produced by expenditure of work.

Mechanical refrigerator are further classified as gas refrigerator and vapour refrigerator. Air is commonly used in gas refrigerator. While R134a, R22, NH_3 etc. are used in vapour refrigerator. Vapour refrigerator can be further classified as vapour compression refrigerator and vapour absorption refrigerator.

10.5 VAPOUR COMPRESSION REFRIGERATION CYCLE :

A schematic diagram of simple vapour compression refrigeration (VCR) cycle is shown in Fig. 10.1. The cycle is represented on T-s and p-h diagram in Fig. 10.2.

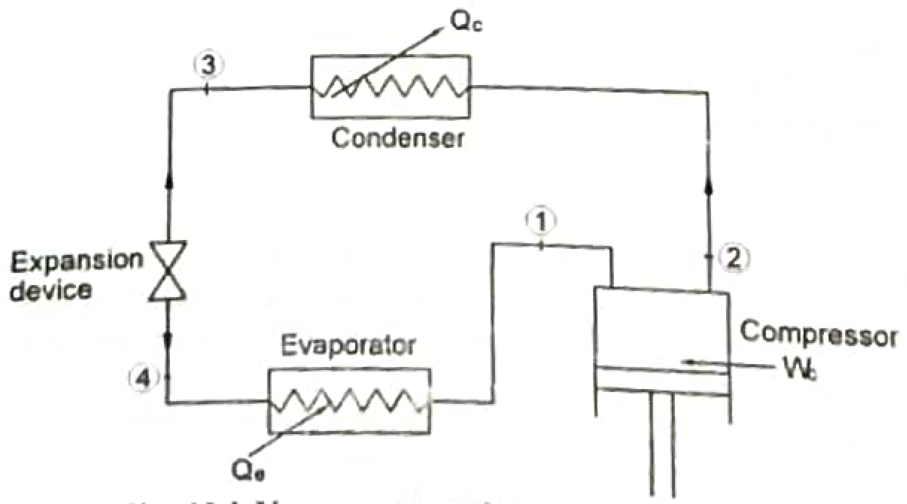


Fig. 10.1 Vapour compression refrigeration cycle

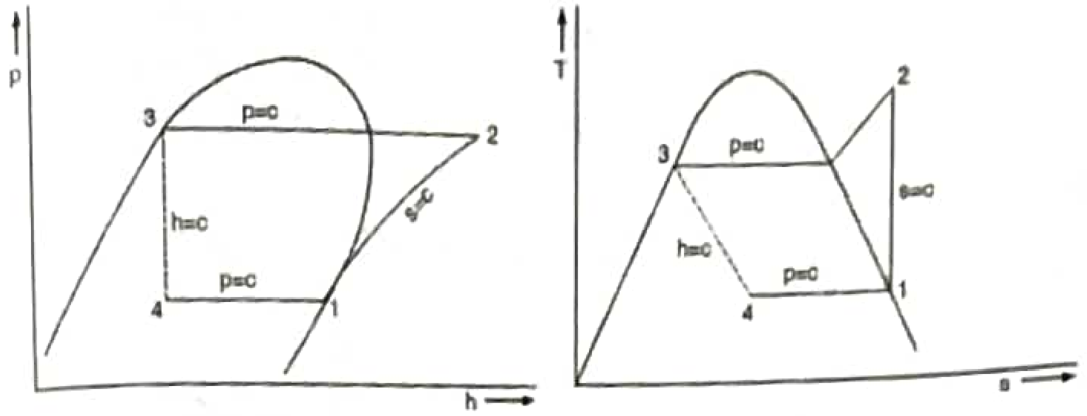


Fig. 10.2 VCR cycle on p-h and T-s diagram

At point 1 low pressure, low temperature vapour enters the compressor. Compressor compresses the vapour and high pressure high temperature vapour leaves the compressor at point 2. This high pressure high temperature vapour condenses in the condenser by rejecting heat to cooling medium which is generally air or water. Condition of refrigerant at exit to condensor (point 3) is generally saturated liquid. This saturated liquid is throttled by expansion device from condenser pressure to evaporator pressure. This process is an isenthalpic process. After throttling (point 4) condition of refrigerant is wet vapour. This wet vapour enters into evaporator where it absorbs latent heat of evaporation from refrigerated system. Due to absorption of latent heat, refrigerant is evaporated and leaves as low pressure, low temperature saturated or superheated vapour. Thus VCR cycle is completed. COP of simple VCR cycle is around 3.

As shown in figure essential components of VCR cycle are compressor, condenser, expansion device and evaporator.

10.6 VAPOUR ABSORPTION REFRIGERATION CYCLE :

There are two widely used absorbent – refrigerant pairs for vapour absorption system.

(1) NH_3 – H_2O system – in which NH_3 is refrigerant and H_2O is absorbent

(2) H_2O – LiBr system – in which H_2O is refrigerant and LiBr is absorbent.

A schematic diagram of simple NH_3–H_2O vapour absorption system is shown in Fig. 10.3.

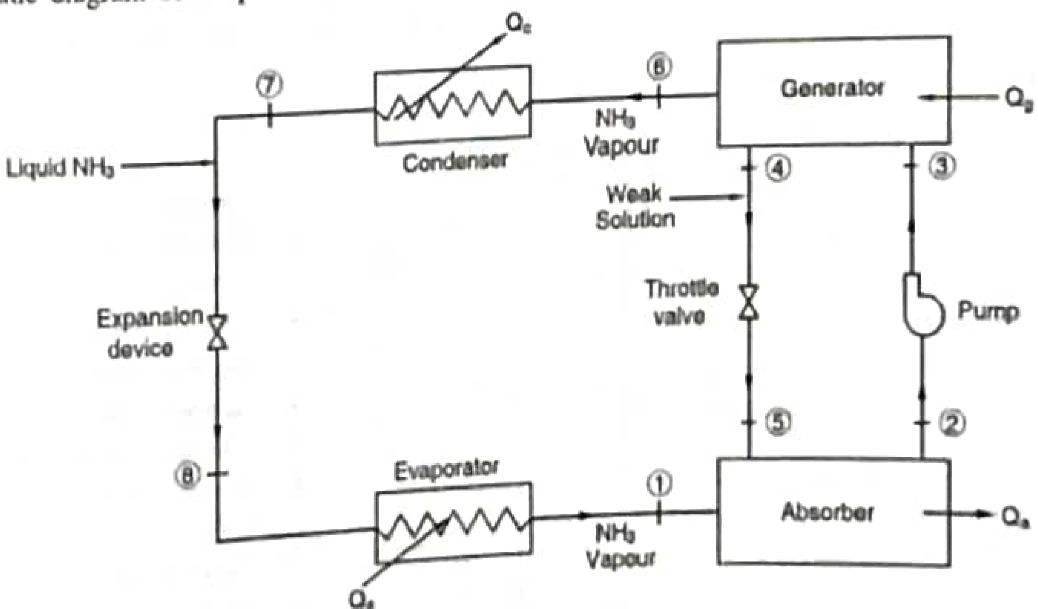


Fig. 10.3 Vapour absorption cycle

At point 1, NH_3 vapour enters the absorber. In absorber it is absorbed by weak solution coming from generator through throttle valve (Point 5). Due to absorption of NH_3 vapour solution becomes strong (Point 2). Heat of absorption (Q_a) is released and it is to be rejected to cooling medium. This strong solution is pumped in to generator at point 3. In generator heat (Q_g) is supplied from external source and NH_3 vapour is generated (Point 6). Weak solution at point 4 is flowing back to absorber through throttle valve. NH_3 vapour is condensed in condenser by rejecting heat (Q_c) to cooling medium. Liquid NH_3 (Point 7) is throttled through expansion device and enters into evaporator (Point 8). In evaporator NH_3 evaporates by absorbing latent heat of evaporation (Q_e) to produce refrigerating effect. Thus cycle is completed. COP of simple vapour absorption cycle is around 0.6.

10.7 AIR REFRIGERATION :

A schematic diagram of air refrigeration system working on Bell–Coleman cycle is shown in Fig. 10.4. Fig. 10.5 shows the cycle on p-V diagram.

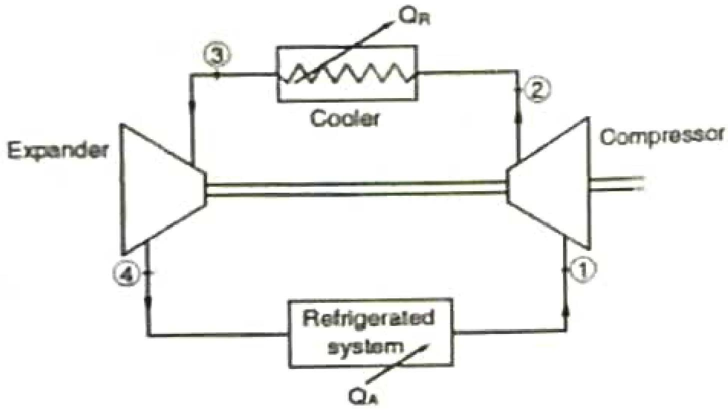


Fig. 10.4 Air refrigeration cycle

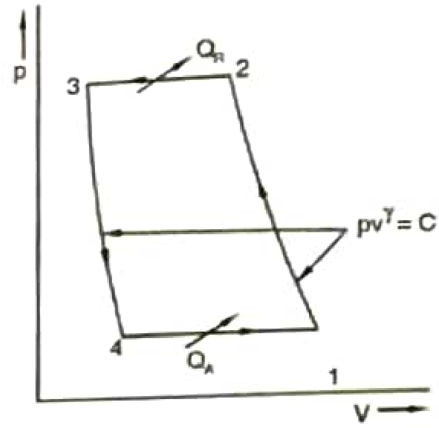


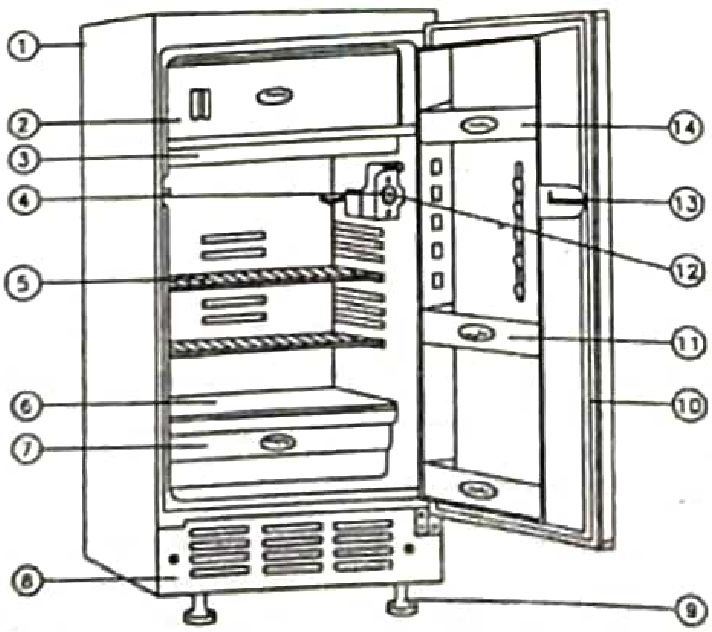
Fig. 10.5 Bell-Coleman cycle on p-V diagram

As shown in figure, at point 1 air enters the compressor at pressure p_1 and temperature T_1. Compressor compresses the air and dischange it at pressure p_2 and temperature T_2. Idealy this is a reversible adiabatic (isentropic) process. At point 2 air enters the cooler where it is cooled at constant pressure by rejecting heat to cooling medium. At point 3 air leaves the cooler at same pressure and temperature T_3. At point 3 air enters the expander where it is expanded reversibly and adiabatically to pressure p_4 and temperature T_4. At point 4 air enters the refrigerated space. Since temperature T_4 is less than refrigerated space temperature air absorbs heat from refrigerated system and its temperature will increase to T_1 at same pressure. Thus cycle is completed.

The modified Bell–Coleman cycle is used in Air craft refrigeration.

Disadvantages of simple Bell–Coleman cycle are low COP, Bulky system, and high volume flow rate.

10.8 DOMESTIC REFRIGERATOR :



1. Table top
2. Freezer door
3. Chiller tray
4. Thermostate knob
5. ADjustablo shelf
6. Crisper glass
7. Crisper (vegetable and fruit try)
8. Front ventilation grill
9. Leg
10. Door gasket
11. Bottle/Can shelf
12. Defrost button
13. Lock
14. Butter cheese self

Fig. 10.6 Different part of 165 litre Refrigerator

Domestic refrigerator is an enclosed cabinet used for preserving perishable food stuffs in small quantities for few days. It is used in stores, bakeries, drug stores, restaurants, hotels, institutions and residences. Vegetables and fruits last longer when kept at temperate just above freezing. The lower temperature slowdown oxidation of the food, reduce the multiplication of the bacteria in the living cell and fibers and reduce the aspiration (removal fluid of the food). Fresh foods may be kept from 3 to 7 days at 2 to 4°C.

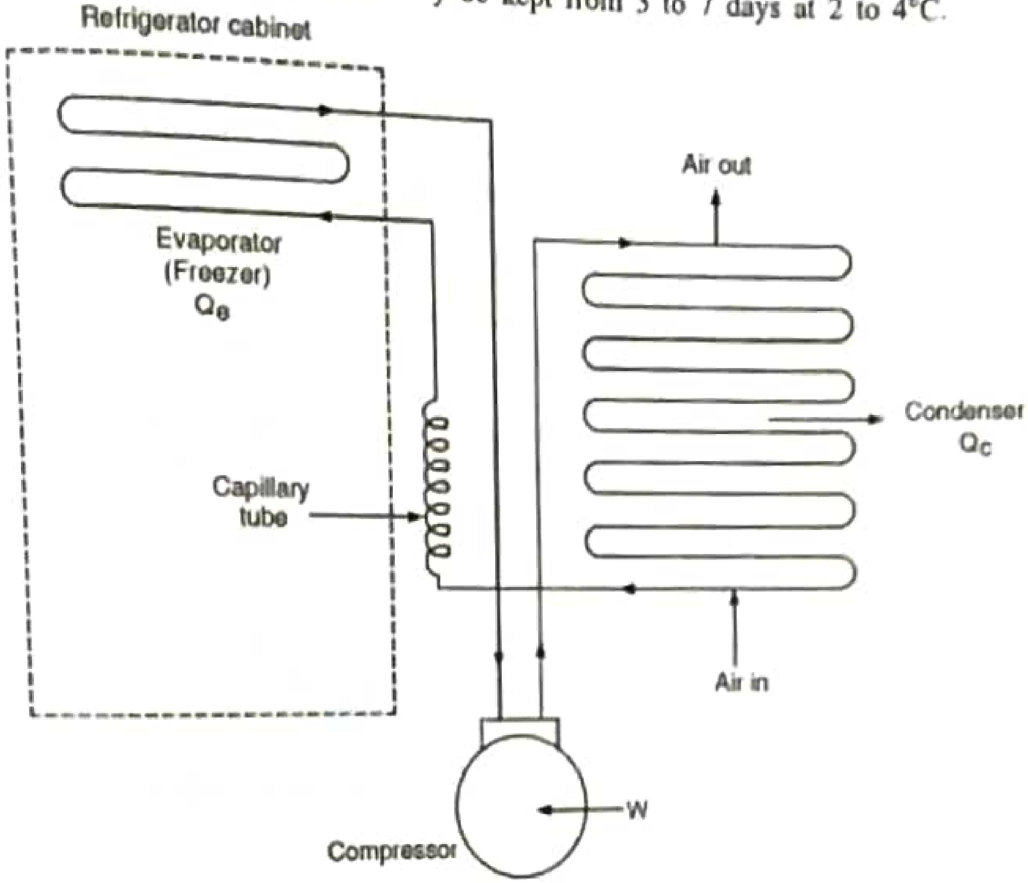


Fig. 10.7 Schematic Diagram of a Domestic Refrigerator

The exterior of the cabinet is constructed from aluminum or pressed steel. The rear of the cabinet is equipped the condenser painted with black colour. The condenser is the part of the cooling system. The dust should be removed periodically from the condenser in order to see that proper condensation be obtained. The refrigerator must have plenty of air movement over the condenser as the condenser is air cooled. The interior of the refrigerator is made up of two parts (a) main compartments (b) door storage area. The compartment liner, the door liner, vegetable tray and baffle tray are made of rust proof high impact polystyrene.

Main components of domestic refrigerator are described below.

(i) **Compressor :** A hermetically sealed compressor is used in the domestic refrigerator. Compressor and motor are placed on the same shaft and housed in sealed unit. Because of sealed unit the leakage problem is minimum.

(ii) **Condenser :** An air cooled condenser is used. It is bolted on the back side of the cabinet. It is finned tube - natural convection condenser. The tubes and fins are usually made of copper or steel or aluminum.

(iii) **Evaporator/ Freezer Chest:** It is placed at the top of the cabinet and can store frozen food stuff in addition to ice trays. The freezer chest door can be closed automatically by means of tow springs. The evaporator is solder on the three side of the freezer chest. Now a days freezer box itself is having internal passages for circulation of refrigerant and it acts as an evaporator. Fin and coil type of evaporator is used in frost free refrigerators. The evaporator coils and the fins are made of copper or Aluminium.

(iv) **Capillary Tube:** It is a long length small diameter tube. Due to small diameter it offers resistance to flow and thus reduces pressure of the refrigerant as it passes through the capillary tube.

(v) **Baffle Tray:** It is located just below the freezer chest. It collects condensate when refrigerator is being defrosted. A deflector is provided in a baffle tray which is helpful in collecting dripping water to pass to the tray. In frost free refrigerator it is not provided.

(vi) **Ice Tray:** It has plastic divider so as to produce cubes of ice from water.

(vii) **Cabinet Shelves:** They are provided for storage space. They are made from steel wire and painted or powder coated so that they can be cleaned easily with moist cloth.

(viii) **Vegetable compartment:** It is provided at the bottom of the refrigerator. The container is made of polystyrene and covered with glass in order to keep vegetable moist.

(ix) **Door storage area:** This area provides the storage for daily food-cream, butter milk, eggs and bottles.

(x) **Temperature control knob:** This is provided below the baffle tray. It has marking line 1,2,3 etc and OFF. It is used to control the temperature of freezer and hence of the refrigerator.

(xi) **Interior Lamp:** The lamp is provided to illuminate the interior space. It is located below baffle tray. A plastic cover is provided to protect the lamp (bulb).

(xii) **Door Switch :** This is located in the cabinet at the hinged side. When the door is closed, the bulb will be OFF and when the door is opened the bulb will be ON.

(xiii) **Door Gasket:** It is provided all along the inner edge of the door for proper seal when the door is closed. It must be kept in good condition to prevent air leakage into the refrigerated space which is turn will increase heat load.

(xiv) **Insulation:** The insulation is provided to reduce heat gain from the atmosphere. Generally polyurethane foam (PUF) is used as insulator.

Domestic refrigerator works on VCR cycle so the cycle description is same as discussed in section 10.5.

10.9 WINDOW AIR CONDITIONER :

Air conditioning means control of (a) temperature (b) humidity (c) air movement (d) purity of air and (e) noise. A window air conditioner is shown in Fig. 10.6. It is having a compressor, a condenser, a filter cum drier, a capillary tube and an evaporator. An electric motor drives the fan to circulate air through condenser coil. The motor also drives a blower which sucks the air from room through evaporator coil and throws it back into the room. A thermostat is provided to maintain the desired temperature by means of an on–off control of the compressor. Filter is fitted near the evaporator coil. The evaporator side is insulated from the condenser side. Dampers are used for the appropiate air distribution. An exhaust air damper is also used to regulate the fresh air supply. A tray is provided to collect moisture which condenses from recirculated air. Window air conditioners are available in size up to 2 ton capacity. Window air conditioner works on Vapour Compression Refrigeration cycle so cycle description is same as discussed in section 10.5.

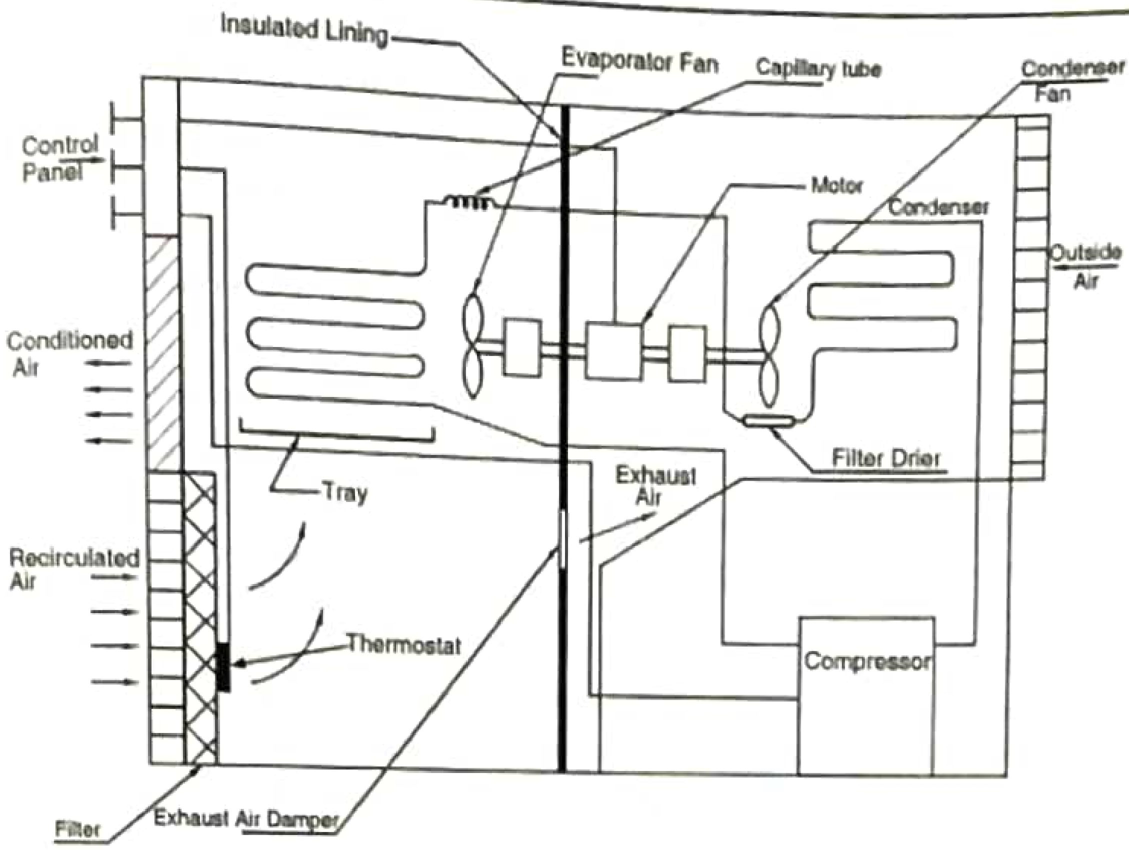


Fig. 10.8 Sectional view of window air conditioner

10.10 SPLIT AIR CONDITIONER :

A typical split air conditioner is shown in Fig. 10.9. It consists of an indoor unit and an outdoor unit. Indoor unit consists of evaporator coil (cooling coil) with blower driven by an electric motor and capillary tube. The cooling coil is mounted in a cabinet and is fixed inside the room. Hence it is named as indoor unit. The cooling coil may be wall mounted at certain convenient height or a floor mounted with suitable base frame or ceiling mounted, where cooling coil is hung from the false ceiling.

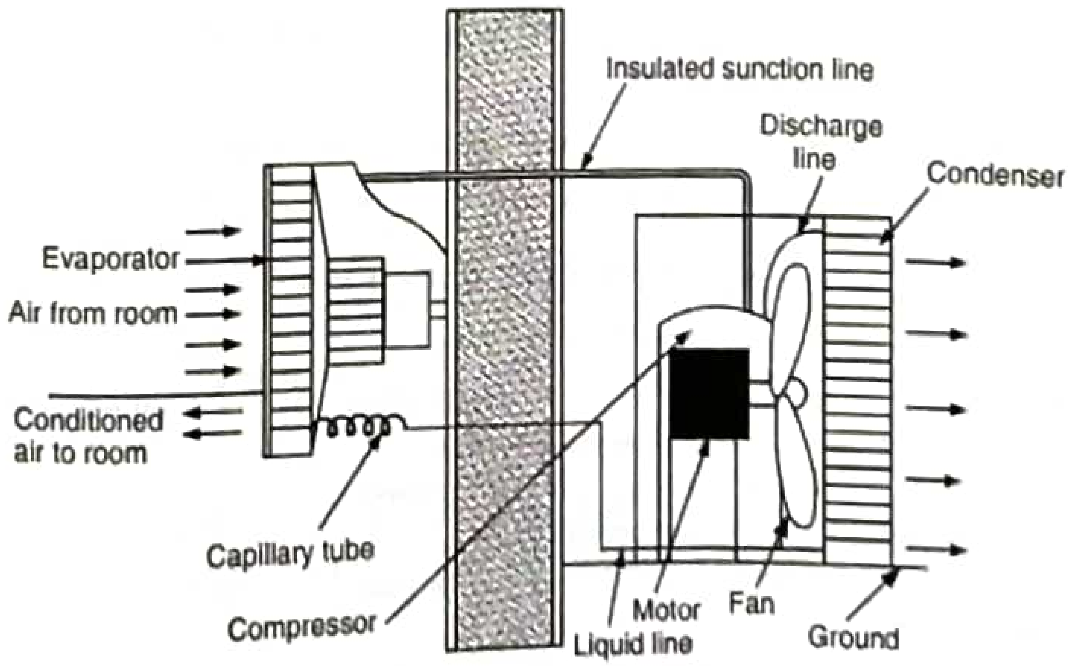


Fig. 10.9 Split air conditioning system

Outdoor unit consists of compressor and condenser with separate fan driven by an electric motor. They are kept inside the casing and mounted outside the room. The indoor and outdoor units are connected by liquid line and well insulated suction line. The distance between indoor and outdoor unit should not be more than 10 to 12 m. Also elevation difference between indoor and outdoor unit should not be more than 5 m.

Working of split air conditioner is similar to that of window air conditioner as both work on vapour compression refrigeration (VCR) cycle. Split air conditioner can be considered as bifurcation of window air conditioner in to two unit i.e. the indoor unit and the outdoor unit.

Following are the advantages and disadvantages of split air conditioner over window air conditioner.

Advantages :

(1) The evaporator coil/indoor unit can be mounted at any convenient location in the room.

(2) Since compressor and condenser are mounted outside the room the noise coming out from these components is eliminated. The only source of noise inside the room is the blower of evaporator.

(3) This type of air conditioner can be installed for interior rooms where wall expose to ambient is not available to reject heat from condenser.

Disadvantages :

(1) Power consumption is higher since condenser and evaporator are located at far distances.

(2) Suction line needs better insulation due to its higher length.

(3) Additional fan motor, length of copper tube and insulation are required. This increases cost of air conditioner.

(4) There is no provision for ventilation air.

EXERCISES

1. Define :
   (a) Refrigeration (b) Refrigerating effect (c) Ton of refrigeration (TR)
   (d) COP (e) Refrigerant
2. State applications of refrigeration.
3. With neat sketches explain the following refrigeration cycles.
   (a) Vapour compression refrigeration cycle (b) Vapour absorption refrigeration cycle (c) Air refrigeration cycle
4. Enlist desirable properties of refrigerant.
5. With neat sketch explain construction and working of window air conditioner.
6. With neat sketch explain construction and working of split air conditioner.

OBJECTIVE TYPE QUESTIONS

1. Performance parameter for refrigeration system is known as **(Summer 2017)**
   (a) efficiency (b) COP (c) effectiveness (d) energy ratio
2. Refrigerant should have ________ latent heat of evaporation.
   (a) high (b) low (c) moderate
3. Refrigerant should have ________ critical pressure.
   (a) high (b) low (c) moderate
4. 1 TR equals to
   (a) 5.25 kW (b) 100 kJ/min (c) 200 kJ/min (d) 3.52 kW
5. Which one of the following is not a standard component of VCR cycle ?
   (a) compressor (b) condenser (c) expander (d) evaporater

6. Function of condenser in VCR cycle is

(a) to suck refrigerant from evaporator
(b) to produce refrigerating effect
(c) to throttle refrigerant
(d) to reject heat to the ambient

7. In VCR cycle, refrigerating effect is produced by **(Summer 2017)**

(a) compressor (b) condenser (c) evaporator (d) expander

8. COP of simple vapour absorption cycle is around

(a) 0.6 (b) 4 (c) 2 (d) 0.1

9. Which one of the following is not a standard component of vapour absorption cycle ?

(a) generator (b) compressor (c) condenser (d) absorber

10. Which one of the following is not a standard component of air refrigeration cycle ?

(a) compressor (b) cooler (c) throttle valve (d) expander

11. ________ is used as expansion device in window air conditioner.

(a) throttle valve
(b) thermostatic expansion valve
(c) automatic expansion valve
(d) capillary tube

12. Number of electric motor(s) used for air circulation in window air conditioner is/are

(a) one (b) two (c) not used (d) three

13. Number of electric motor(s) used for air circulation in split air conditioning is/are

(a) one (b) two (c) not used (d) three

14. ________ is used to maintain temperature of the room.

(a) throttle valve (b) exhaust air damper (c) thermostat (d) expansion valve

15. In window and split air conditioners which line is insulated ?

(a) liquid line (b) suction line (c) discharge line (d) vapour line

16. During refrigeration cycle, heat is absorbed by refrigerant in **(Jan. 2013)**

(a) compressor (b) evaporator (c) condenser (d) expansion valve

17. Which is not a part of Vapour compression refrigeration system? **(Jan. 2013)**

(a) compressor (b) throttle valve (c) receiver (d) absorber

18. During a refrigeration cycle, heat is rejected by the refrigerant in a ______. **(Winter 2016)**

(a) compressor (b) condenser (c) evaporator (d) expansion valve

19. Refrigerant used in domestic refrigerators is generally ________. **(Winter 2017)**

(a) R134a (b) carbon dioxide (c) oxygen (d) ammonia

ANSWERS

1. (b)	2. (a)	3. (a)	4. (d)	5. (c)	6. (d)	7. (c)	8. (a)	9. (b)	10. (c)
11. (d)	12. (a)	13. (b)	14. (c)	15. (b)	16. (b)	17. (d)	18. (b)	19. (a)	

❖ ❖ ❖

11

COUPLINGS, CLUTCHES AND BRAKES

Couplings and clutches are used to couple in-line shafts of prime mover and load. Disengagement of two shafts connected with coupling is possible only when the shafts do not rotate. If shafts need to engage or disengage, even while they rotate, a clutch is used. Clutches cannot be used for transmission of very heavy load as they basically remain engaged due to friction. Brakes are used to control speed of a machine or stop a machine.

11.1 COUPLINGS :

A coupling connects shafts of machines that are manufactured separately, such as a motor and a generator. A long line-shaft is composed of a number of small shaft pieces put together end to end by couplings.

Couplings can be classified into two categories :

(1) Rigid Couplings :

This type of couplings have no flexibility. So the shafts to be coupled should be in good alignment. e.g. Muff coupling, Split muff coupling and Flange coupling.

(2) Flexible Couplings :

This type of coupling allows for imperfect alignment of two joining shafts (e.g. Bushed pin type flange coupling), two parallel shaft with small offset (e.g. Oldham coupling) or two intersecting shaft (e.g. Universal coupling).

11.1.1 Muff (Sleeve) Coupling :

This coupling is simply a hollow cast iron cylinder (muff) which is fitted over the ends of two shafts to be connected. A long sunk taper key is driven through both the shafts and the muff. The motion of one shaft is communicated to the sleeve and then to the other shaft.

This type of coupling is simple to design and manufacture. It has no projecting parts as is evidenced by its perfect smooth exterior. The disadvantage is that it is difficult to disassemble and there is need of perfect alignment between shafts.

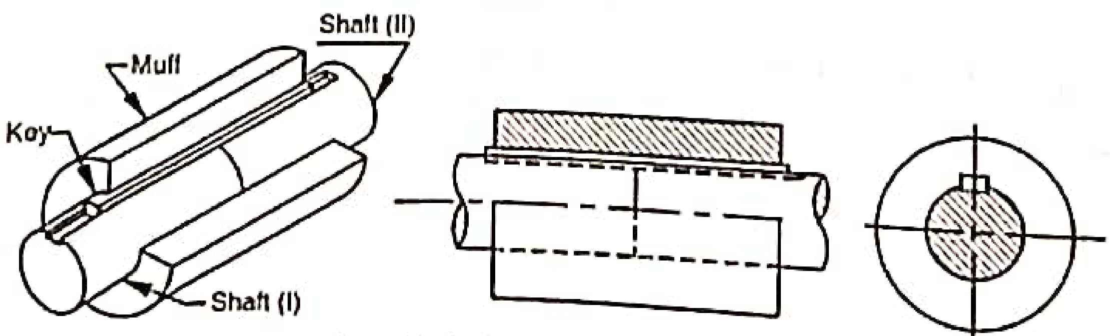


Fig. 11.1 Box or muff coupling

11.1.2 Flange Coupling :

This form of coupling is very extensively used. It consists of two cast-iron flanges, keyed to the ends of two shafts. The faces of the flanges are brought and held together by a series of bolts arranged concentrically about the shaft. The circular projection of one flange fits into corresponding recess of other flange. This ensures proper alignment of shafts.

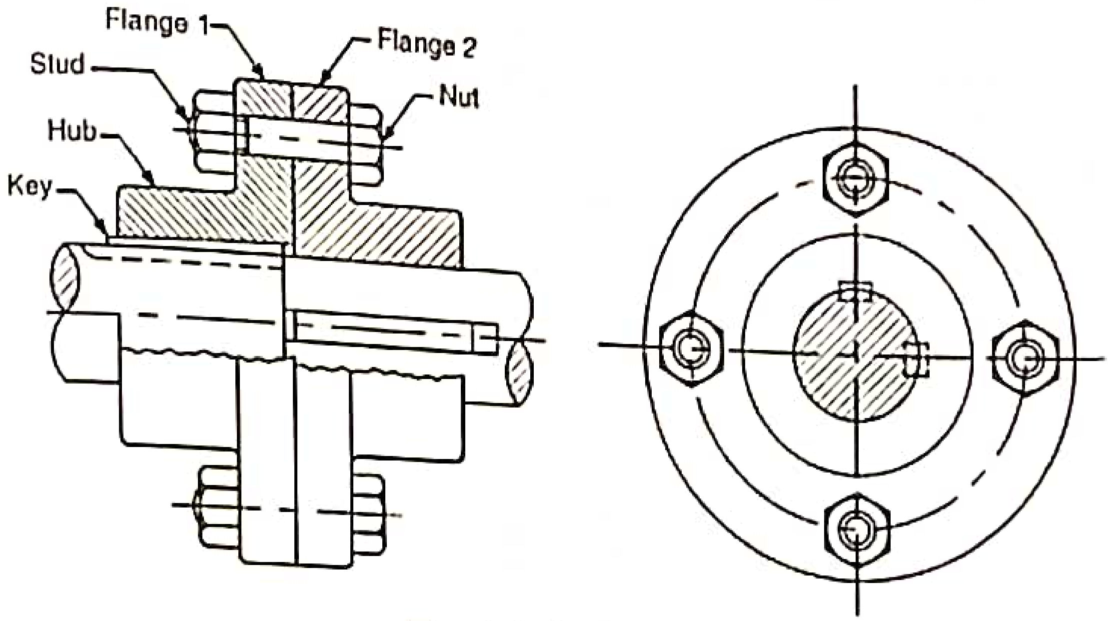


Fig. 11.2 Flange coupling

Sometimes, a flange is provided with a shroud (see Fig. 11.3) which shelters the bolt heads and nuts. This prevents them catching clothes of workmen. Such coupling is called **protected type flange–coupling**. Flange couplings ensure the most accurate rigid and strong connection of shafts. It is adapted to heavy loads also.

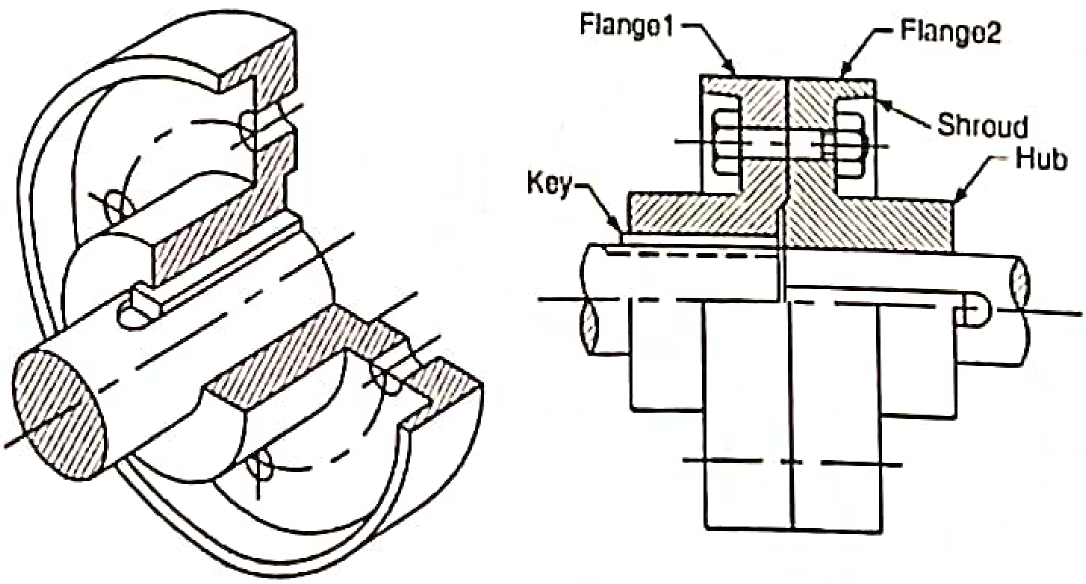


Fig. 11.3 Protected flange coupling

11.1.3 Pin Type Flexible Coupling :

This type of coupling also has one flange each mounted on a shaft.

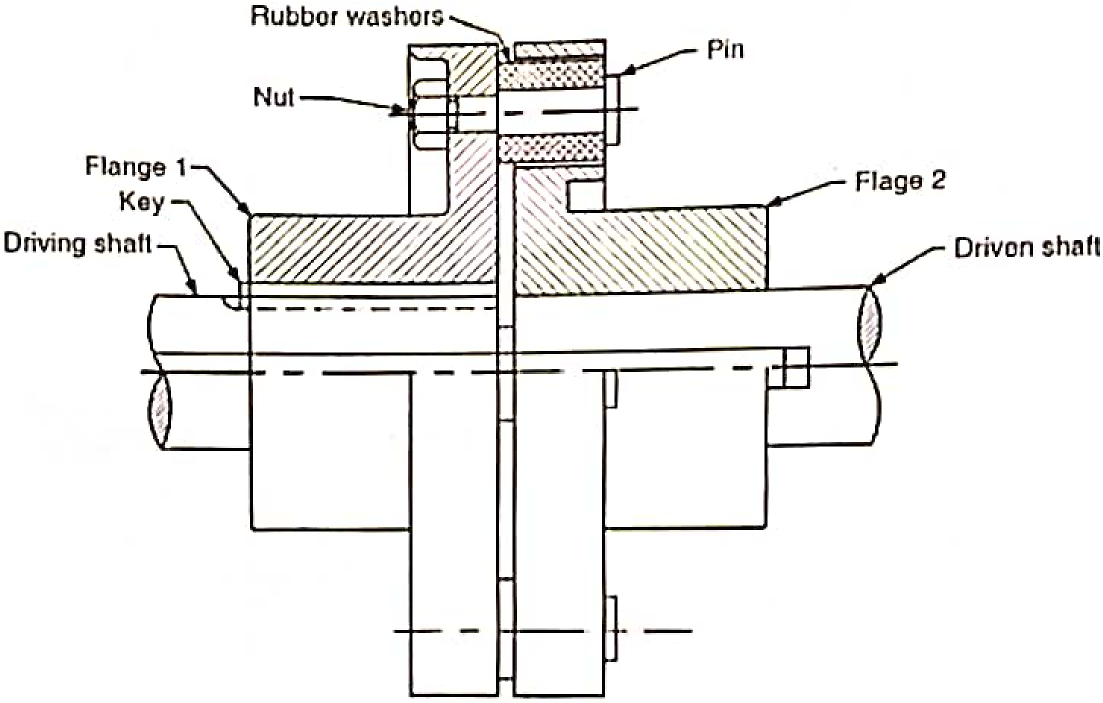


Fig. 11.4 Pin type flexible coupling

The pins are rigidly fastened by nuts to one of the flanges while they are covered with leather or rubber washers (bushes) and kept loose in the other flange. This coupling makes up for the small parallel misalignment, angular misalignment and axial displacement. It can also absorb shocks and vibration during its operation. This type of coupling is commonly used for directly connecting an electric motor to a machine.

11.1.4 Universal Coupling (Hook's Joint) :

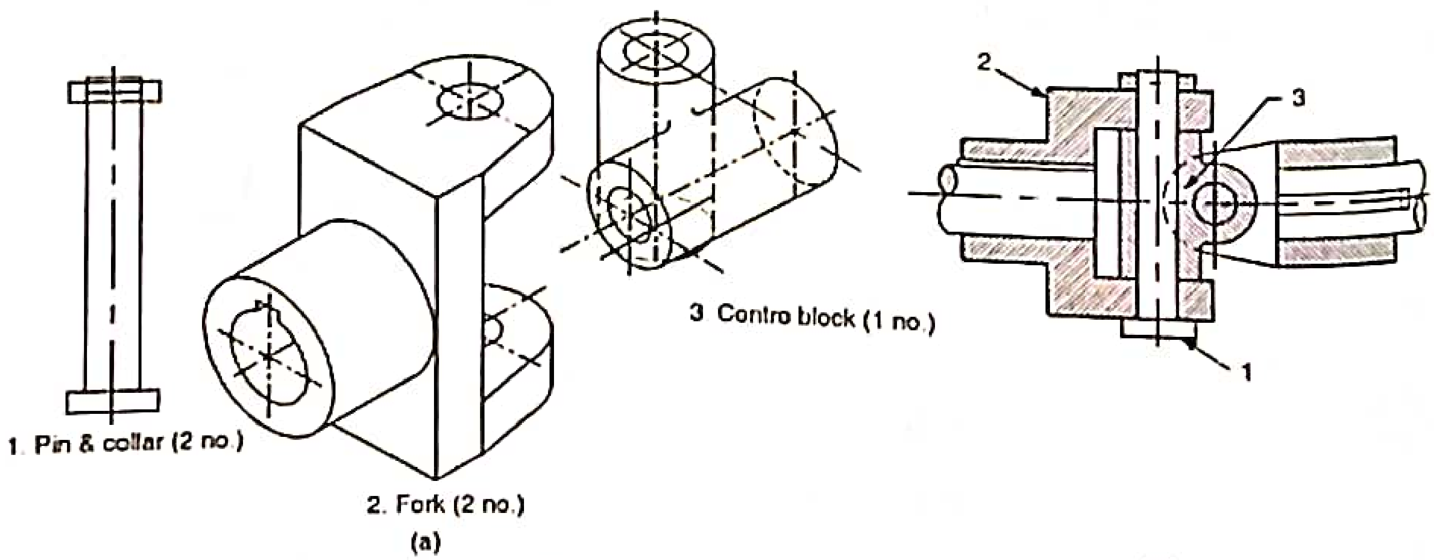


Fig. 11.5 Universal coupling

In cases where the angular or offset misalignment of the shaft is more, universal flexible coupling can be applied. It does not allow parallel misalignment i.e. shaft must intersect. Two similar forks are keyed on to the ends of two shafts. The holes in each fork coincide with hole in the centre piece. Two perpendicular pins fasten the forks with each other by the centre piece.

11.1.5 Oldham's Coupling :

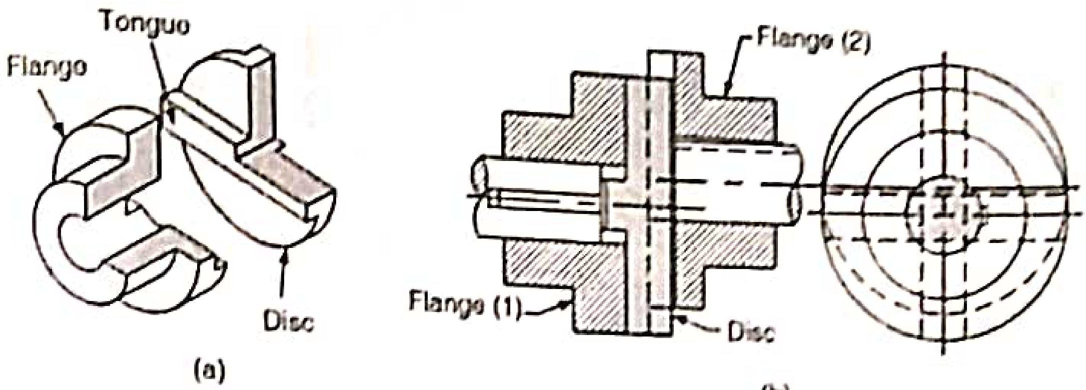


Fig. 11.6 Oldham's coupling

When the axes of the shaft are parallel but not in alignment, Oldham's coupling can be used to couple them. Two flanges, each having a rectangular recess are keyed one on each shaft. The intermediate circular disc has rectangular projections (tongue) on either side, at right angles to eachother. These projections fit into the corresponding recesses in the flanges. The power is transmitted from driving shaft to driven shaft through the intermediate piece which rotates as well as slides in the slots.

11.2 CLUTCHES :

The basic function of the clutch is to control the flow of mechanical power within a machine. The driven shaft can be started or stopped without stopping the prime mover.

Clutches

- Mechanical
  - Positive contact clutches
    e.g. Jaw clutch
    Toothed clutch
  - Friction clutches
    e.g. Disc clutch
    Cone clutch
    Centrifugal clutch
- Electromagnetic
- Pneumatic
- Hydraulic

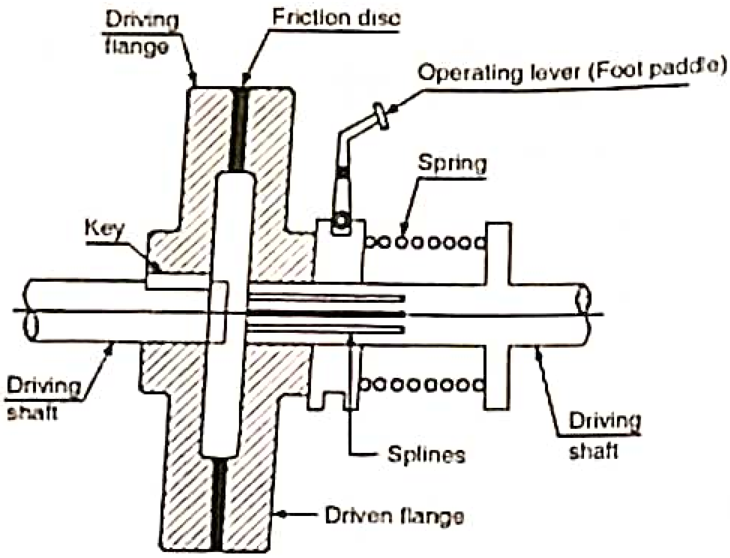
11.2.1 Friction Clutches :

The operation of friction clutches is based on the friction force developed between surfaces of two clutch members. When engaged, the clutch members tend to rotate as a single unit but can slip under certain conditions. This type of clutches can be engaged at high speeds with minimum shock.

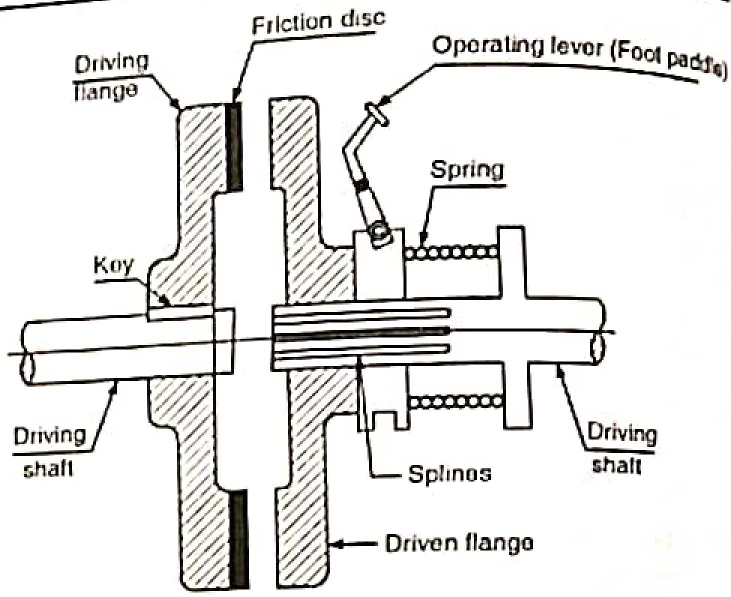
(i) Disc Clutch :

This type of clutch has two flanges, one each on driving shaft and driven shaft. One of the flanges is lined with a material having high co-efficient of friction. The flange on driving shaft is keyed rigidly while the flange on driven shaft can move along the axis of shaft using a splined shaft. The torque can be transmitted from the driving flange to driven flange through friction lining when they press upon each other. Single disc clutches are used in automobiles.

When large torque is to be transmitted, multidisc clutches are used. They have more than one driving and driven plates and contact surfaces.



(a) Engaged position



(b) Disengaged position

Fig. 11.7 Disc clutch

(2) Centrifugal Clutch :

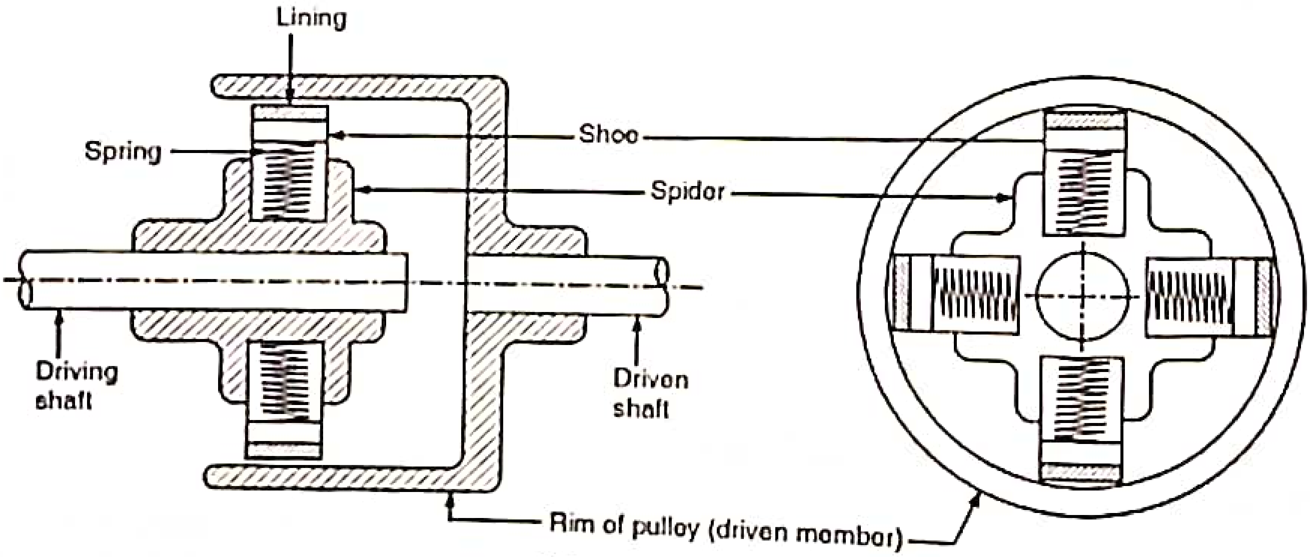


Fig. 11.8 Centrifugal Clutch

This type of clutch is used to connect two parts of a transmission after the driving part has attained a definite speed of rotation. The shoes are pulled inward by the springs and forced outward due to centrifugal action by rotation of driving shaft. When the driving shaft attain certain speed, the centrifugal force on shoes increase and become greater than spring force. The shoes are engaged with the inner surface of the cylindrical drum which is the driven member.

(3) Cone Clutch :

In cone clutch, torque is transmitted using friction between internal surface of one cone mounted on driving shaft and external surface of another cone mounted on driven shaft. The cone on driven shaft can move axially by a suitable mechanism. Cone clutch can couple two shafts without excessive axial pressure but it is difficult to disengage.

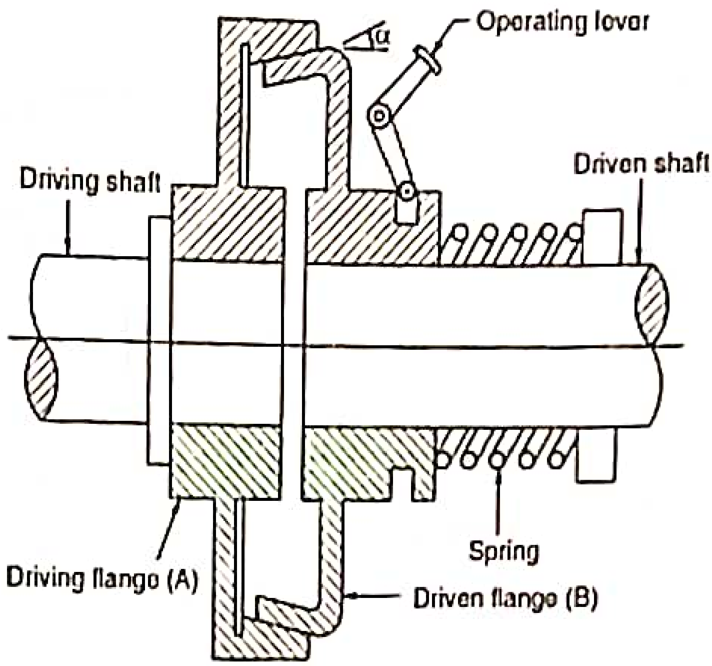


Fig. 11.9 Cone Clutch

11.3 BRAKES :

The brake is a frictional device whose primary function is to control the motion of a machine member. In doing so, it is called upon to bring to rest, a body which is in motion or to slow it down or to hold it, in state of rest. It is required to absorb kinetic energy of moving parts or the potential energy of objects being lowered by hoists, elevators etc. The classification of brakes is given below :

Brakes

- Mechanical
  - Block brake
  - Band brake
  - Shoe brake (Internal or external)
- Electrical
- Hydraulic

(1) Block Brake :

In this type of brake, blocks press against outside surfaces of a brake drum. The brake drum is keyed onto the shaft. A double shoe brake is shown in Fig. 11.10. The spring pushes the upper ends of brake arms together, and thus the brake is applied. The force P at the end of the lever is applied using a solenoid or mechanically. This force overcomes spring force and drum starts rotating. When P becomes zero, the brakes will get engaged due to spring force and brake is applied. Such brake is frequently used in hoisting machinery. Prony brake dynamometer also uses wooden blocks for braking.

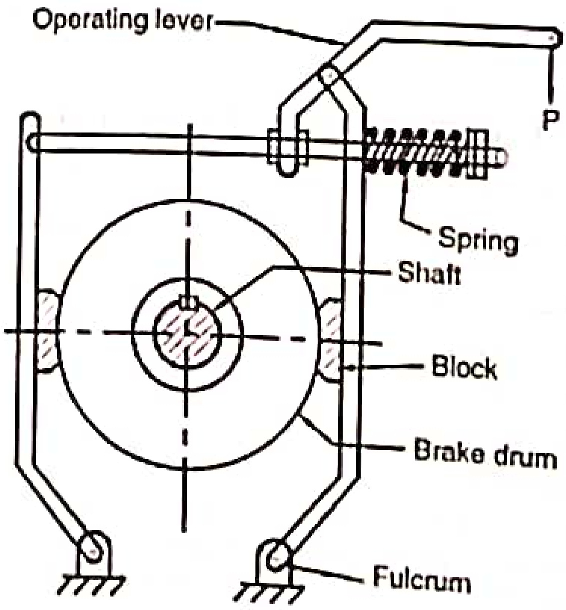


Fig. 11.10 Block brake

(2) Shoe Brake :

Internal shoe brake is shown in Fig. 11.11. Each shoe is pivoted at one end about a fixed fulcrum. The other end rests against the face of a cam. The outer surfaces of the shoes are lined with friction material. To apply brake, the cam is operated by some means, expanding the shoes. This will press the shoes against the inner rim of the brake drum, braking the torsional moment of the drum. When the cam is not operated, the shoes come to origional 'off' position by the spring force.

It is compact and its working elements are enclosed and protected from dirt etc. by the drum. This type of brake is universally adopted for automobiles. External shoe brake is similar to block brake.

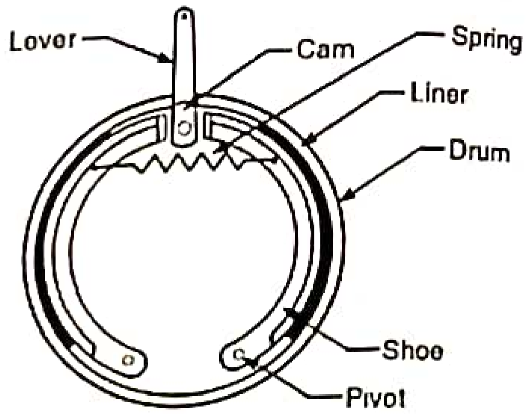


Fig. 11.11 Shoe brake

(3) Band Brake :

In a band brake, a flexible steel band lined with friction material embraces a portion of circumference of brake drum. When actuating force P is applied on the lever, the band tightens around the brake drum applying frictional force. This type of brake is widely used in construction equipment as well as in automobiles as hand brake.

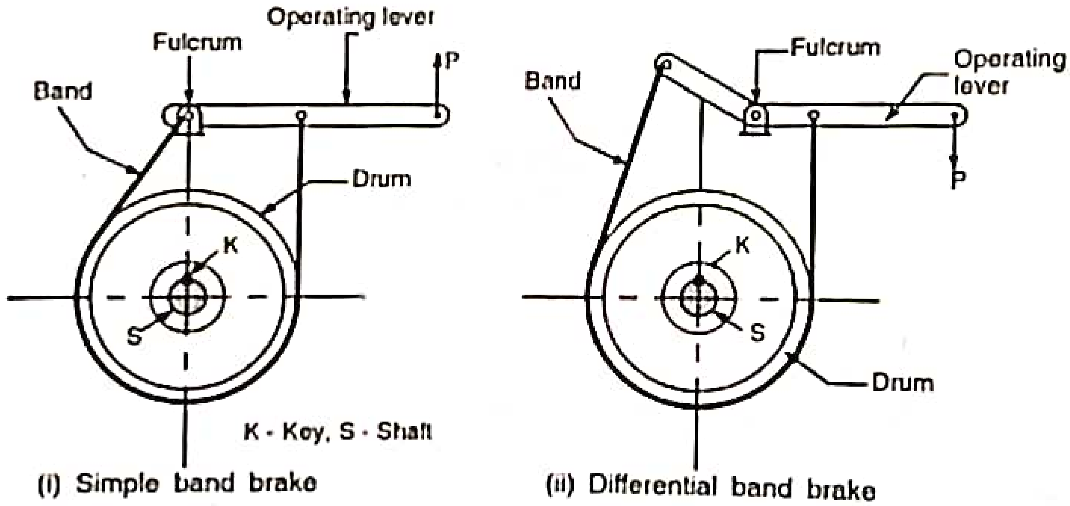


Fig. 11.12 Band brake

11.4 DIFFERENCE BETWEEN A CLUTCH AND A BRAKE :

Clutch	Brake
(1) It is used to transmit the motion and power of one machine member or prime mover to another member.	(1) It is used to slow down or stop the motion of a machine member
(2) Most energy is transmitted from one member to another, but a little is lost in friction.	(2) The energy of the machine member is dissipated in friction due to braking action.
(3) In an automobile, the clutch normally remains in engaged condition.	(3) In an automobile, the brake normally remains in disengaged condition.
(4) In machine tools, presses etc., the clutch normally remains in disengaged condition.	(4) In hoists, the brake normally remains in engaged condition.

EXERCISES

1. What are the uses of coupling ?
2. What is the difference between muff and split muff coupling ?
3. What is function of coupling ? Name only various types of couplings. Explain any one type of coupling used to connect two shafts.
4. How couplings are classified ? What is split muff coupling ?
5. What is difference between rigid coupling and flexible coupling ? Describe bushed pin type flexible coupling with a neat sketch.
6. Explain Oldman's coupling with a neat sketch.
7. Which coupling can be used to couple two shafts whose axis intersect ? Give names of different parts of this coupling.
8. What is the function of a clutch in an automobile vehicle ? What are various types of clutches ? Name the clutch used in scooters and cars.
9. Differentiate between a coupling and a clutch. Classify the clutches and state the function of clutch used in automobiles.
10. With a neat sketch, describe the working of a cone clutch.
11. With a simple sketch explain the working of a disc clutch.
12. What is clutch ? Mention broad classification of clutches.
13. Explain the working of a centrifugal clutch with a neat sketch.
14. What is function of brakes ? What are different types ? Explain with neat sketch the working of internal expanding shoe brake.
15. Explain with neat diagram the working of internal expanding shoe brake.
16. What is function of brakes ? How are they classified ? Explain with neat diagram working of any one type of brake.
17. What is brake ?
18. What is clutch ? How it differs from brake ? When multiplate clutches are used?
19. Explain with neat sketch the working of a band brake.
20. Draw neat diagrams of :

    (i) Block brake (ii) External shoe brake

OBJECTIVE TYPE QUESTIONS

1. Function of coupling is to
   (a) transmit power from one rotating shaft to another (b) control flow of mechanical power
   (c) control speed of a machine (d) All of the above
2. Function of clutch is to
   (a) transmit power from one rotating shaft to another (b) control flow of mechanical power
   (c) control speed of a machine (d) all of the above
3. Function of brake is to
   (a) transmit power from one rotating shaft to another (b) control flow of mechanical power
   (c) control speed of a machine (d) all of the above
4. Which one of the following is not a rigid coupling?
   (a) Muff coupling (b) Flange coupling (c) Oldham coupling (d) Split muff coupling

5. Which one of the following is not a flexible coupling?
   (a) Muff coupling (b) Bushed pin type coupling
   (c) Oldham coupling (d) Universal coupling
6. To connect on electric motor to a machine directly, which one of the following coupling is preferred.
   (a) Universal coupling (b) Pin type flexible coupling
   (c) Oldham coupling (d) Split muff coupling
7. When two shafts are intersecting, which one of the following coupling is used?
   (a) Universal coupling (b) Pin type flexible coupling
   (c) Oldham coupling (d) Split muff coupling
8. Which one of the following is not a friction clutch?
   (a) Disc clutch (b) Cone clutch (c) Centrifugal clutch (d) Jaw clutch
9. For high speed engagement between two shafts with minimum shock _______ clutch is used.
   (a) positive contact (b) friction (c) (a) or (b) (d) none of above
10. Which type of clutch is used, when it is intended to engage the shafts after driving shaft attains certain speed?
   (a) cone clutch (b) disc clutch (c) multi disc clutch (d) centrifugal clutch
11. Normally which type of brake is used for automobile?
   (a) Internal expanding shoe brake (b) external shoe brake (c) block brake (d) band brake
12. The clutch ordinarily remains in disengaged condition when it is used for power transmission in **(June 2015)**
   (a) Automobile (b) Machine tools (c) Crane (d) Elevator
13. The energy absorbed by brakes is released in surroundings in form of
   (a) heat energy (b) kinetic energy (c) potential energy (d) pressure energy
14. Which of the following elements is used to connect two shafts _______
   (a) clutch (b) brakes (c) couplings (d) none of above
15. Plate type, Cone type and Centrifugal type are the types of _______.
   (a) Couplings (b) Brakes (c) Clutches (d) Gear drives
16. A hydraulic coupling belongs to the category of _______. **(Winter 2016)**
   (a) power absorbing machines (b) power developing machines
   (c) energy transfer machines (d) energy generating machines
17. Following type of coupling has a centre block
   (a) Flanged coupling (b) Protected flanged coupling
   (c) Universal coupling (d) Muff coupling
18. The friction coupling does not contain following part.
   (a) Jaw (b) Flange (c) Friction disc (d) Spring

ANSWERS

1. (a)	2. (b)	3. (c)	4. (c)	5. (c)	6. (b)	7. (a)	8. (d)	9. (b)	10. (d)
11. (a)	12. (d)	13. (a)	14. (c)	15. (c)	16. (c)	17. (c)	18. (a)		

❖ ❖ ❖

12

TRANSMISSION OF MOTION AND POWER

NTRODUCTION :

echanial Power is transmitted from the prime mover to a machine, from one machine to another or from e member of machine to another, by means of intermediate mechanisms called 'drives'. The drives are used stead of directly coupling the prime mover to machine due to following reasons :

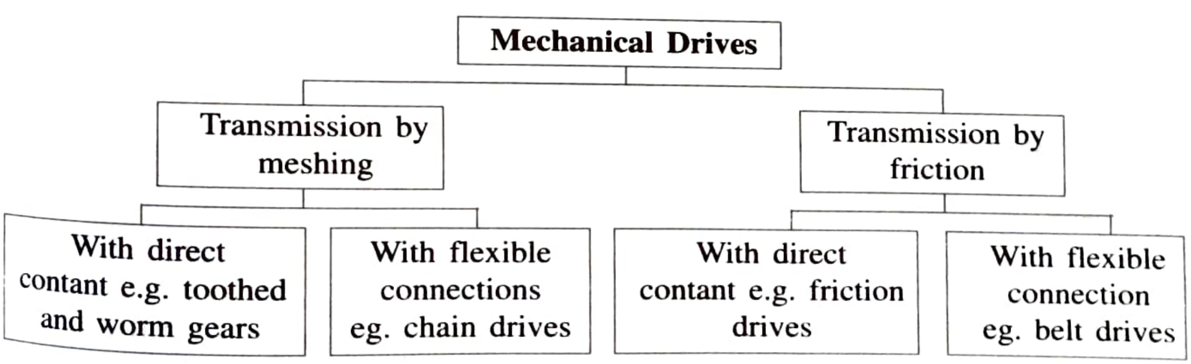
) The prime movers (generally electric motors) have high speeds while the machines require a smaller speed with larger torque.

) The speed of driven member may have to be frequently changed whereas the speed of prime mover should be kept constant for its use to the full advantage.

) Sometimes, several machines are operated from only one prime mover e.g. group drive.

) Sometimes the machines are not coupled directly to the prime mover shaft due to considerations of safety, convenience and maintenance.

YPES OF MECHANICAL POWER TRANSMISSION ELEMENTS (MECHANICAL DRIVES) :



e **selection of drives** is based upon following considerations :

Magnitude of power to be transmitted

Speeds of driving and driven shafts

Distance between the shafts

Overall dimensions

12.3 SHAFT AND AXLE :

Shafts are machine members mostly with circular cross-section which support revolving parts of machine such as pulleys, gears and flywheels. They are subjected to bending as well as torsional loads. An **axle** may or may not rotate and supports revolving parts. It is subjected to bending only. The part of shaft within the bearing is known as journal. A **spindle** is a machine shaft that drives or supports either a cutting tool or the workpiece on which machining is performed. The power transmitted by the shaft P (in Watts) is given by

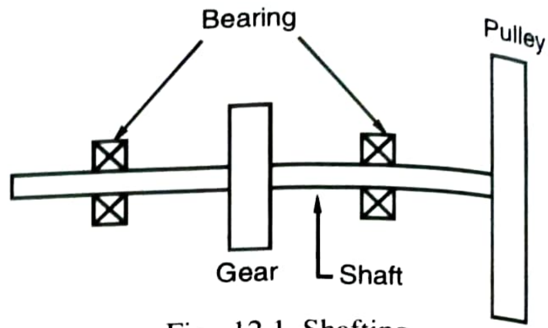
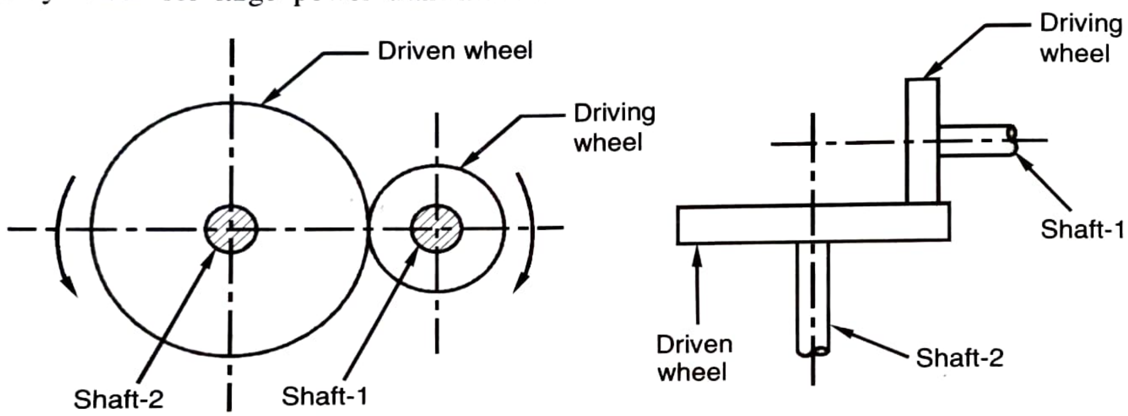


Fig. 12.1 Shafting

$$P = \frac{2\pi NT}{1000 \times 60}$$ where, N = speed in RPM, T = torque in N.m.

12.4 FRICTION DRIVE :

Friction drive is used for light load transmission between parallel shafts or between shafts with intersecting axes. The driving and driven wheel are in contact with sufficient pressure between them. The driving wheel drive the driven wheel by virtue of friction between them. The friction wheels do not give a positive drive and slip may occur for large power transmission.



(a) Drive with parallel axes (b) Drive with intersecting axes

Fig. 12.2 Friction drive

If the friction wheels are assumed to operate without slip, the surface speed of both wheels will be equal.

So, $\pi D_1 N_1 = \pi D_2 N_2$

$$\therefore \quad \frac{N_2}{N_1} = \frac{D_1}{D_2} \tag{12.1}$$

Thus velocity ratio is inversely proportional to the ratio of diameters.

There will be slip between friction wheels for transmission of large power. Instead teeth may be cut on the cylindrical or conical surface of the wheels to create positive action. The teeth of the wheels mesh and transmit power. Such wheels are nothing but gears.

12.5 BELT DRIVE :

A belt is a thin inextensible band wrapped tighty over two pulleys which are mounted on shafts. Belt-drive is one of the most common and effective means for transmission of motion from one shaft to another. It is extensively used in mills and factories when the distance between the shafts is not very big.

The belt transmits power from the driving pulley to the driven pulley by frictional resistance between belt and surface of pulley. There is always possibility of some slipping between the belt and faces of pulley when the belt moves over pulleys. Thus the character of motion transmitted is not positive. Where positive drive is required, gears or chains should be used.

Types of Belt Drive :

The flexibility of the belt helps in arranging the shafts of the driving and driven pulleys in different manners and in using many pulleys. Flat belt drives can be divided into the following.

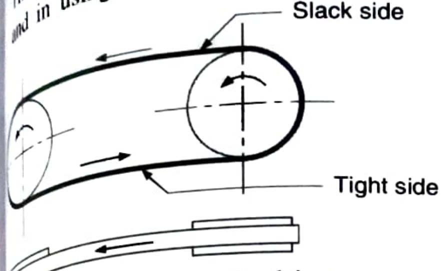


Fig. 12.3 Open belt drive

(1) Open Belt Drive :

In this type of drive, the shafts are arranged in parallel and they rotate in the same direction.

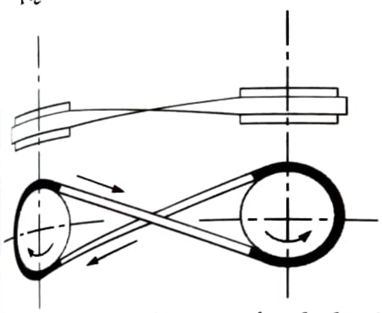


Fig. 12.4 Crossed belt or twist belt drive

(2) Crossed Belt or Twist Belt Drive :

When the shafts are parallel but need to be rotated in opposite directions, this drive is used. As the belts cross eachother, there will be too much wear and tear. So this type of drive should be used for larger distance between the shafts and lower speeds only.

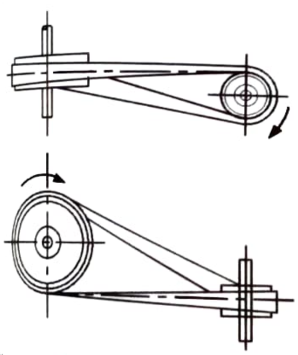


Fig. 12.5 Quarter twist drive

(3) Quarter Twist Drive :

The shafts are at right angles and rotate in the same definite direction (Clockwise or anticlockwise). The face of the pulley should be wide enough, not allowing the belt to leave the pulleys.

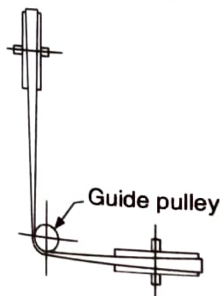


Fig. 12.6 Right angle drive

(4) Right Angle Drive :

It is used with shafts with axis making 90° with eachother and where the type of arrangement shown in Fig. 12.5 is not possible. It may also be used when reversible motion is required, i.e. direction of rotation of shaft can be reversed.

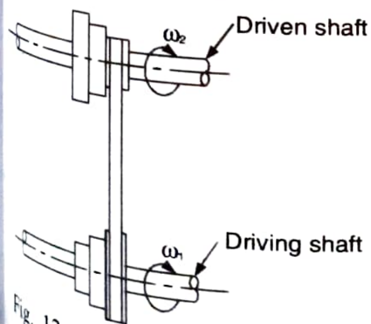


Fig. 12.7 Stepped pulley drive

(5) Stepped Pulley Drive :

This is used for stepped change (increase or decrease) in speed of driven shaft for constant speed of driving shaft.

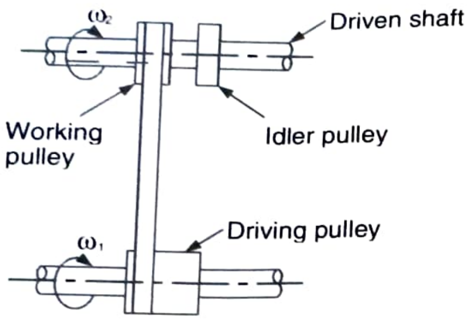


Fig. 12.8 Fast and loose pulley drive

(6) Fast and Loose Pulley Drive :

This type of drive is used when the driving shaft rotates continuously but the driven is to be rotated and stopped too often. There are two pulleys mounted on the driven shaft, a fast and a loose. The fast pulley is keyed to the shaft while the loose pulley (idler) can rotate freely on the shaft. When the driven shaft is to be stopped, the belt is pushed to the loose pulley with the help of a lever.

(7) Compound Drive :

This type of drive is used when several shafts are driven from one central shaft, as shown in Fig. 12.9 (a), (b) and (c).

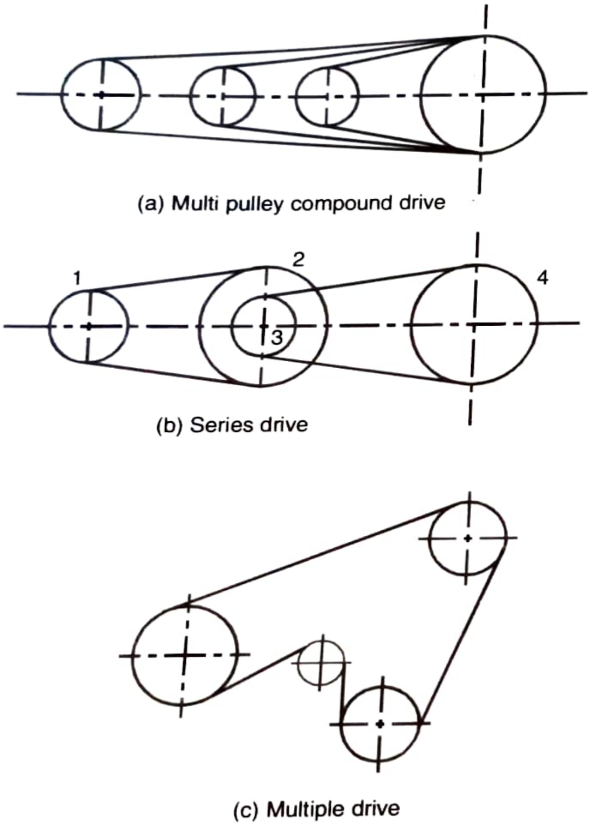


Fig. 12.9 Compound drives

12.5.2 Types of Belts :

There are basically four types of belts used. Flat belt, V–belt, Ribbed belt and toothed (timing) belt. Flat belt and V–belt are the most widely used out of above types. The choice among belt drives depends upon the factors such as speed, reduction ratio, positive drive requirements, centre distance, load capacity etc.

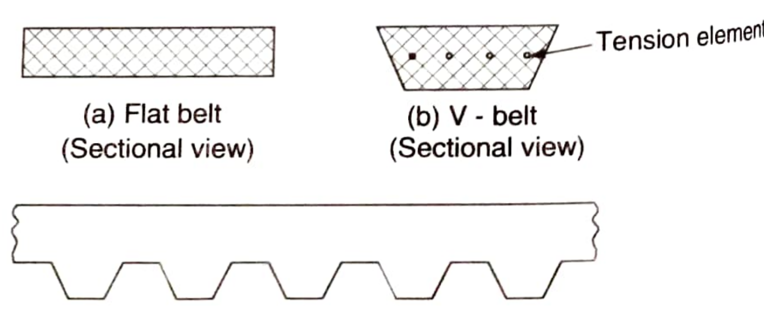


Fig. 12.10 Types of belt

(1) Flat Belts :

The main materials used for flat–belts are leather, rubber, cotton and balata. The flat belts can give a greater speed reduction ratio and operate at greater speeds. They can also be crossed to provide opposite rotation of driven and driving pulley. These belts are available in form of long strap which can be joined to make it endless.

(2) **V – Belts :**

The V–belts are able to transmit higher torque at less widths and tensions than flat belts. The wedging action of the belt in its groove enables the belts to be used on short centre distance where flat belts would have insufficient contact arc.

V–belts are available in endless form with standard lengths and cross–section. The belts are made from fabric and vulcanised rubber with a cotton or nylon cord tension elements.

(3) **Timing Belt :**

They are molded endless flat belts with regularly spaced teeth formed on one side. Drives using timing belts incorporate the positive action of a chain and sprocket drive with most of the advantages of the other types of belt drives. There is positive tooth and groove engagement of the belt without slip, creep and speed variations. So there is precise synchronization between driving and driven elements. These belts can also be used for power transmission with high efficiency. They are available in endless form with wide variety of standard lengths, widths and pitches to choose from.

12.5.3 Velocity Ratio of Pulleys :

Let D_1 and D_2 be the diameters of the driver and follower pulleys respectively. Let N_1 and N_2 denote their speeds in revolutions per minute (or second).

Surface speed of driver $= \pi D_1 N_1$

Surface speed of follower $= \pi D_2 N_2$

Assuming that there is no slip,

Surface speed of driver = speed of belt = surface speed of follower.

or, $\pi D_1 N_1 = \pi D_2 N_2$

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \tag{12.2}$$

Above equation is true for open as well as crossed belts but sense (direction) of rotation is the same for open belt drive pulleys while opposite for crossed belt drive pulleys.

If we take into consideration the thickness of belt 't',

$$\frac{N_2}{N_1} = \frac{D_1 + t}{D_2 + t} \tag{12.3}$$

For the compound drive shown in Fig. 12.9,

$$\therefore \quad \frac{N_2}{N_1} = \frac{D_1}{D_2} \quad \text{and} \quad \frac{N_4}{N_3} = \frac{D_3}{D_4}$$

$$\therefore \quad \frac{N_4}{N_3} \times \frac{N_2}{N_1} = \frac{D_3}{D_4} \times \frac{D_1}{D_2}$$

But $N_2 = N_3$ as both pulleys are mounted on same shaft

$$\therefore \quad \frac{N_4}{N_1} = \frac{D_1}{D_2} \times \frac{D_3}{D_4} \tag{12.4}$$

12.5.4 Slip and Creep in Belt Drive :

Motion of belt is achieved by virtue of friction between the surface of the pulley and belt. But there is some amount of slip between them when power is being transmitted. Slip of about 1.5 to 2 percent is present under normal conditions.

Creep is a phenomenon caused by the elasticity of the belt material. The belt is stretched more on the tight side than on the slack side. Due to this, the length being received and being delivered by a pulley is different. This phenomenon is called creep.

In practice, the combined effect of slip and creep is called slip. The value of slip should not exceed 3 percent.

The equation for the ratio of speed of followers to speed of driver becomes

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \times \frac{100 - s}{100} \quad (s = \text{percentage slip})$$

Considering thickness of belt as well as slip, $\frac{N_2}{N_1} = \frac{D_1 + t}{D_2 + t} \times \frac{100 - s}{100}$ (12.5)

12.5.5 Pulleys :

The pulleys for transmission of power should have the following qualities :

(1) Ability to absorb shock
(2) Strength combined with low weight
(3) Ability to conduct heat
(4) Minimum air resistance
(5) Smooth surface for low belt wear

The material of construction for pulleys are : (1) Cast iron (2) Fabricated steel (3) Wood (4) Wood rim and cast iron centre and (5) Paper rim and cast iron or steel centre.

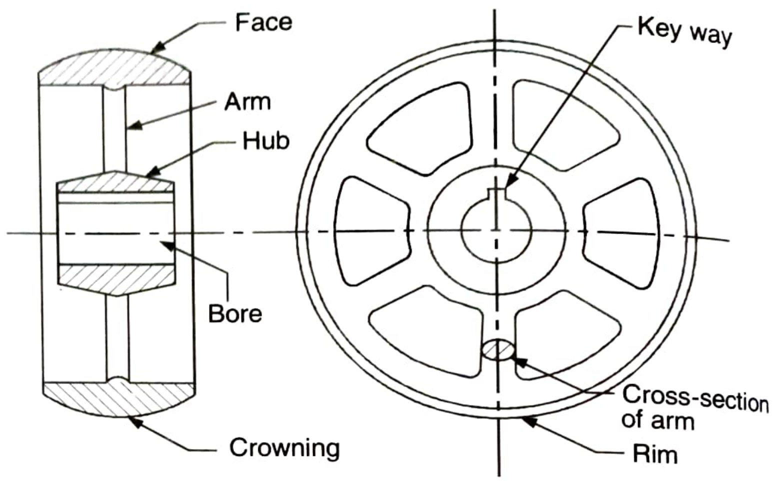


Fig. 12.11 Construction of pulley

Fig. 12.11 shows a pulley for flat belt drive. The main parts of pulley are hub or boss, arms or rib and rim.

(1) Hub :

It is the central, hollow cylindrical portion of pulley. The bore on the hub corresponds to the diameter of the shaft on which it is mounted. A keyway is provided to fasten the pulley to the shaft with the help of a key.

(2) Arms :

They join the hub and the rim of pulley. They may be straight or curved and the cross section may be circular or elliptical. Pulleys with smaller diameter are provided with a rib which is like a circular disc joining hub and rim.

(3) Rim :

It is the periphery of the pulley on which the belt runs. The outer face of the rim is made slightly convex which is called crowning. The crowning keeps belts from running off (come out) when pulley is misaligned.

12.6 CHAIN DRIVE :

A chain drive consists of an endless chain running over two sprockets – driver and driven. It provides positive drive but can not be used where precise timing is required. The alignment of the shaft must be more accurate than belt drives. Chain drive is generally used for low and medium speed service. Chain drives find wide applications in agricultural machinery, bicycles, motor cycles, conveyers and transport mechanisms.

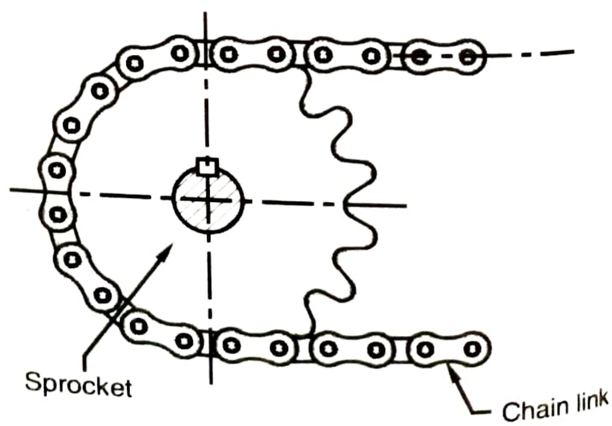


Fig. 12.12

Advantages of Chain Drive :

(1) It can be employed both for relatively long or short centre distances. The centre distance may be as large as 8 metres.

(2) It is small and compact as compared to flat belt drive.

(3) It can have efficiency of 98 to 99 percent under ideal conditions.

(4) It is possible to transmit power to more than one shafts with the help of one pulley only.

Disadvantages of Chain Drive :

(1) Due to wear of chain joints, the chain gets stretched. This increases chain length resulting in velocity fluctuations.

(2) The production cost is relatively high

(3) The operation is noisy

(4) It requires more amount of servicing, maintenance and repairs as compared to belt drives.

(5) Its design is more complicated than belt drive.

Roller chains, bush chains and silent chain or inverted tooth chains are the main types of chains used for power transmission. Previous two types are used for low and medium speed service whereas the silent chain is used for high speed ratios due to its smooth and quiet action.

12.7 GEAR DRIVE :

Use of the gear drive is advisable in following conditions :

(1) Shaft centre distances are short

(2) Constant speed ratio of shafts must be maintained

(3) Shaft speed is too slow for belt drive

(4) High torque must be transmitted

Toothed gears make it possible to drive shafts which are parallel, intersecting or which are non–parallel non-intersecting. Positive, no–slip drive is the most important single characteristic of gear drives compared to belt and, to some extent, chain drives.

Many different forms of gears are used. Some of them, most commonly used are :

(1) Spur gear

(2) Helical gear

(3) Bevel gear

(4) Spiral gear

(5) Worm and worm wheel

(6) Rack and pinion

12.7.1 Spur Gear :

Spur gears have teeth parallel to the axes of the gears. They operate on parallel shafts. The teeth are cut in involute shape. The material of construction may be cast iron, cast steel, bronze, fiber or synthetic plastic material. Spur gears are used in a wide range of articles – watches, machine tools, gear boxes in automobiles etc.

Spur gears are the most common type of gears and their advantages are simplicity in design, economy of manufacture and low maintenance. Only radial load acts on bearings, thrust load is absent. Spur gears are generally known as slow speed gears as noise is a problem at higher speeds. Internal gearing may be used to reduce centre distance between driving and driven shafts related to gears (Refer Fig. 12.13).

Definitions :

(1) **Pitch Circle Diameter (D_p) :** It is the diameter of a cylinder which by pure rolling action would produce the same motion as that produced by the toothed gear under reference. In case of spur gear, this represents the diameter of the cylinder which the gear has replaced. (The meshing gears may be thought as two friction wheels in contact whose diameters are equal to pitch circle diameters of gears with addendum added to them and dedendum deducted. The definations may be interpreted with reference to this.)

(2) **Pitch Surface :** It is the surface of the disc which the toothed gear under reference has replaced.

(3) **Pitch Point :** It is the point of contact of pitch circles of two gears in mesh.

(4) **Circular Pitch (p_c)** : It represents distance along the circumference of the pitch circle, from any one point of a tooth to a corresponding point on the adjecent tooth. Thus, circular pitch p_c for a spur gear of pitch circle diameter d_p having no. of tooth Z is given by

$$p_c = \frac{\pi D_p}{Z}$$

(5) **Diametral Pitch (p_d)** : It is defined as number of tooth per unit pitch diameter. Thus,

$$p_d = \frac{Z}{D_p}$$

(6) **Module (m)** : It is the length of pitch diameter per tooth.

$$\therefore \quad m = \frac{D_p}{Z}$$

(7) **Addendum** : The height of a tooth above the pitch circle is termed as addendum.

(6) **Dedendum** : The depth of a tooth below the pitch circle is referred to as dedendum.

(7) **Clearance** : Difference between dedendum and addendum of a tooth is termed clearance.

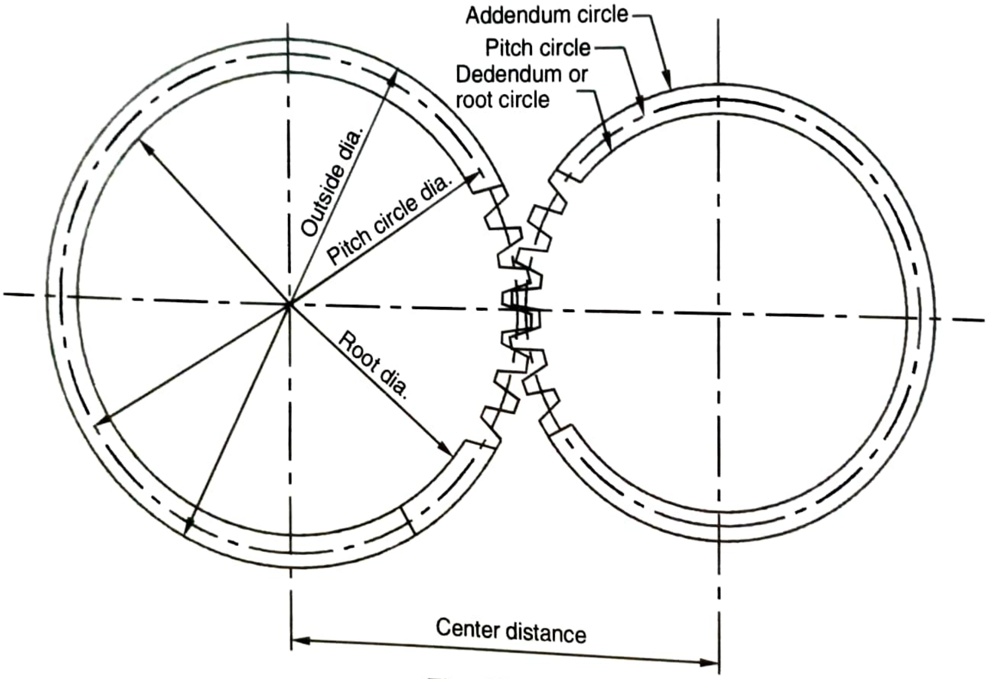


Fig. 12.13

Geometry Relations :

Module, $m = \frac{D_p}{Z}$ where, Z = number of teeth on gear

Diametral pitch, $p_d = \frac{Z}{D_p}$

Circular pitch $p_c = \frac{\pi D_p}{Z}$

$= \pi \cdot m$

So, $p_c \cdot p_d = \pi$

Centre distance between pair of gears

$$C = \frac{D_{p1} + D_{p2}}{2} = \frac{mZ_1 + mZ_2}{2}$$

$$= \frac{m}{2}(Z_1 + Z_2)$$

.2 Helical Gear :

Helical gears are gears in which the teeth are inclined to the axis of the shaft and are in the form of a helix. They are used for parallel as well as non-parallel, non-intersecting shafts.

The main advantage of helical gear is that the contact between two mating gears is gradual, not sudden as in spur gear. This eliminates noise but more lubrication is required due to sliding action between the teeth. The sliding action also produces a thrust along the shaft upon which the gear is mounted. So a thrust bearing must be provided to accomodate it.

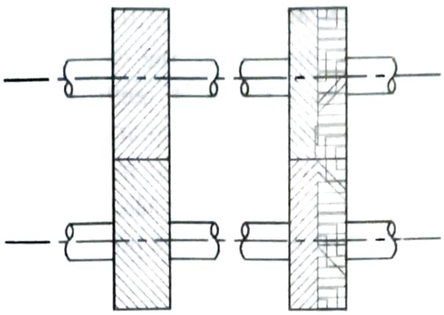


Fig. 12.14 Helical gear

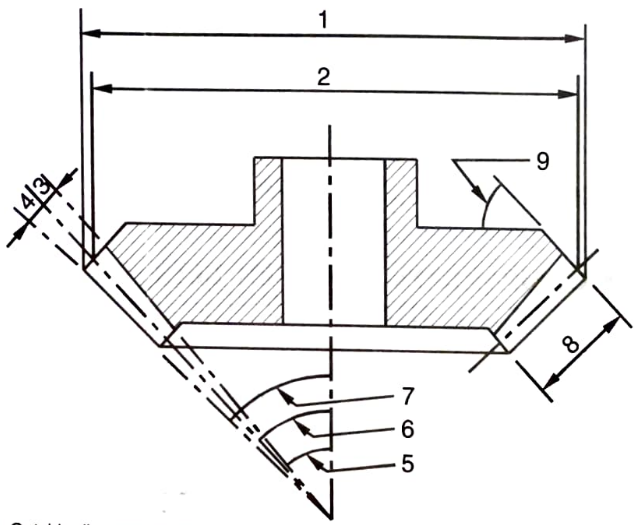
Double Helical Gears (Herringbone Gears) have two sets of spiral teeth cut in the gears. Each set of tooth counteract the thrust set up by the other and thus no thrust is produced. This type of gear is particulary used in speed reducers.

The motion in helical gear is smoother and quieter than spur gears. So they can be used at higher speeds.

7.3 Bevel Gears :

Bevel gears are used to connect two intersecting shafts. Bevel gear is essentially a truncated cone upon the sloping face of which teeth are cut to give positive action. The teeth are tapered in thickness as well as in height. Bevel gears are not interchangeable and must be made in pairs.

When the angle between the intersecting shafts is 90°, the two gears have same numbers of teeth. These bevel gears are known as **miter gears**. For the angle other than 90° of the shafts, they are called **angular bevel gears**.



1. Outside diameter 2. Pitch diameter 3. Dedendum (large end) 4. Addendum (large end) 5. Root ange or Cutting angle 6. Pitch angle 7. Tip angle or Face angle 8. Face width 9. Back angle

Fig. 12.15 Bevel gear

.7.4 Worm Gears :

Worm gears are actually a special case of spiral or helical gears where in the shafts do not intersect and make 90° angle between them. This type of gear can give very large speed reduction in a compact space. So it is widely used in machine tools like lathe drill, milling etc. to get large velocity ratio.

The teeth of the worm are similar to threads on a screw. The velocity ratio in worm gearing depend upon the ratio of number of teeth on the worm gear to number of threads on worm. Generally the helix angle of the worm is so small that the gear can not turn the worm. This self–locking feature of this mechanism is used to advantage in case of worm-gear drives for hoisting mechanisms.

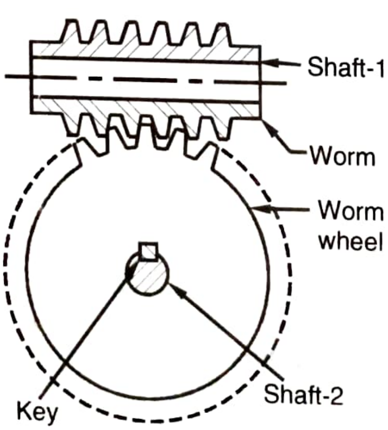


Fig. 12.16 Worm gear

12.7.5 Rack and Pinion :

In this mechanism, the smaller gear is known as pinion and the rack has a series of teeth on a straight line. The rack can be considered a spur gear of infinite radius. This mechanism transforms the circular motion of pinion to rectilinear motion of rack and vice–versa. Machine tools like lathe, drill, planner etc. are fitted with rack and pinion mechanism to convert rotary motion to rectilinear motion.

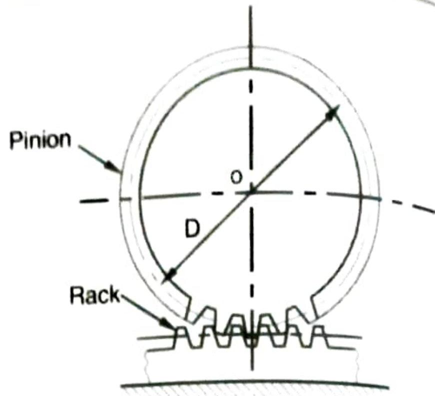


Fig. 12.17 Rack and pinion

12.7.6 Power Transmitted by Gearing :

If losses due to friction are neglected, the power output at the driven shaft is equal to power input at driving shaft.

Let, F = driving (tangential) force at pitch line (in Newton)

D_p = diameter of pitch circle (in meters)

V = velocity at pitch line (in m/s)

N = speed of gear (r.p.m.)

The power transmitted (in Watt)

= effort applied to the driver × velocity

$= F \times V$

$$= \frac{F \times \pi D_p N}{60}$$

or $$P = \frac{F \times \pi D_p N}{60000} \text{ (in kW)} \quad (12.7)$$

12.8 COMPARISON BETWEEN BELT, CHAIN AND GEAR DRIVE :

Belt Drive	Chain Drive	Gear Drive
1. Power transmission takes place by means of frictional resistance, so slip is always present. The efficiency of drive is low.	1. Power transmission take place by progressive engagement of chain link and sprocket teeth. The efficiency of drive is 98 to 99% under ideal conditions.	1. Power transmission is by means of progressive engagement of teeth. So, velocity ratio is almost perfectly maintained.
2. Alignment of driving and driven shaft is not very critical.	2. Alignment of driving and driven shaft is very much necessary, but not as critical as gear drive.	2. Driving and driven members should be aligned precisely.
3. It allows considerable flexibility to designer in location of driving and driven member.	3. Its design is more complicated than belt drive.	3. It allows very less flexibility for the same.
4. It can be used for large centre distances in location of driving and driven member.	4. The centre distance can be as large as 8 m.	4. It is used for shorter centre distances only.
5. It is simple in construction and cost is less.	5. It is simple in construction and cost is somewhere between belt and gear drive.	5. Its cost is high because manufacturing of gears is complex.
6. Operation is quieter. It can absorb shock loads and damp out vibration on account of longer lengths and elastic properties.	6. Its operation is noisy; more so when the chain joints wear out with time.	6. Due to error in manufacturing, drive may become noisy; accompanied by vibration at high speeds.
7. It can be used for lighter loads only.	7. It is used for intermediate loads.	7. It can be used for wide range of transmitted power, from one tenth of a kW to tens of thousands of a kW.

8. Service life is short.	8. Service life is short. Requires more maintenance, repairs and service.	8. If lubricated and operated properly, they have very long service life.
9. Failure of belt does not cause further damage to machine.	9. Failure of chain does not cause further damage to machine.	9. Failure of gear may cause severe breakdown of machine.
10. It is used as first drive in transmission.	10. Used in agricultural machinery, bicycles, motor cycles, conveyers etc.	10. Used in machine tools, gear boxes etc.

EXERCISES

1. Differentiate between individual drive and group drive.
2. What are the factors affecting the selection of drives. What are the different types of mechanical drives ?
3. What are main elements of power transmission ? Mention them.
4. Write a short note on : Types of belt drive
5. With a neat sketch describe open belt and cross belt drive.
6. Draw neat figures of any four types of belt drives.
7. Explain with a neat sketch the working of fast and loose pulley.
8. State the different types of pulleys used in power transmission and define velocity ratio of pulleys.
9. What is rider pully ? How does it work ?
10. Explain different parts of a pulley with a neat sketch.
11. Write advantage of chain drive over belt drive. Draw neat sketches of simple and compound gear train.
12. State the (i) applications (ii) advantages and (iii) disadvantages of
    (a) Rope drive (b) Chain drive (c) Gear drive.
13. Explain with neat sketch : simple and compound gear trains.
14. Describe any three types of gears in short.
15. Define following for gears :
    (i) Clearance (ii) Pitch circle diameter (iii) Module
16. State the application of following gears :
    (i) Helical gear (ii) Worm and Worm gear (iii) Rack and pinion.

OBJECTIVE TYPE QUESTIONS

1. Drives are used instead of coupling.
   (a) due to different speeds of prime mover and machine (b) to facilitate group drive
   (c) due to safety, convenience and maintenance (d) all of the above
2. Shaft is subject to
   (a) bending load only (b) torsional loading only
   (c) both bending and torsional loading (d) neither bending nor torsional loading
3. Axle is subject to
   (a) bending load only (b) torsional loading only
   (c) both bending and torsional loading (d) neither bending nor torsional loading
4. When two shafts are to be rotated in opposite direction _____ drive is used.
   (a) open belt (b) crossed belt (c) stepped pulley (d) Fast and loose pulley
5. When shafts are at right angle _____ drive is used.
   (a) open belt (b) twist belt (c) quarter twist (d) stepped pulley
6. When driving shaft rotate continuously but driven shaft operates intermittently _____ drive is used.
   (a) open belt (b) quarter twist (c) stepped pulley (d) fast and loose pulley
7. When several shafts are driven from one central shaft _____ drive is used.
   (a) stepped pulley (b) fast and loose pulley (c) compound drive (d) twist belt
8. To transmit power through long distances _____ belt is used.
   (a) flat (b) V (c) timing (d) b or c

9. To transmit power from electric motor to reciprocating compressor of small and medium capacity ______ belt is used
(a) flat (b) V (c) timing (d) none of the above
10. Which type of belt has highest transmission efficiency?
(a) flat (b) V (c) timing (d) (a) and (b) both
11. Speed of machine spindle can be varied in stepped using ______.
(a) solid pulley (b) split pulley (c) speed cones (d) guide pulley
12. Jockey pulley is used to
(a) increase arc of contact (b) produce more tension in belt
(c) (a) and (b) both (d) none of above
13. Chain drive is used for ______ speed services.
(a) low (b) low and medium (c) medium (d) high
14. Friction drives are used for ______ load transmission.
(a) light (b) light and medium (c) medium (d) heavy
15. Spur gear have teeth ______ to the axes of the gears. **(Dec. 2015, Summer 2018)**
(a) inclined (b) perpendicular (c) parallel (d) any of the above
16. Helical gear have teeth ______ to the axes of the gears.
(a) inclined (b) perpendicular (c) parallel (d) any of the above
17. Bevel gears are used to connect ______ shafts.
(a) parallel (b) inclined (c) intersecting (d) any of the above
18. Which one of the following gear has self-locking feature?
(a) bevel gear (b) spur gear (c) Helical gear (d) Worm gear
19. ______ can be used to convert rectilinear motion in circular motion.
(a) Rock and Pinion (b) Worm gear (c) bevel gear (d) helical gear
20. Function of idler gear is to obtain ______ direction of rotation for driver and follower.
(a) same (b) opposite (c) any of (a) or (b) (d) none of above
21. Idler ______ velocity ratio.
(a) increase (b) decreases (c) does not affect (d) (a) or (b)
22. To obtain ______ velocity ratio, compound gear train is used.
(a) lower (b) higher (c) same (d) none of the above
23. Belt drive provide ______ flexibility compared to gear drive.
(a) more (b) less (c) same (d) can't say
24. When driving and driven shaft are at comparatively larger distance apart, the type of drive suitable is **(June 2015)**
(a) Gear drive (b) Belt drive (c) Friction drive (d) Chain drive
25. In a simple gear train having two gears , if driving gear rotates in clockwise direction then driven gear rotates in **(June 2015)**
(a) Clockwise direction (b) Anti clockwise direction
(c) Depend on size of gear (d) depend on no. of teeth
26. Belt drive provides ______ flexibility compared to gear drive.
(a) more (b) less (c) same (d) can't say
27. An open belt drive is used when **(Winter 2016)**
(a) shafts are arranged parallel and rotate in the opposite directions
(b) shafts are arranged parallel and rotate in the same directions
(c) shafts are arranged at right angles and rotate in one definite direction
(d) driven shaft is to be started or stopped whenever desired without interfering with the driving shaft
28. The size of gear is specified by **(Winter 2017)**
(a) number of teeth (b) pitch circle diameter (c) pressure angle (d) none of above
29. Double helical gears are also known as ______ gears.
(a) Bevel gears (b) Worm gears (c) Harringbone gears (d) None of above

: ANSWERS :

1. (d)	2. (c)	3. (a)	4. (b)	5. (c)	6. (d)	7. (c)	8. (a)	9. (b)	10. (c)
11. (c)	12. (c)	13. (b)	14. (a)	15. (c)	16. (a)	17. (c)	18. (d)	19. (a)	20. (a)
21. (c)	22. (b)	23. (a)	24. (d)	25. (b)	26. (a)	27. (b)	28. (b)	29. (c)	

❖ ❖ ❖

13

ENGINEERING MATERIALS

To cater various needs of engineering, for different assignments, often processes are done on the materials. Such materials are called engineering materials. Success of engineering projects greatly depend on proper selection of engineering materials for various components/equipments.

1 CLASSIFICATION OF ENGINEERING MATERIALS :

Engineering Materials are classified in two categories (a) Metals and (b) Non–metals.

(a) Metals : A metal is defined as a chemical element that is hard, malleable, heavy, ductile, tenacious and is good conductor of heat and electricity. Iron, copper, aluminium, gold, silver, nickel, tin, zinc, lead etc are some of the important metals.

Metals can be further classified as ferrous metals and non–ferrous metals. Steel, cast iron, wrought iron are some of the ferrous metals while copper, aluminium, zinc, lead, tin etc. are non–ferrous metals.

(b) Non–metals : Materials such as timber, plastic, glass, are considered as non–metals.

Sometimes, available pure metals do not possess all the required properties for certain application. Then 'alloy' is obtained by mixing or melting together two or more metals. Thus alloy is a combination of elements which has properties of metal.

2 PROPERTIES OF METALS AND ALLOYS :

Some of the important physical, mechanical, chemical, electrical and other properties of metals and alloys are now described.

2.1 Physical Properties

Properties of the material which describes it in absence of external forces are called physical properties. Colour, density, melting point, lustre etc. are physical properties.

Colour : Metals have specific colours which differentiate them from one another. Gold and brass are yellow in colour. Copper is reddish–brown. Aluminium, Mercury, Tin, Nickel, Silver are white in colour. Alloying elements may change colour of base material.

Density : Mass per unit volume is called density of the materials. The metals which have higher mass per unit volume are generally referred as heavier metals. Since density of copper is higher than aluminium, comparatively copper is said to be heavier than aluminium.

Melting point : Melting point is an important property when metals are subject to high temperatures. Depending upon the requirements metal with suitable melting point is to be used. For example in boiler for fusible plug low melting point metal like lead is used. While fire tubes or water tubes are made from metals which can withstand high temperatures like steel.

Lustre : It is ability of metallic surface to reflect light.

13.2.2 Mechanical Properties :

Properties of the material which describes it under action of external forces are called mechanical properties. These properties are related to the strength of the metals. Strength, Elasticity, Ductility, Plasticity, Malleability, Toughness, Stiffness, Brittleness, Hardness, Fatigue etc. are some of the important mechanical properties of metals.

The knowledge of mechanical properties of material is essential for manufacturing any product, as every material undergoes external forces during the process of manufacturing. They also determine service life of the product when it is subjected to the work.

The mechanical properties can be determined experimentally in the laboratory. Before starting with various mechanical properties we will shortly recall the concepts of stress and strain.

Stress : It is the internal resistance set up in a material against deformation due to application of external force.

$$\text{Stress } (\sigma) = \frac{\text{Load (P)}}{\text{Area (A)}}$$

Strain : It is the change in unit length of the material due to application of external force.

$$\text{Strain } (\varepsilon) = \frac{\text{Change in length } (\Delta l)}{\text{Original length } (l)}$$

Strength : Ability of a metal to withstand external forces is measured as strength.

Elasticity : It is a property by virtue of which metal regains its original size and shape after removal of external load. It is measure of resistance to permanent deformation. Material possessing this property is known as elastic material. According to Hooke's law within elastic limit, stress are proportional to strain.

$$\sigma \propto \varepsilon \; ; \qquad \sigma = E\varepsilon$$

Here, E is constant of proportionality, known as Young's modulus or modulus of elasticity.

Ductility : It is a property by virtue of which metal can ungergo considerable plastic deformation before fracture. The property is very important for the metals which are used for drawing metals in to wires. Iron, Copper, Aluminium, Nickel, Zinc, Tin and Lead are ductile metals. Ductility can be measured by fixing a measured specimen in tensile testing machine, applying load till it breaks and measuring the length/area after failure.

Plasticity : It is a property by virtue of which metal can be deformed in to desired shape. If the applied load is beyond the elastic limit, metal can not regain its original shape and size and permanent deformation will occur. The state of the metal is called plastic state. The property allows to shape metals in solid state.

Malleability : It is a property by virtue of which metal can be hammered or rolled in to thin sheets without rupture. Gold, Silver, Aluminium, Copper, Tin, Lead, Zinc, Nickel, and Iron are malleable metals.

Toughness : It is a property by virtue of which metal is able to withstand torsion or bending without fracture. If a metal has good ductility and high elastic limit, the metal will be tough. Toughness of a material decreases with increases in temperature. It is an important property in materials used for gears, chains, crane hooks, freight car couplings, etc. vibrating parts of machine.

Stiffness : It is resistance offered by the material to deformation below the elastic limit. The slope of stress-strain curve below elastic limit gives indication of the stiffness of the metal.

Brittleness : It is a property of the metal which makes is to crack and break under sudden load. A brittle metal possesses lesser toughness and lacks ductility. Brittleness and ductility are opposite properties. Cast iron is an example of brittle metal.

Hardness : It is a measure of resistance offered by a metal to surface penetration by other metals/materials.

Fatigue : It is a resistance to failure offered by the material under repeated application and removal of the load.

Creep : It is gradual plastic flow (permanent elongation) of a metal induced by combination of steady stress and high temperature.

Impact strength : It is capacity of material to resist or absorb shock energy before it gets fracture. Compared to brittle material, ductile material posses higher impact strength.

Resilience : The capacity of materials to absorb energy when tensile or compressive load is applied upto elastic limit. On removal of the load, the material gives off the stored energy. It is capacity to resist shock and impact loads. The property is essential for spring materials.

.2.2 Thermal Properties

Thermal properties indicate the response of a material to application of heat.

Specific heat : The amount of heat required to raise temperature of unit mass of a substance by one degree at constant pressure (c_p) or constant volume (c_v) is termed as specific heat. The unit of specific heat is kJ/kg K. Mathematically specific heat,

$$c = \frac{Q}{m \cdot dt}$$

where, c = specific heat of the solid,

m = mass of the solid,

Q = heat input

dt = change in the temperature.

Specific heat is an important property for processes such as casting and heat treatment.

Heat capacity : The amount of heat required to produce a unit temperature rise is termed as heat capacity of the material. The unit of heat capacity is kJ/K.

$$C = \frac{Q}{dt}$$

where, Q is the energy required to produce a temperature change of dt.

Thermal expansion : Almost all materials expand on heating and contract on cooling. This phenomenon is called thermal expansion. The rate of change in unit length of material with unit rise of temperature is termed as coefficient of thermal expansion(α).

$$\alpha = \frac{1}{l}\frac{dl}{dt}$$

where, dl = change in length

dt = change in the temperature, and

l = length of the material.

Thermal conductivity : The ease with which heat flows through the material is known as thermal conductivity. It represents the amount of heat flowing per unit time through unit cross sectional area of the element when temperature difference between two end surfaces of the element is unity.

Thermal conductivity decreases in following order

Metals → Non metals → Liquids → Gases

Metals → Alloys → Semiconductors → Dielectrics

The heat is conducted both by lattice vibration and transport of free electrons.

13.2.3 Electrical Properties

Properties which indicate response of materials to flow of electric current are known as electrical properties.

Resistivity : The property of the material to opposes the flow of current through it is defined as resistivity of material. Unit of resistivity is ohm–metre. Resistivity of a material is given by the equation.

$$\varrho = R \frac{A}{l}$$

where, R = Resistance in ohm

l = Length, m

A = Area, m^2

ϱ = Resistivity, ohm-m

A high electrical resistance are required for heating elements of electrical appliances, while low electrical resistance is recommended for long distance transmission lines. The materials like rubber, bakelite, mica etc. process high resistivity.

Conductivity : It may be defined as the flow of electric charge in the material. In other terms it is the reciprocal of resistivity. The unit of conductivity is $ohm^{-1} \cdot m^{-1}$ or mho/m.

$$\sigma = \frac{1}{\varrho} = \frac{l}{RA}$$

The metals like silver, copper, aluminium etc. have high conductivity.

13.3 METAL :

The development and advancement of societies have been intimately tied with the developments in the field of materials. Metals have played a key role in transforming the life of human beings. Metals are the most common material and have largest share in engineering applications. Right from needles to aeroplanes, and chips to missiles to satellites, everywhere metals have marked their presence.

Metals are grouped into two classes – Ferrous and Nonferrous. Ferrous materials include cast irons and steels. Nonferrous materials have a long list of aluminium, copper, tin, lead, etc. and their alloys. Cast irons and steels account for about 90% of the world production of metals, which is mainly because of their combination of good strength, ductility, hardness and toughness at relatively low cost.

Ferrous alloys are produced in larger quantities than any other metal type. They are especially important as fabricating and construction materials. The reasons behind their wide usage are :

(1) They are extremely versatile and by giving proper treatment a wide range of physical and mechanical properties can be developed.

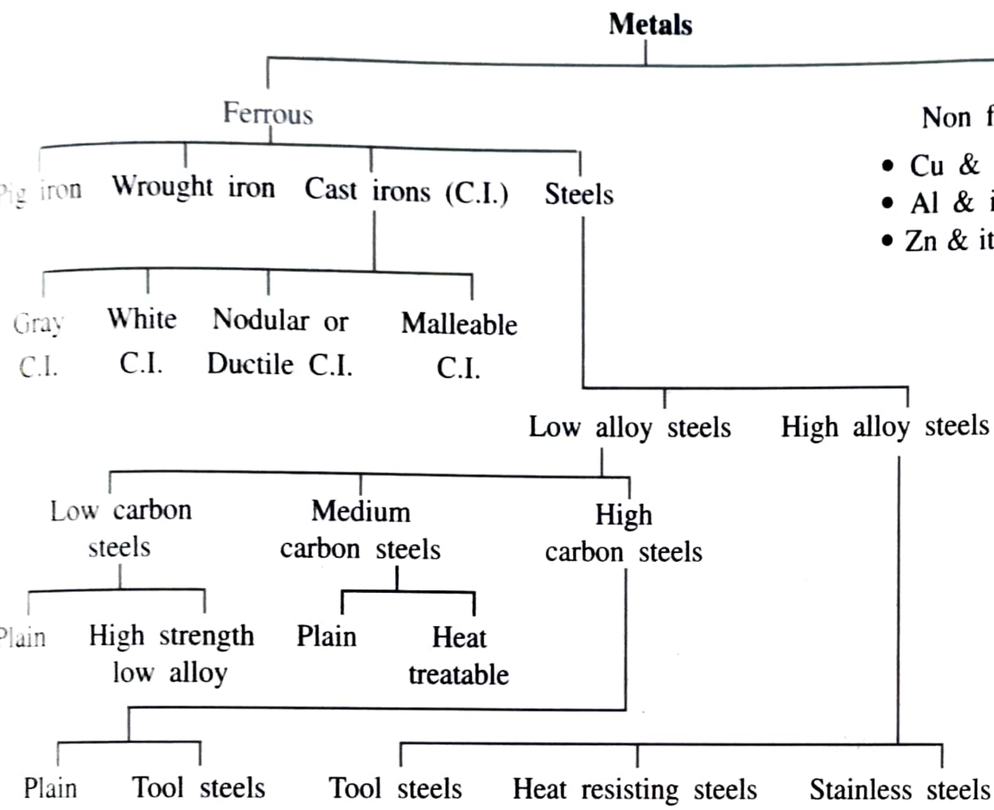
(2) Their raw-materials are abundantly available within the earth crust.

(3) Iron and steels can be produced economically.

The main disadvantage of many ferrous alloys is their susceptibility to corrosion.

13.4 CLASSIFICATION OF METALS :

Metals can be classified as follows.



13.5 PIG IRON :

The metallic products from a blast furnace is known as pig iron or molten metal. It is the basic raw material for all ferrous products like cast irons, wrought irons, and steels. The raw materials required for production of pig iron are iron ore, coking coal, and flux.

Pig iron contains carbon, silicon, phosphorous, manganese and sulphur as the main impurities. The total amount of these impurities could be upto 8% by weight.

Composition :

Carbon	3.5 – 4.2 %
Silicon	0.5 – 2.5 %
Manganese	0.5 – 1.5 %
Phosphorous	0.04 – 1.0 %
Sulphur	0.04 – 0.10 %
Iron	Remainder

13.6 WROUGHT IRON :

It is the most refined form of iron with very small amount of slag.

Composition :

Carbon	0.02 – 0.03 %
Silicon	0.10 % maximum
Manganese	0.02 % maximum
Sulphur	0.01 – 0.02 %
Phosphorous	0.05 – 0.20 %
Slag	0.05 – 1.50 %
Iron	Remainder

The wrought iron has fibrous structure which improves strength, fatigue resistance and corrosion resistance of iron. It is highly malleable and ductile and was used for making hooks and chains.

Mechanical properties :

Tensile strength	3400 – 3500 kg/cm^2
% Elongation	20 – 30 %
% Reduction of area	35 – 45 %

At working temperature, it becomes very soft to take desired shape under hammer, press etc. It can neither be hardened nor tempered like steel. It can be joined by welding.

Applications : Hooks, chains, blast plates, drainage lines, sludge tanks, condenser tubes, heat exchangers, acid and alkali process lines, railway coupling, exhaust pipes, underground services etc.

13.7 CAST IRON

Cast iron is an alloy of iron and carbon in which carbon content varies between 2.0 to 6.67%. However, most cast irons contain 2 to 4% carbon and 1 to 3% silicon. Sulphur, phosphorous and manganese are other elements present in cast iron.

Cast iron is a brittle material. Because of its poor ductility and malleability, it can not be forged, rolled, extruded, drawn, or pressed at room temperature. Most of the cast irons are not malleable at any temperature. Because of its relatively lower melting point, cast iron can be easily melted and casted into the required final shape and size. Since casting is the only suitable process applied to these alloys, they are known as cast irons.

Cast irons have following advantages over steel and other materials.

(1) They have superior casting properties such as high fluidity, moderate shrinkage, casting soundness, higher yield and ease of production.

(2) They have very good of strength and hardness.

(3) They possess very high compressive strength, about 3 to 4 times that of their tensile strength.

(4) They are easy to machine.

(5) Proper alloying can develop good wear, abrasion, and corrosion resistance cast irons.

(6) They are least expensive because the raw materials used are relatively cheaper.

But cast iron have relatively poor impact resistance and ductility.

Cast irons are widely used due to their comparatively low cost and versatile engineering properties. Carbon in the cast iron exists in the form of either cementite or graphite. Cementite imparts a specific light colour lustre to the cast iron surface while graphite imparts gray colour to the surface.

13.7.1 Gray Cast Iron :

In gray cast iron, carbon is present in the form of graphite flakes. Because of the presence of these graphite flakes, a fractured surface appears gray and hence it is called gray cast iron. The presence of free graphites can be seen while filing or machining of gray cast iron. As it makes hands black or gray.

Gray cast iron is a very important engineering material because of its low cost.

Composition :

Carbon	2.5 – 3.8 %
Silicon	1.5 – 3.0 %
Manganese	0.5 – 1.0 %
Sulphur	0.06 – 0.25 %
Phosphorous	0.10 – 0.90 %
Iron	Remainder

In addition to carbon, silicon has a great effect on its structure and properties.

Important features of gray cast iron are as under :

(1) It is comparatively weak and brittle in tension because of the presence of graphite.

(2) Its strength and hardness are much higher under compressive loads. Its compressive strength is 3 to 5 times more than that of tensile strength.

(3) It has excellent vibration damping capacity.

(4) It has high resistance to wear.

(5) It has good corrosion resistance.

(6) It has excellent machinability.

Drawbacks of gray cast iron :

It has low impact resistance and poor ductility.

Mechanical properties :

Ultimate tensile strength	120 – 350 N/mm^2
Compressive strength	550 – 750 N/mm^2
Hardness	150 – 300 BHN
Elongation	less than 1 %

Applications : It has wide range of engineering applications such as machine bases, engine frames, drainage pipes, man-holes, clutch plates, brake drums, pump housings, cylinders and pistons of I.C. engines, flywheels, elevator counter weights, industrial furnace counter weights, gear housing etc.

13.7.2 White Cast Iron :

In white cast iron, carbon is present in the form of iron carbides. The appearance of surface is white because of the absence of graphite and, therefore it is called white cast iron.

Composition :

Carbon	2.0 – 3.5 %
Silicon	0.5 – 1.2 %
Manganese	0.5 – 1.0 %
Sulphur	0.06 – 0.15 %
Phosphorous	0.06 – 0.20 %
Iron	Remainder

Important feactures of white cast iron are as under :

(1) It is extremely hard and brittle because of the presence of large amount of cementite (Fe_3C).

(2) It has excellent resistance to wear and abrasion.

(3) It is raw material for production of malleable cast iron.

(4) It has very poor machinability, very high hardness and brittleness.

Mechanical properties :

Ultimate tensile strength	150 – 500 N/mm^2
Compressive strength	1400 – 1750 N/mm^2
Hardness	350 – 550 BHN

Applications :

Applications of while cast iron include rolls in rolling mills, road roller surface, wearing plates, grinding balls, pump liners, dies and extrusion nozzles.

13.7.3 Nodular (or Ductile) Cast Iron :

In nodular cast iron, graphite is present in the form of nodules. It is produced by adding 0.03 to 0.06 % of magnesium to the gray cast iron before casting. Magnesium causes the graphite to precipitate in all directions as nodules or spheroids during solidification of the cast iron. Hence, this iron is named as nodular cast iron.

Composition :

Carbon	3.0 – 3.6 %
Silicon	2.0 – 2.5 %
Manganese	0.10 – 1.0%
Sulphur	0.04 % max.
Phosphorous	0.04 % max.
Iron	Remainder

Mechanical properties :

Tensile strength	400 – 700 N/mm²
Yield strength	270 – 390 N/mm²
Hardness	100 – 300 BHN
Elongation	10 – 20 %

Important characteristics :

(1) It has good fluidity, good castability, excellent machinability and good wear resistance.

(2) It possesses high strength, toughness, ductility, hot workability and hardenability comparable to those of steel.

Applications :

Typical applications of nodular cast iron include friction blocks, railway couplings, impellers, conveyor rollers, locomotive wheels, valves, pump and compressor bodies, crankshafts, camshafts, steering knuckles, suspension parts, gears and other automotive & machine components.

13.7.4 Malleable Cast Iron :

Malleable cast iron is produced from white cast iron. It is produced by prolonged heating of white cast iron for several days at high temperature (900 – 950°C) in a neutral atmosphere. The annealing treatment makes the malleable cast iron ductile, shock resistant and machinable.

Composition :

Carbon	2.5 – 3.0 %
Silicon	0.7 – 1.5 %
Manganese	0.3 – 1.0 %
Sulphur	0.12 % maximum
Phosphorous	0.18 % maximum
Iron	Remainder

The lower carbon content increases ductility because this reduces the amount of graphite. The lower silicon content excludes the precipitation of flaky graphite in the structure upon cooling.

Properties :

Through proper control of heat treatment a wide range of physical and mechanical properties such as strength, ductility, machinability, castability and wear resistance can be produced in malleable cast iron.

Tensile strength	250 – 750 N/mm²
Yield strength	150 – 450 N/mm²
Ductility	5 – 20 %
Hardness	80 – 280 BHN

Applications :

(a) Connecting rods, transmission gears, crankshafts, camshafts, axles, gears and differential housing in automobiles.

(b) Pipe fittings, rolls, pumps, nozzles, valves, chains, flanges, farm equipment, rail-road, marine and machinery parts.

(c) Switch gear parts, railway electrification systems and fittings for power transmission & distribution system.

3.7.5 Chilled Cast Iron :

The term chilling refers to rapid cooling. Chilled cast iron is obtained when the casting gets solidified as white cast iron on the surface and gray cast iron at the interior. Therefore, the fractured surface of chilled cast iron shows both white and gray structures. It is also known as mottled cast iron. It is produced by casting the molten metal of suitable composition, against a metal or graphite chiller. Generally, carbon content varies between 3.3 to 3.5 %.

Chilled cast iron possesses high hardness and wear resistance at the surface and low hardness and strength at the core.

Applications :

It is used where high wear resistance is main requirement. Typical applications include grinding balls, extrusion nozzles, grain-mill rolls, jaws for crushing ores or stones, rolls for crushing ores, rail-road-freight-car wheels, hammers etc.

3.8 STEEL :

Steel is an alloy of iron and carbon in which carbon varies from 0.008 to 2 %. Commercial steels always contain some amount of manganese, silicon, sulphur and phosphorous in addition to carbon. Sulphur and phosphorous are very harmful and are treated as undesirable elements. To overcome the undesirable effect of sulphur, manganese is always added in some amount to the steel. Many other elements such as nickel, chromium, vanadium, tungsten, molybdenum, etc. may be present in certain amount in steel depending upon the grade of steel.

Steels may be classified as :

(a) Plain carbon steels, and

(b) Alloy steels.

3.8.1 Plain Carbon Steel :

These steels are relatively low in cost. However, they have some limitations as follows :

(1) Plain carbon steels have low corrosion and oxidation resistance.

(2) Plain carbon steels have poor impact strength at low temperatures.

(3) Plain carbon maintaining uniform properties throughout the cross section is difficult with large thickness.

(4) The strength of plain carbon steels can not be increased beyond 700 MPa without a substantial loss in ductility and impact strength.

(5) Deep hardenable plain carbon steels can not be produced.

Effect of Impurities on Properties of Carbon Steels :

There are four common impurities in plain carbon steel, namely silicon, manganese, sulphur, and phosphorous. Their effects on properties of plain carbon steel is given below :

Carbon : It is responsible for hardness in plain carbon steels. In increases tensile strength, yield strength and hardness but decreases ductility and impact strength. For plain carbon steels having carbon more than 0.25%, the hardness is usually developed by heating and rapid cooling in water or oil.

Silicon : It increases strength, hardness and toughness without loss of ductility. It is a strong deoxidizer and removes dissolved gases and oxides. Its content in steel usually varies from 0.05 to 0.3%.

Manganese : The manganese content in plain carbon steels usually varies from 0.30 to 1.0%. It reduces harmful effect of sulphur i.e. brittleness at high temperature by forming MnS. It increases the hardenability of the steel. It increases yield strength, tensile strength, toughness and ductility.

Sulphur : Sulphur content should not exceed 0.05%. In the absence of manganese, it forms FeS which is a low melting compound and may melt when the steel is heated to high temperature and increases brittleness at high temperature. The problem can be overcome by adding manganese by more than 5 times the weight of sulphur.

Phosphorous : Normally, the phosphorous content in plain carbon steels does not exceed 0.04%. It reduces impact strength at low temperature and increases strength and hardness but greatly reduces the ductility.

Classification of Plain Carbon Steels :

On the basis of carbon content plain carbon steels can be classified as

(a) Low carbon steels (up to 0.25 % carbon),

(b) Medium carbon steels (0.25 – 0.65 % carbon), and

(c) High carbon steels (0.65 – 1.50 % carbon)

(a) Low Carbon Steels :

- Low carbon steels are popularly known as **mild steels**.
- These steels contain carbon upto 0.25 %.
- These steels hold about 90 % share of total plain carbon steel consumption.
- These shows poor response to heat treatment for improving strength and hardness.
- These steels are least expensive to produce.
- The strength of low carbon steels can be improved by cold working.
- They possess good formability and can be easily welded.
- They are relatively soft and weak but have outstanding ductility and toughness.
- They have good machinability.
- Surface hardness and wear resistance can be improved by a surface hardening process called carburizing.

Mechanical properties :

Tensile strength	300 – 450 MPa.
Yield strength	200 – 350 MPa.
Elongation	25 – 40 %

Applications :

(1) Because of excellent formability, these steels are suitable for automobile and refrigerator bodies, tin cans, corrugated sheets, structural shapes (I-beam, H-beam, Angles, channels etc.) and girders.

(2) Ship plates, boiler plates, pipelines, cams, shafts, wheel hubs, nuts and bolts, brake housings and brake pendal levers.

(3) They are also useful for structural and industrial applications.

Drawbacks :

(1) They are not heat treated as their hardenability is too low.

(2) They have poor corrosion resistance.

Medium Carbon Steels :

- Medium carbon steels contain carbon between 0.25 to 0.65 %.
- Their response to heat treatment is better than that of low carbon steels.
- These steels are heat treated to improve their mechanical properties.
- Addition of chromium, nickel and molybdenum improve the ability of these steels to be heat treated

Applications :

Railway wheels and tracks, railway couplings, gears, crankshafts, axles, pinions, cylinders, cylinder liners, cams, hand tools, sockets, levers, tubes for bicycle and automobiles, spindles of machine tools, bolts, rifle barrels, and balls for ball-mill.

(c) High Carbon Steels :

- High carbon steels contain carbon between 0.65 to 1.5 %.
- These steels are hardest and strongest but least ductile among plain carbon steels.
- They are always used in hardened and tempered condition. A hardness of Rockwell 55 to 60 on C-scale can be obtained.
- They possess good wear resistance.
- They have poor fabricability, formability, machinability and weldability.
- Mechinability and formability of high carbon steels be improved by annealing.
- Addition of the alloying elements such as chromium, vanadium, tungsten and molybdenum in high carbon steels make these steels suitable for making tools and dies.

Applications :

Cutting tools, dies, shearing knives, razors, hacksaw blades, springs, gauges, piston rings, chiesels and hand-tools.

13.8.2 Alloy Steels :

When elements other than carbon such as Cr, V, Ni, Ti, Mo, Mn, Si, W etc. are added in sufficient quantities in steels to improve its properties or to develop some specific properties, the elements so added are called alloying elements and the steels thus developed are called alloy steels.

Alloy steels are superior to plain carbon steels and possess the following properties :

(i) High strength, hardness, ductility and toughness at both low and high temperatures

(ii) Better resistance to wear and abrasion

(iii) Better corrosion and oxidation resistance

(iv) Better electrical and magnetic properties

(v) More uniform properties throughout the cross section

However, the alloy steels are costly compared to plain carbon steels.

On the basis of the amount of alloying elements, alloy steels are classified as :

(a) Low alloy steels (upto 5 % alloying elements)

(b) Medium alloy steels (5 to 10 % alloying elements)

(c) High alloy steels (more than 10 % alloying elements)

Some important alloy steels are now be discussed.

(a) Stainless Steels :

Stainless steels are the most popular and widely used alloy steel. They are high alloy steels and have excellent corrosion and oxidation resistance. They do not corrode in usual environment and hence they are called stainless steels. The high corrosion resistance is due to the presence of chromium in steels. In addition to chromium, nickel, molybdenum, copper, aluminium and silicon may be added to stainless steels to improve corrosion resistance and other properties. They also possess good creep strength.

Applications :

Power plants, nuclear plants, chemical and petrochemical industries, food processing units, dairy industries, heat treating furnaces, pulp and paper manufacturing plants, surgical instruments, household utensils, and general engineering applications.

(b) High Speed Steels :

These steels are well suited for manufacturing of cutting tools which can be operated at high speeds. Generally tungsten, molybdenum, chromium and vanadium are used for alloying. Tungsten increases toughness, wear resistance and cutting ability. Chromum increases hardenability and vanadium does the grain refinements. Carbon is responsible for high hardness and wear resistance. Sometimes, cobalt is added in order to enhance cutting ability of the tool.

They cut at twenty times the speed of a plain carbon tool without loosing their sharpness. Materials with poor machinability can be cut successfully with such tools.

The total alloy contents vary from 20 to 40 % in high speed steels. Carbon generally varies from 0.70 to 1.5 %.

High speed steels retain their hardness up to 600°C.

Applications :

High speed cutting tools, heavy-cut tools, milling cutters, deep hole drills, tools for lathe centres, blanking dies, hot forming dies and wearing plates.

(c) Bearing Steels :

They are used for the manufacture of balls, rollers and bearing races, which are subjected to wear, corrosion and fatigue loading. It contains carbon, chromium, silicon and manganese as main alloying elements.

High carbon provides for high hardness and fatigue strength, while chromium increases hardenability and abrasion resistance.

Apart from ball and roller bearings, they are also used for spindles, cold forming rolls and hardened machine parts.

(d) Heat Resisting Steels :

These steels are also known as high temperature steels. Many heating devices require special materials for conversion of electrical energy into heat. Since parts made from these steels are exposed to elevated temperature service conditions, such steels should have good resistance to oxidation/scaling, sufficient strength at high temperature, and good dimensional and structural stability.

Plain carbon steel (upto 300°C), low alloy steel (upto 600°C), stainless steel (upto 750°C), Nichromes, a nickel-chromium alloy (upto 1200°C), are some of the steels used for the purpose.

Applications :

(1) Heating coils in ovens and furnaces,

(2) Components of gas turbines and boilers like steam pipelines, superheaters, steam drum etc.

(3) Components of jet engines and rockets like

13.9 NONFERROUS METALS AND ALLOYS :

Aluminium, copper, lead, tin, magnesium, nickel, zinc and titanium and their alloys are important nonferrous metals and alloys. They do not contain iron as a major element. Nonferrous metals and alloys possess certain favourable properties such as good electrical and thermal conductivity, better corrosion resistance, good ductility, non-toxicity, lightness, and high strength-to-weight ratio. The main drawbacks of nonferrous metals and alloys are their lower hardness and relatively poor strength. Some of the nonferrous metals and their alloys will now be described.

0 COPPER AND ITS ALLOYS

Copper :

It is the most important nonferrous metal. Its melting point is 1083°C and density is 8890 kg/m^3. It forms extremely useful alloys with metals such as Zn, Sn, Be and Ni.

Properties :

(1) Highest electrical and thermal conductivity of all metals except silver.

(2) Good ductility and malleability.

(3) High resistance to various types of corrosion.

(4) Non-magnetic and have reddish-brown colour.

(5) The tensile strength of copper varies between 150 – 170 N/mm^2.

(6) Good machinability and ease of fabrication.

(7) Ability to get alloyed with other metals which improve its properties.

(8) High scrap value.

Applications :

Copper is used in electrical applications, heat conductors, structural purposes, telecommunications and automobiles, railways, current carrying members, components of turbo generators and high speed commutators, plumbing accessories, automobile radiators, pressure vessels, utensils, water heaters, refrigerators, heat exchangers, condenser plates, roofing, tubing etc.

Copper Alloys :

Copper has limited engineering applications because of its poor strength. Alloying elements such as zinc, tin, nickel, aluminium etc. results in increase in strength of copper.

(a) **Brass :** Brass is an alloy of copper and zinc. Addition of zinc improves colour, strength, machinability, hardness etc. Brasses have higher strength but are less expensive than copper.

Applications :

Cartridge casing, automotive radiators, medals, coins, screws, sockets, propeller shafts, piston rods, costume jewellery, musical instruments, utensils etc.

(b) **Bronze :** Bronze is an alloy of copper, tin, aluminium, silicon and nickel. Generally, tin percentage varies from 5 to 25 % and the balance is copper. The tensile strength of bronze increases with increasing tin content. Bronze has higher strength, hardness and better corrosion resistance than brass. But it is costlier than brass. It has good fatigue resistance and good bearing properties.

Applications :

Bronzes can be rolled into wires, rods and sheets because of good ductility and malleability. They are used for bearings, bushes, springs, valve-fittings, propellers, pump castings, gears, cylinder heads, dies, bell-metals, utensils, and electrical contacts.

.11 ALUMINIUM AND ITS ALLOYS :

Aluminium :

Aluminium is at third place among commercially used engineering materials after iron and copper. It has a silver-white appearance. Its melting point is 660°C and density is 2700 kg/m^3.

Properties :

(1) It is lighter than all other engineering materials except magnesium and beryllium.

(2) It possesses good electrical and thermal conductivity.

(3) It has high strength-to-weight ratio.

(4) It is good corrosion resistant due to the formation of a thin film of alumina (Al_2O_3) on the metal surface.

(5) It has high ductility and malleability.

(6) It is non-mangetic.

(7) It has very high reflectivity for heat and radiant energy.

(8) It can be easily casted, rolled, extruded, formed and machined.

(9) It is non-toxic and hence, is suitable for food packaging purpose.

(10) It is readily available and less expensive.

The main drawbackof aluminium is its low hardness and poor strength.

Applications :

(1) It is widely used in electrical applications such as overhead cables, electric wires, windings for motors, generator and power transformers.

(2) It is also used for pistons, oil and fuel pumps, fly wheels, connecting rods, frames, roofs, light fixtures etc.

(3) It is used as airframes, engines, propellers and body parts in aircraft, missile, spacecraft and transportation industries.

(4) It is used for roofing, ventilators, door and window frames, railings, traffic control towers etc.

(5) It is used as an alloying element in other materials such as steels, copper, magnesium and zine alloys.

(6) It is used as cooking utensils, food containers, and silver foil for packing purpose.

(7) It is a good substitute for copper due to its low cost, availability, high strength-to-weight ratio and good thermal & electrical conductivity.

(ii) Aluminium Alloys :

Due to higher strength, aluminium alloys are extensively used in commercial applications. Some of the important aluminium alloys are as follows :

(a) Duralumin :

It contains 94% Al, 4% Cu, and 0.5% each of Mg, Mn, Si and Fe.

It can be casted, forged and stamped. It has high tensile strength and have high electrical conductivity. Its melting point, density and specific heat are 650°C, 2800 kg/m^3 and 214 J/kg K respectively. Its hardness ranges between 60 and 100 BHN.

Application :

(1) Used for tubes, sheets, forgings, rivets, nuts, bolts and similar parts.

(2) Used for making electrical cables.

(3) Used in aircraft and automobile applications.

(4) Used in surgical and orthopedic instruments.

(b) Hinduminium :

It is an alloy of aluminium and copper with small amount of Ni, Mn, Ti, Co, Zr and Sb. It contains about 5% Cu, 1.5% Ni.

It is used in high temperature service applications up to 300°C.

(c) Hindalium :

It is the trade name of the aluminium alloy produced by Hindustan Aluminium Corporation Ltd., Renukoot, Mirzapur (UP). It is an alloy of Al, Mg, Mn, Cr and Si etc.

It is used for anodized utensile. The Hindalium utensils are hard and strong. They can be given fine finish and can be easily cleaned. Due to lower heat capacity, they do not absorb much heat while cooking and hence save fuel. They do not react with food. They have low cost.

13.12 LEAD AND ITS ALLOYS :

(a) Lead :

It is the softest and heaviest among all the common metals.

Properties :

(1) It is very soft, ductile and malleable.
(2) It has melting point of 327°C.
(3) Its density is 11340 kg/m^3.
(4) It has low electrical conductivity and high coefficient of thermal expansion.
(5) It has high corrosion resistance and good lubricating properties.
(6) Its x-rays and γ-rays absorbing power is high.
(7) Lead improves the machinability of brasses, bronzes and steels.

Applications :

(1) It is used in batteries, cables, and flexible sheets & pipes.
(2) It is used for sheathing electric cables.
(3) Lead is used for roof covering, gutters etc. in a form of sheet.
(4) Sheets and pipes made of lead are used in chemical industries because they offer excellent resistance to corrosion by chemicals.
(5) Lead alloys are used in the manufacture of solders, printing metal and bearings.
(6) It is also used as weights and counter balances.
(7) It is as container for radiation source.

(b) Lead Alloys :

Lead-tin alloys (67% Pb, 33% Sn) are widely used for soldering purpose.

Lead-tin-antimony alloys (typically 80% Pb, 10% Sn, and 10% Sb popularly known as white metals) are used for manufacturing of bearings because of good antifriction properties.

13.13 NICKEL AND ITS ALLOYS :

Nickel is an important alloying element that is being largely consumed in the fields of chemical processing, space research and nuclear reactor engineering.

Properties :

(1) It is ductile and malleable metal.
(2) It has silvery-white appearance.
(3) It has good corrosion and oxidation resistance.
(4) It has good electrical conductivity.
(5) It is a valuable alloying constituent in large number of commercial alloys.
(6) It has very good formability.

Applications :

(1) Used for production of stainless steel.
(2) Used in electroplating industry for plating iron and brass as a protective coating.
(3) Used for producing heat resisting alloys namely inconel, nichrome etc. which are used in electric heaters and thermocouples.
(4) Pure nickel is used as a catalyst in many reactions.
(5) It is used as alloying element in producing permanent mangnets (Alnico), which are used in microphones, speakers and motors.
(6) Nickel alloy is used for making measuring instruments as verniers, scales etc. as it possesses very good dimensional stability and low coefficient of thermal expansion.
(7) It is used as crucibles.
(8) It is used in radio and telecommunication as magnetic soft materials.
(9) It is used in chemical processing, space research and nuclear reactor engineering.

Nickel has very good ability to get alloyed with other metals and produces a range of alloys.

13.14 TITANIUM AND ITS ALLOYS :

Titanium is playing an important role in the present age of special alloys.

Properties :

(1) Titanium is soft, ductile and strong material.
(2) It is light weight metal having density 4540 kg/m^3.
(3) Its melting point is 1675°C.
(4) Its strength-to-weight ratio is very high.
(5) It possesses very high corrosion resistance.
(6) It has lower coefficient of thermal expansion than steel.
(7) It has lower thermal conductivity.
(8) Its stiffness is between aluminium and steel.
(9) It is a powerful deoxidizer.
(10) Titanium alloys retain their strength even at higher temperature and show less creep.

Applications :

(1) Titanium is used in the form of sheets, tubes, rods, bars and forgings in chemical industries.
(2) Titanium is widely used as an alloying element in steel industry for deoxidation.
(3) Because of high strength-to-weight ratio, high corrosion resistance and high temperature strength, titanium alloy are widely used in aircraft applications.
(4) Used in high speed rolls, pumpshafts, jet engine components, heat exchangers, steam turbine blades etc.

Some of the important non-metallic material will now be described.

13.15 CERAMIC MATERIALS

Ceramics are inorganic, non-metallic materials. Ceramic materials include glass products, cements and concrete, abrasive, bricks, tiles and drain pipes, electrical insulation materials, refractory linings for furnaces, and sanitary wares.

Properties :

(1) They are hard and brittle
(2) They are strong in compression but weak in tension
(3) They are abrasive resistant, heat resistant, stable and have strength at high temperature
(4) They are poor conductor of heat, and non conductor of electricity
(5) They have good corrosion resistance
(6) Generally they are chemically inert and have poor machinability

13.16 GLASS :

Glass is a ceramic material. It used for building construction, automobiles, aeroplanes, missiles, spacecraft, chemical industry, electrical and electronics industry, laboratory apparatus, optical instruments etc.

Properties :

(1) It has no specific crystalline structure
(2) It has no specific melting point
(3) Glass can be easily shaped
(4) It has very good optical properties
(5) It has good rigidity. hardness and strength
(6) It has excellent corrosion resistance
(7) It is good electrical and thermal insulation
(8) It can be cleaned very easily

(9) Glass is available in nice colours
(10) It is brittle
(11) It is not affected by ordinary chemicals, atmospheric gasses and water
(12) The pieces of glass can be easily fused or welded together

CONCRETE :

Concrete is the most widely used construction material. It is prepared by mixing cement with sand, crushed rock and water. It is a major building material.

Advantages :

The advantages of using concrete over other engineering materials are given below.

(1) The materials required to prepare concrete are relatively inexpansive and readily available.
(2) It can be easily formed into a variety of shapes and sizes.
(3) Concrete posses excellent resistance to water therefore it is used for construction of dams, canals, water pipes, storage tanks etc.
(4) It is free from the corrosion.
(5) It has resistant to fire.
(6) It makes a strong bond with steel, hence steel rods can be integrated in concrete elements.
(7) It is not affected by the attack of insects and fungi.
(8) Its compressive strength is high.
(9) The maintenance cost of concrete structures is very less.
(10) Concrete structures have good appearance.
(11) The production of concrete require considerably less energy input as compare to other engineering materials.

Disadvantages :

(1) Concrete is brittle material having low tensile strength.
(2) It allows seepage of water.
(3) Skilled labour and inspection is required during concrete works.
(4) Initial cost of construction of concrete structures is high.
(5) It is affected by alkalies and sulphates.
(6) It shrinks on setting and hardening.
(7) Concrete construction requires special formworks, till the concrete sets and hardens, hence the construction takes more time.

13.18 PLASTICS :

Plastic is defined as organic materials which can be moulded to different shapes by the application of pressure at moderately high temperature. Plastics are composed of resin, catalyst, accelerator, inhibitors and pigments. Plastic has low density, low mechanical strength, low coefficient of friction, low thermal conductivity and low softening temperature. It can be produced in different colours. It is nonconductor of electricity and has good corrosion resistance. It has high strength to weight ratio and give excellent surface finish. It has high dielectric strength. It is chemically inert. It has good mouldability and good durability. It has almost no absorption of moisture. It can produced transparent with low brittleness compared to glass.

Advantages :

(1) Ease in fabricating a complex part as whole.
(2) Expansive finishing processes are not required.
(3) No lubrication is required due to low coefficient of friction.
(4) Noise of moving parts is less.
(5) Efficiency of a machine may be increased due to reduction of weight of machine part.
(6) Ease in assembling the parts.

13.19 TIMBER :

Timber is obtained from trees. It has been used in construction of buildings, furniture, carts, wheels, instruments, decorative articles etc.

Merits :

The merits of using timber is given below :

(1) It is easily available.

(2) It gives high strength to weight ratio.

(3) Timber pieces can easily cut, planked, sawn and joined by ordinary carpenter tools.

(4) It gives good thermal and electrical insulation.

(5) It has attractive appearance.

(6) Timber articles can be easily repaired and reused.

(7) It can be used to make both loadbearing (e.g. beam, column, floor etc.) and non load bearing (e.g. door, window etc.) members of building.

(9) Timber is suitable to use in hot, cold and earthquake prone areas.

(10) It can be used to manufacture artificial wood which is cheap, durable and attractive in appearance.

(11) It has long life if against rain, moisture and termites.

(12) It can be easily transported.

Demerits :

The demerits of using timber is given below :

(1) Properties of timber changes with change in moisture content.

(2) Strength of the timber varies along and across the fibers.

(3) Strength of timber reduces due to natural defects.

(4) It is available in limited sizes.

(5) It requires proper drying.

(6) It is prone to attacked by fungus and insects.

(7) It is subjected to risk of fire.

(8) If not locally available, it proves to be costly.

EXERCISES

1. Explain classification of various engineering materials.
2. Explain various physical properties of metals.
3. Explain various mechanical properties of metals.
4. Explain various thermal properties of metals.
5. Explain various electrical properties of metals.
6. Give detail classification of metals.
7. Write applications of :

(a) Pig iron (b) Wrought iron (c) Gray cast iron (d) White cast iron

(e) Nodular cast iron (f) Malleable cast iron (g) Chilled cast iron

What is steel? Name various constituents of steel.

Explain the effects of following impurities on properties of carbon steels.

(a) Carbon (b) Silicon (c) Manganise (d) Sulphur (e) Phosphorous

Explain classification of plain carbon steels.
Write applications of low, medium and high carbon steels.
What is alloy steel?
Mention applications of stainless steels, high speed steels, bearing steel and heat resisting steel.
Enlist properties of copper. Also state its applications.
Write short notes on brass and bronze.
Enlist properties of aluminium. Also state its applications.
Write short notes on Duralumin, Hinduminium and Hindalium.
Enlist properties and applications of lead. Also mention uses of its alloys.
Enlist properties and applications of Nickel and Titanium.
Write short notes on :
(a) Ceramic materials (b) Glass (c) Concrete (d) Plastics (e) Timber.

OBJECTIVE TYPE QUESTIONS

Most malleable material is...
(a) tin (b) copper (c) gold (d) silver

Most important property of lead is...
(a) brittleness (b) malleability (c) ductility (d) hardness

Steel containity carbon between 0.15 to 0.30% is called as...
(a) mild steel (b) medium carbon steel (c) high carbon steel (d) non of the above

Material commonly used for machine tool bodies is...
(a) copper (b) mild steel (c) cast iron (d) wrought iron

Crank shaft of motorcar is made of...
(a) silicon steel (b) medium carbon steel (c) high speed steel (d) high carbon steel

Material used for crane hook is...
(a) cast iron (b) mild steel (c) wrought iron (d) aluminium

Material used for automobile radiator is...
(a) copper (b) aluminium (c) lead (d) nickel

Mild steel contains ________% of carbon. **(Winter 2017)**
(a) 0 to 0.5 (b) 0.5 to 1 (c) 1 to 2 (d) 2 to 4

Brass is fundamentally alloy of _________. **(Summer 2018)**
(a) Copper and zinc (b) Copper and nickel
(c) Copper and tin (d) Copper, zinc and molyblednum

: ANSWERS :

1. (c) **2.** (b) **3.** (a) **4.** (c) **5.** (b) **6.** (c) **7.** (a)
8. (a) (correct answer is upto 0.25%) **9.** (a)

❖ ❖ ❖