INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad -500 043

CIVIL ENGINEERING

COURSE LECTURE NOTES

Course Title	**ELEMENT OF MECHANICAL ENGINEERING**
Course Code	**AME551**
Programme	B.Tech
Semester	VI
Course Coordinator	Mr. G.Sarat Raju, Assistant Professor.
Course Faculty	Mr. M. Sunil Kumar, Assistant Professor.
Lecture No	1-60
Topic Covered	All

Course Objectives:

The course should enable the students to:	
I	Familiarize with fundamentals of mechanical systems.
II	Understand and appreciate the significance of mechanical engineering in different fields of engineering.
III	Understanding of application and usage of various engineering materials.

COURSE OUTCOMES (CO's)

CO 1: Understand the laws of thermodynamics and determine thermodynamic properties, gas laws.
CO 2: Visualize the basics of thermodynamics and components of a thermal power plant.
CO 3: Understand the working related to 2S and 4S and injection systems for SI and CI engines.
CO 4: Understand the concepts various metals cutting machines like lathe describe various driving mechanisms of lathe.
CO 5: Identify engineering materials, their properties, manufacturing methods encountered in engineering practice

COURSE LEARNING OUTCOMES(CLOs):

Students who complete the course will have demonstrated the ability to do the following:

CLO Code	At the end of the course, the student will have the ability to:
AME551.01	Understand prime movers and concept of force, pressure, energy, work, power, system, heat, temperature, specific heat capacity.
AME551.02	Explain change of state, path, process, cycle, internal energy, enthalpy, statement of zeroth law and first law.
AME551.03	Understand the application, different types of energy sources.
AME551.04	Knowledge of Gas laws, Boyle's law, Charle's law, gas constant, relation between Cp and Cv, various non-flow processes like constant volume processes, constant pressure process, isothermal process, adiabatic process, poly-tropic process.
AME551.05	Demonstrate knowledge of formation of steam and use of steam table for identifying the various parameters at given conditions.
AME551.06	Derive the efficiency of various heat engines and problem solving.
AME551.07	Knowledge of different types of steam boilers and its mountings.

AME551.08	Explain the working principle of Internal combustion engines classification.
AME551.09	Demonstrate the working of pumps and air compressors.
AME551.10	Explain the refrigeration and air conditioning and their types.
AME551.11	Knowledge of various machining process of lathe, drilling and milling Machine tools
AME551.12	Explain the fundamentals of robotic and automation based on the coordinate systems.
AME551.13	Understand the concepts about flexible automation, NC/CNC machines.
AME551.14	Knowledge of Engineering materials and joining processes.
AME551.15	Understand the applications of ferrous metals, non-ferrous metals, alloys,
AME551.16	Knowledge of Composites and their applications in the aircraft and automobiles.

Syllabus:

UNIT-I	INTRODUCTION TO ENERGY SYSTEMS

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, statement of zeroth law and first law; Energy: Introduction and application, of energy sources like fossil fuels, nuclear fuels, hydels, solar, wind, and bio-fuels, environment issues like global warming and ozone depletion; Properties of gases: Gas laws, Boyle‘s law, Charle‘s law, gas constant, relation between Cp and Cv, various non flow processes like constant volume processes, constant pressure process, isothermal process, adiabatic process, poly-tropic process

UNIT-II	STEAM TURBINES, HYDRAULIC MACHINES

Properties of steam: Steam formation, types of steam enthalpy, specific volume, internal volume, internal energy and dryness fraction of steam, use of steam tables, calorimeters; Heat engine: Heat engine cycle and heat engine, working substances, classification of heat engines, description and thermal efficiency of carnot, Rankine, otto cycle, diesel cycles; Steam boilers: Introduction, cochran, lancashire, babcock, and Wilcox boiler, functioning of different mountings and accessories.

UNIT-III	INTERNAL COMBSUTION ENGINES, REFRIGERATION AND AIR-CONDITIONING

Internal combustion engines: Introduction, classification, engine details, four stroke, two stroke cycle, petrol engine, diesel engine, indicated power, brake power, efficiencies; Pumps: Types, operation of reciprocating. rotary, centrifugal pumps, priming.

Air compressors: Types, operation of reciprocating, rotary air compressors, significance of multi-staging; Refrigeration and air-conditioning: Refrigerant, vapor compression refrigeration system, vapor absorption refrigeration system, domestic refrigerator, window and split air conditioners.

UNIT-IV	MACHINE TOOLS AND AUTOMATION

Machine tools and automation machine tools operation: Turning, facing , knurling, thread cutting, taper turning by swiveling the compound rest, drilling, boring, reaming, tapping, counter sinking, counter boring, plane milling, end milling, slot milling; Robotic and automation: Introduction, classification based on robot configuration, polar, cylindrical, cartesian, coordinate and spherical, application, advantages and advantages; Automation: Definition, types, fixed, programmable and flexible automation, NC/CNC machines, basic elements with simple block diagrams, advantages and disadvantages.

UNIT-V	ENGINEERING MATERIALS, JOINING PROCESS

Engineering materials and joining processes: Types, applications of ferrous metals, non-ferrous metals, alloys; Composites: Introduction, definition, classification and application (Automobile and Air Craft).

Text Books:

1. V. K. Manglik, “Elements of Mechanical Engineering”, Prentice Hall, 1st Edition, 2013.
2. Mikell P. Groover, “Automation, Production Systems and CIM”, Prentice Hall, 4th Edition, 2015.

Reference Books:

1.S. Trymbaka Murthy, "A Text Book of Elements of Mechanical Engineering", University Press, 4th Edition, 2006.

2. K. P. Roy, S. K. Hajra Choudary, Nirjhar Roy, "Element of Mechanical Engineering", Media Promoters & Publishers, 7th Edition, 2012.

3. Pravin Kumar, "Basic Mechanical Engineering", Pearson, 1st Edition, 2013.

UNIT-I
INTRODUCTION TO ENERGY SYSTEMS

Introduction

Prime movers

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

Sources of energy

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

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

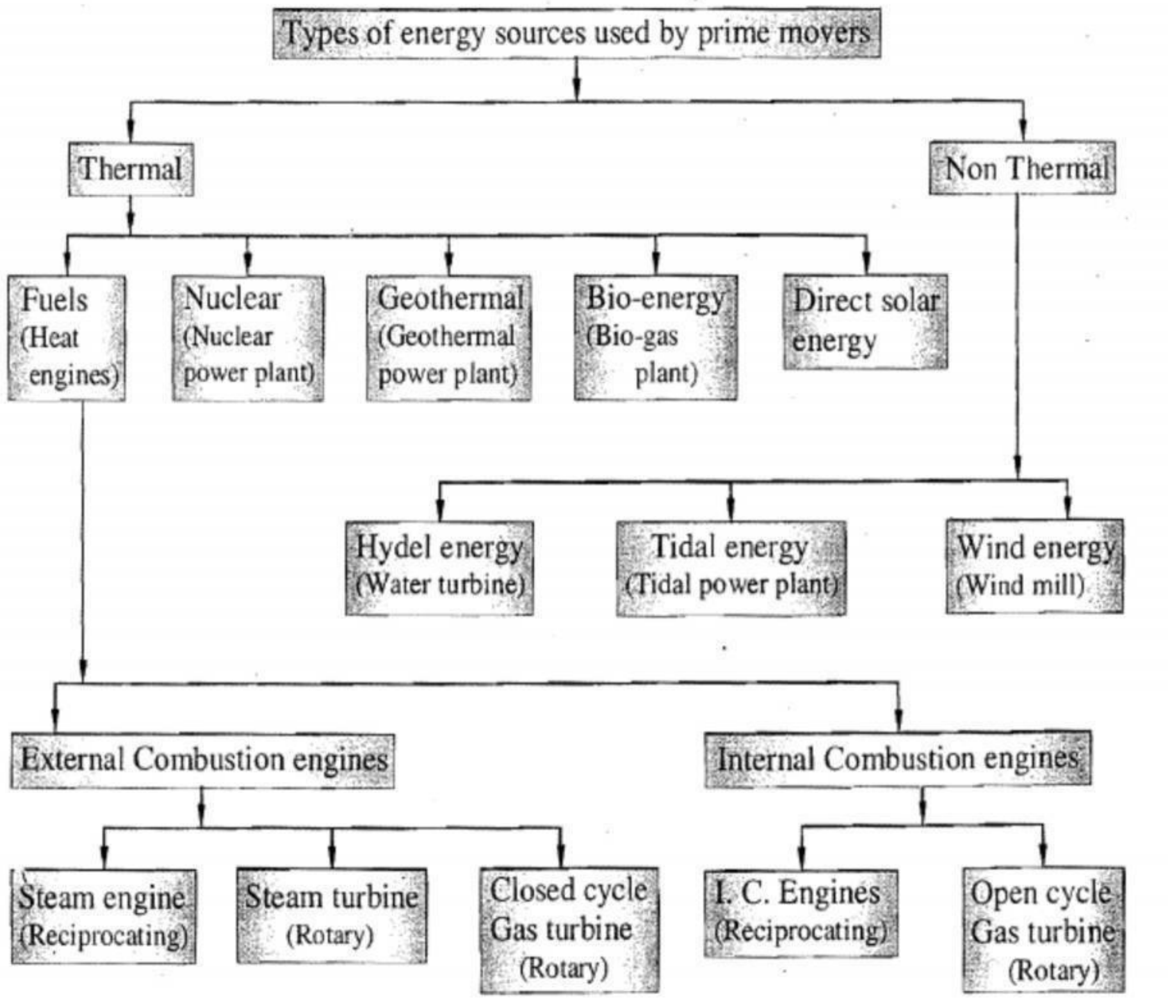
(ii) Flow of river water: This is another useful source of energy. Water stored at high elevation contains potential energy. When water starts flowing, potential energy gets converted to kinetic energy. Hydraulic turbine is a prime mover which converts kinetic energy of flowing water into mechanical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

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

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

Types of prime movers

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



Force and mass

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

As per Newton's second law of motion

Force α acceleration

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

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

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

Weight = Mass x Gravitational acceleration

$$w = m \times g$$

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

Pressure

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

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

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

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

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

Mathematically, Absolute pressure = Atmospheric pressure + Gauge pressure

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

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

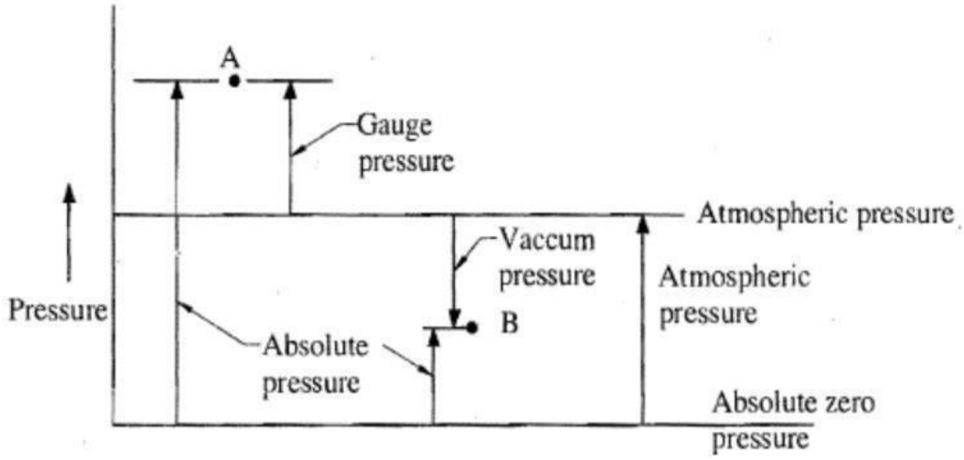


Fig. 1.1. *Relation between different pressures*

Work

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

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

Work output of the system = + W

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

Work output of the system =- W

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

= N × m or joule

Power

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

Mathematically

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

unit Joule/second is called Watt (W)

Watt is very small unit, so recommended larger units are

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

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

Energy

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

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

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

• Forms of energy:-

The different forms of energy are;

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

(3) Chemical energy (4) Electrical energy

(5) Nuclear energy

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

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

. • High and Low Grade energy

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

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

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

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

Types of energy:

Energy may be classified as

(1) Stored energy

(2) Energy in transition

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

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

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

• Types of Mechanical Energy:

There are two types of mechanical energy

(a) Potential energy (b) Kinetic energy

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

Example: Water stored at higher level in a dam

g=Gravitational acceleration = 9.81 m/s2.

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

Heat

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

• Definition of Heat:

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

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

• Positive and negative heat

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

• Comparison of work and Heat

Similarities:

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

Dissimilarities:

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

Temperature

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

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

• Unit of temperature

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

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

• Temperature Scale:

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

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

Units of Heat

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

1 kcal = 4186.8 joules = 4.1868 kilojoules

Specific heat capacity

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

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

Mathematically, the heat transfer rate Q is written as

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

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

• Specific heats in thermodynamics:

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

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

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

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

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

Internal Energy

In non flow processes, fluid does not flow and has no kinetic energy. There is very small amount of change in potential energy because change in centre of gravity is negligible. From the first law of thermodynamics, we can say that the amount of heat transferred to a body is not fully converted tp work. When heat (Q) is supplied to a body, some amount of heat is converted into external work (W) due to expansion of fluid volume and remaining amount of heat causes either to increase its temperature or to change its state. Internal Energy is one type of energy which is neither heat nor work; hence it is stored form of energy. It is denoted by U.

Mathematically,

$Q = W + U$

Where Q is amount of heat, W is work and *U* is internal energy.
The internal energy per unit mass is called specific internal energy. The eq. (1.6) is referred as nonflow energy equation. In other words, for nonflow process

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

Enthalpy

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

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

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

Efficiency

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

Hence,

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

Zeroth Law of Thermodynamics

Zeroth law of thermodynamics states that “the bodies A and B are in thermal equilibrium with a third body C separately then the two bodies A and B shall also be in thermal equilibrium with each other”.

First law of thermodynamics

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

Thermodynamic systems

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

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

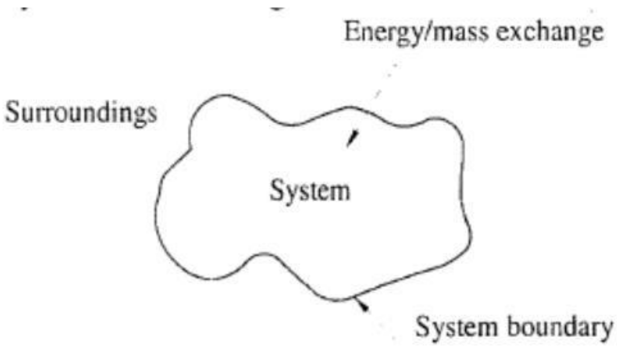


Fig. 1.7 Thermodynamic system

• Types of system: The systems may be classified as

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

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

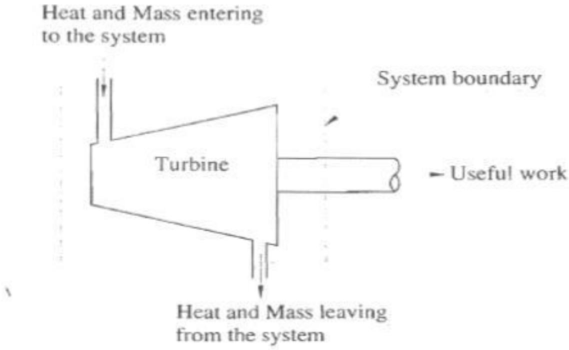


Fig. 1.8 Open system

close system

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

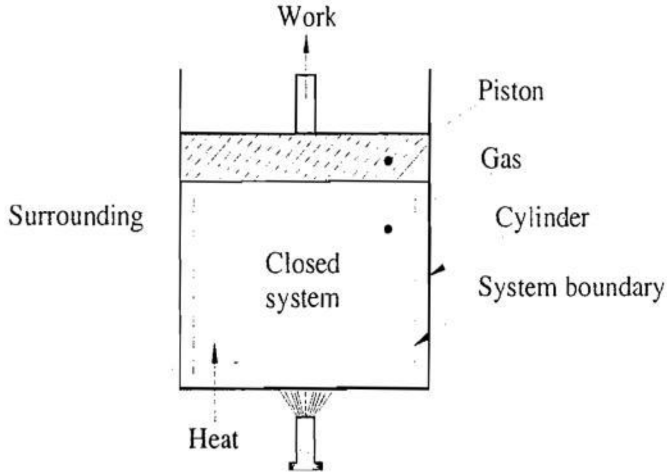


Fig. 1.9 closed system

Isolated Systems:

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

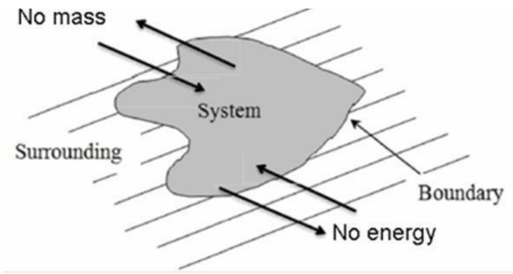


fig. 1.10 Isolated systems

Thermodynamic properties

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

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

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

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

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

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

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

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

ENERGY

Sources of energy

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

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

The various sources of energy can be listed as follows:

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

Energy from fossil fuel

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

Classification of fuel

Fuel can be classified as under

According to nature of their existence

(i) Solid

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

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

(a) Natural: Petroleum

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

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

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

Solid fuels
(A) Natural (primary) solid fuels

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

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

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

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

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

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

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

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

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

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

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

Liquid Fuels

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

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

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

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

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

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

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

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

The advantages and disadvantages of liquid fuels compared to solid fuel

Advantages:

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

Disadvantages:

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

Gaseous fuel

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

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

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

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

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

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

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

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

(7) **Sewer gas**: It is produced from sewage disposal waste in which fermentation and decay occurs. It consists of CH_4 collected at large disposal plants. It is used as fuel for gas engine which is turn drives the plants pumps and agitators.

Advantages and disadvantages of gaseous fuels:

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

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

LPG (Liquefied Petroleum Gas):

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

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

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

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

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

fuel utilization

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

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

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

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

Nuclear Fuel and utilization

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

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

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

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

Hydraulic or Water Energy

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

Solar Energy

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

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

Wind Energy

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

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

Bio-fuel

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

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

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

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

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

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

Advantages of using bio-fuel in vehicles:

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

Increases national energy security.

Limitations of bio-fuels:

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

Some of the bio-fuels are described below:

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

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

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

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

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

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

Hydrogen (H_2) Gas

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

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

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

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

Global warming

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

Cause of global warming

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

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

Mitigation of global warming:

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

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

Ozone Depletion

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

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

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

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

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

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

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

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

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

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

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

Introduction of Energy Conservation Act 2001

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

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

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

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

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

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

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Electricity Act 2003

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

The main/features of the act are as follows:

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

Properties of GasesVapour:

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

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

Perfect Gas:

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

Gas laws:

1. Boyle's law:

This law was discovered by Robert Boyle in 1662 A.D. and it can be defined as follows:
"The volume of a given mass of a perfect gas varies inversely as the absolute pressure when the temperature is constant."

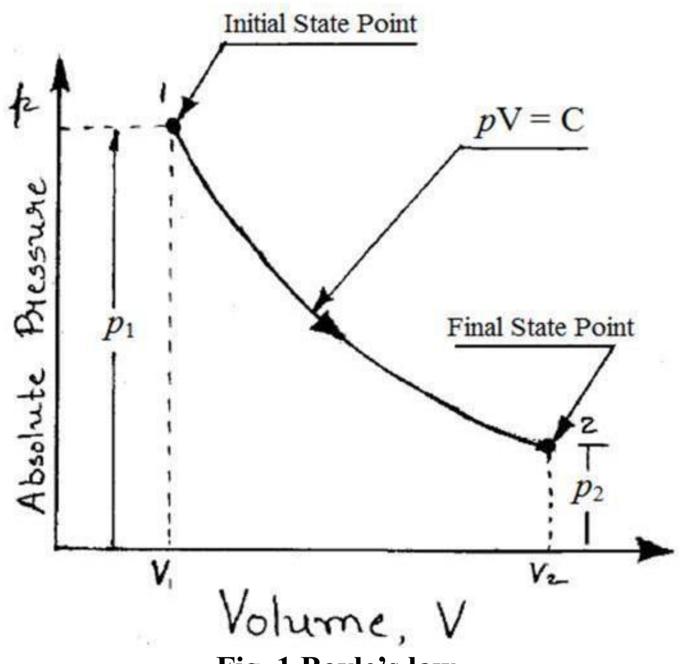
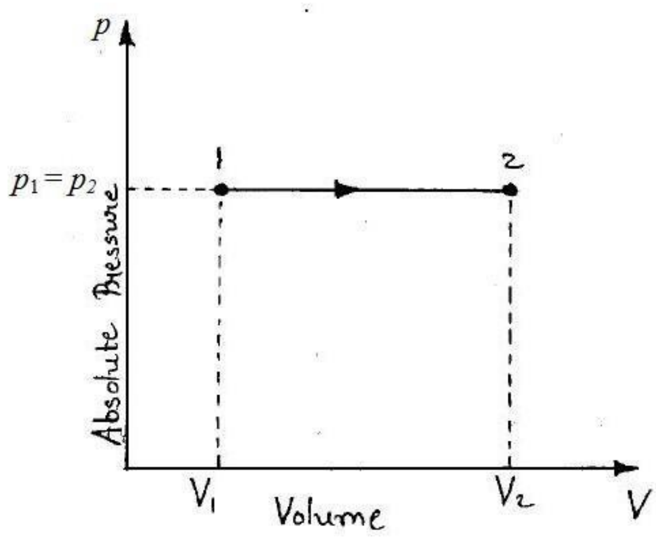


Fig. 1 Boyle's law

Charles law:

This law was discovered by Charles in 1787 A.D. and it can be defined as follows:
"If the pressure of the given mass of a gas is kept constant, then the volume of the gas varies directly in proportion to its absolute temperature."


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

Referring to fig. 2,

Fig. 2 Charles law If V_1 and T_1 = Initial conditions of volume and absolute temperature at point 1

V_2 and T_2 = Final conditions of volume and absolute temperature at point 2

∴ By using above equation

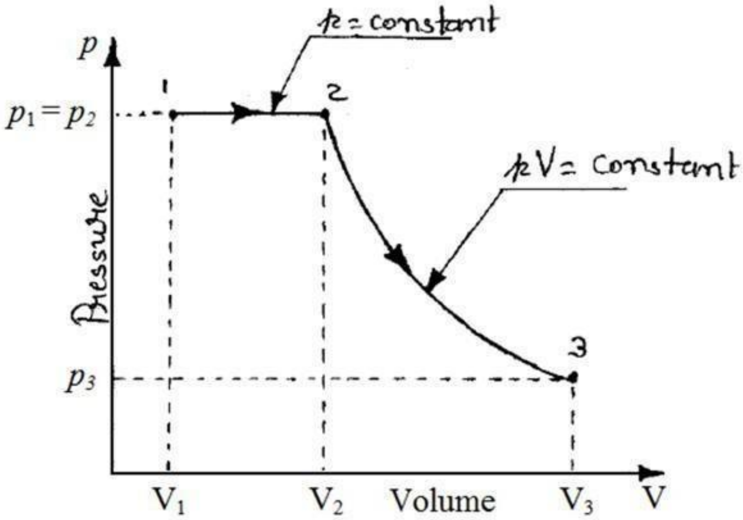


Fig. 3 Combined gas law

Non flow processes:

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

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

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

Constant Volume Process

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

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

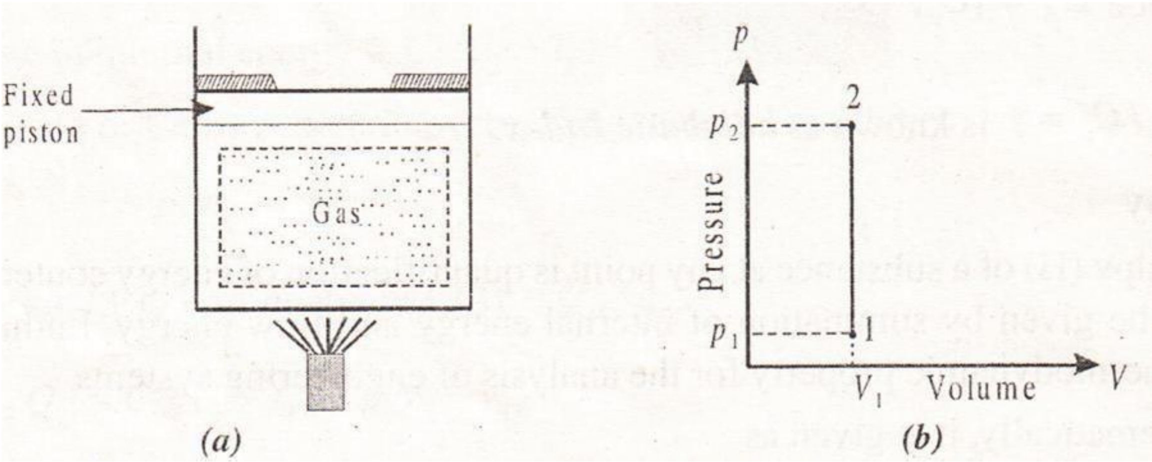


Fig. 3.1 Constant volume process

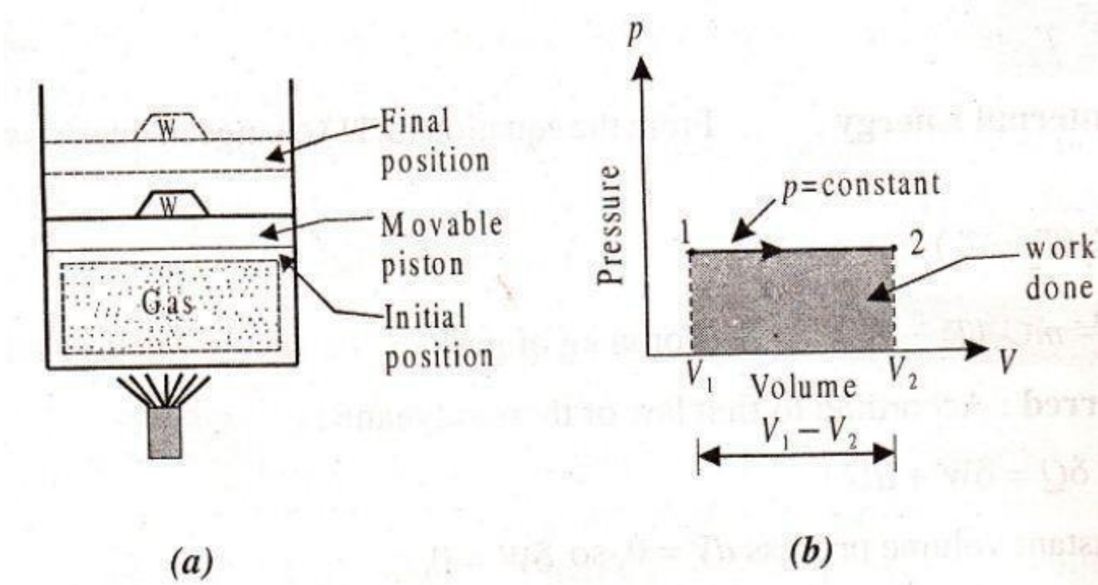


Fig. 3.2 Constant pressure process

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Isothermal Process

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

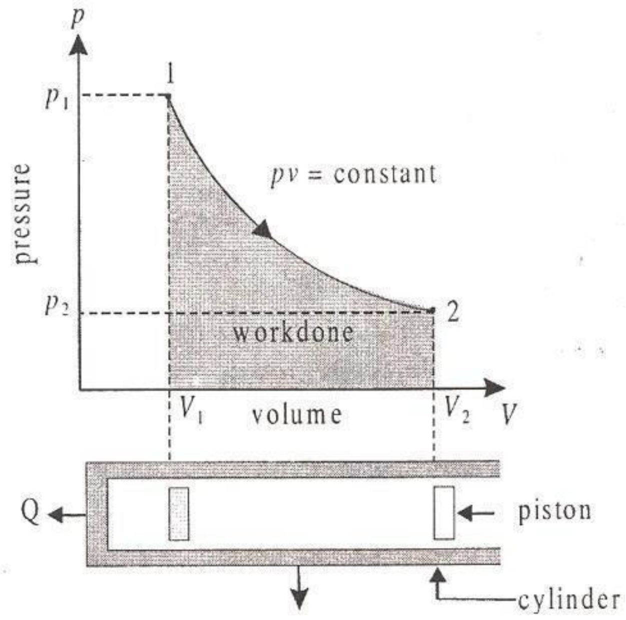


Fig. 3.3 Isothermal process

Adiabatic Process

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

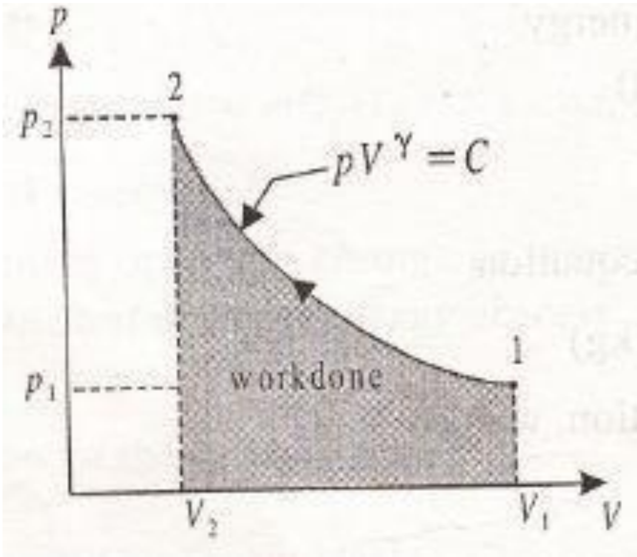


Fig. 3.4 Adiabatic process

Change in internal energy:

According to first law of thermodynamics, $\delta Q = \delta W + \delta U$
But for adiabatic process $\delta Q = 0$. (No heat transfer)
Therefore, $dU = - \delta W$
So, change in internal energy = - work done

For adiabatic process, change in internal energy is numerically equal to work done. When the work is done by the gas, it loses internal energy and gains internal energy when the work is done on the gas.

Heat transferred:

During adiabatic process, heat transfer is zero.
So, $\delta Q = 0$.

Change in enthalpy:

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

Polytropic Process

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

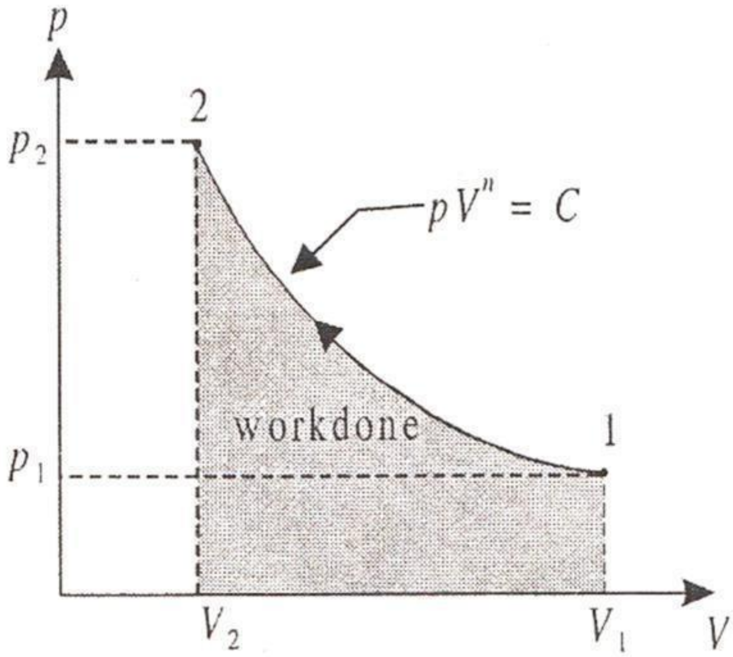


Fig. 3.5 Polytropic process

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

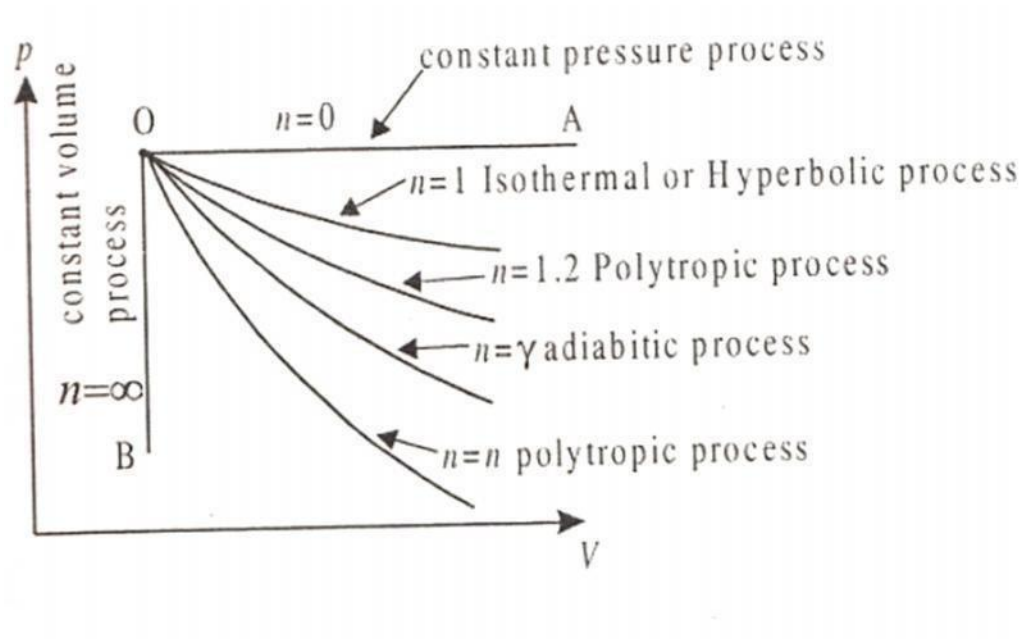


Fig. 3.6 Polytropic processes on *p* – V diagram

UNIT-II
STEAM TURBINES, HYDRAULIC MACHINES

Properties of Steam

Difference between Steam and Gas:

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

Steam Formation:

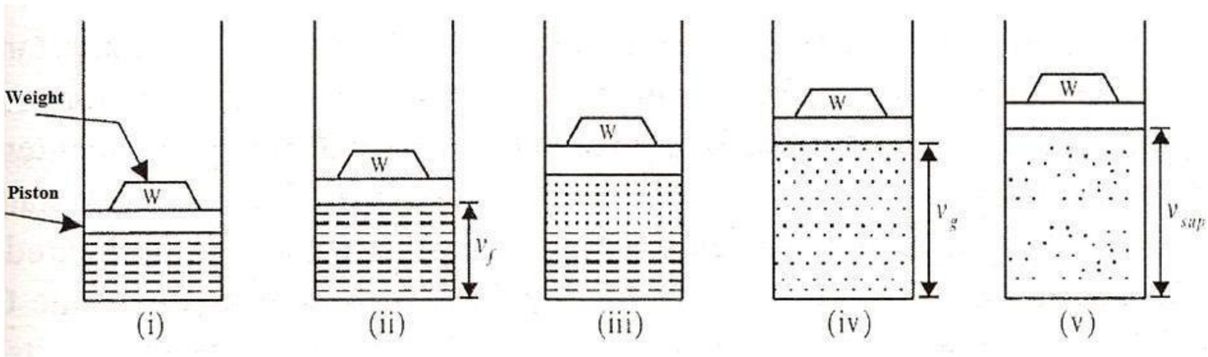


Fig. 4.1 Formation of steam

Fig. 4.2 Temperature – Enthalpy diagram

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

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

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

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

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

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

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

Types of Steam:

1) **Wet steam:** A wet steam is a two-phase mixture of entrained water molecules and steam in thermal equilibrium at the saturation temperature corresponding to a given pressure.

The quality of the wet steam is specified by the dry fraction which indicates the amount of dry steam present in the given quantity of wet steam and is denoted by *x*. **Dryness fraction of steam**: It is the ratio of the actual dry steam present in a known quantity of wet steam to the total mass of the wet steam.

Let m_s = mass of dry steam present in the given quantity of wet steam.

m_w = mass of superheated water molecules in the given quantity of wet steam.

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

2) **Dry saturated steam**: A steam at the saturation temperature corresponding to a given pressure and having no water molecules entrained in it is known as dry saturated steam or dry steam. Its dryness fraction will be unity.

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

Enthalpy of Steam:

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

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

2) Enthalpy of Dry Saturated Steam: It is defined as the total amount of heat required to convert 1 kg of water into 1 kg of dry saturated steam from its freezing point. It is denoted by h_g.

h_g = Heat required to raise the temperature of 1 kg of water to the boiling point + Heat required to convert the same water from its boiling point to dry saturated

steam at constant temperature (T_s)

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

4) Enthalpy of Superheated Steam: It is defined as the total amount of heat required to convert 1 kg of water at 0° C into 1 kg of superheated steam. It is denoted by h_{sup}.

h_{sup} = Heat required to raise the temperature of 1 kg of water to the boiling point + Heat required to convert the same water from its boiling point to dry saturated steam at constant temperature (T_s) + Heat required to convert the same steam into superheated steam(T_{sup})

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

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

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

Specific Volume of Steam:

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

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

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

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

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

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

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

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

volume is determined approximately applying Charle"s law.

Throttling Process:

It is the type of expansion process, in which steam passes through a narrow passage and expands with a full of pressure without doing any external work.

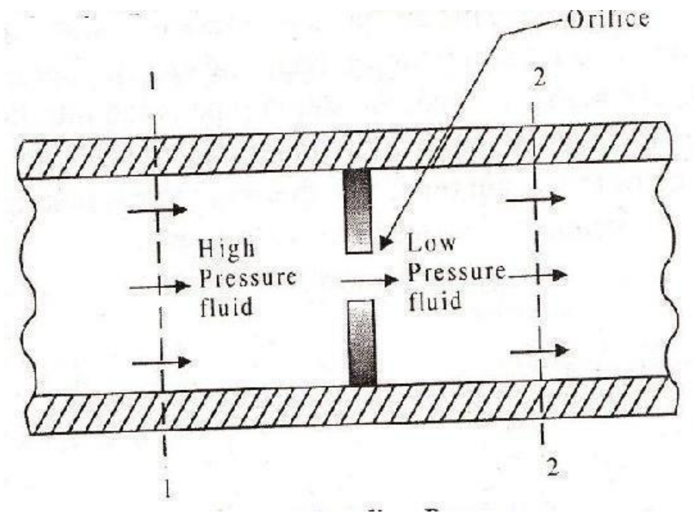


Fig. 4.3 Throttling Process

In this process, there is no interchange of heat and the enthalpy remains constant therefore this process is also called **constant enthalpy process**. Throttling process is a steady flow process hence steady flow energy equation can be
applicable.

Measurement of Dryness Fraction:

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

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

Bucket or Barrel Calorimeter

Construction

Bucket calorimeter consists of a calorimeter which is placed on wooden blocks in a vessel. The vessel is large enough to provide an air space around the calorimeter. This air space provides insulation to prevent heat loss. The top cover is made of wood and it closes both the calorimeter and the vessel. This cover has two holes. Through one hole, the steam pipe is led into the calorimeter. The steam is distributed in the calorimeter by the holes in the bottom ring which is connected to the end of the steam pipe. The thermometer is inserted from the second hole to measure the temperature of water in the calorimeter.

Working

The calorimeter is placed in the vessel. The top cover is placed in position and the steam pipe is connected to main steam pipe. The steam comes in contact with water in the calorimeter when steam is passed through the water. It condenses and gives out its entire enthalpy of evaporation (latent heat) and part of its sensible heat. Due to heat transfer from steam to water in the calorimeter, the temperature of water increases. Condensation of steam will increase the mass of water. Sufficient quantity of steam should be blown in the calorimeter so that sufficient rise in temperature of water and thereby errors are reduced to minimum. Afterwards the steam cock is closed.

Limitations

1) This method is not accurate.
2) Accuracy decreases as temperature difference (t2-t1) increases because of losses are more at higher temperature difference.

Separating Calorimeter

Construction Separating calorimeter consists of two chambers, viz inner chamber and outer chamber. At the top of inner chamber perforated tray is provided where water droplet in the wet steam is separated due to its inertia. Separated droplet is collected in inner chamber while steam is condensed in barrel calorimeter.

Working

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

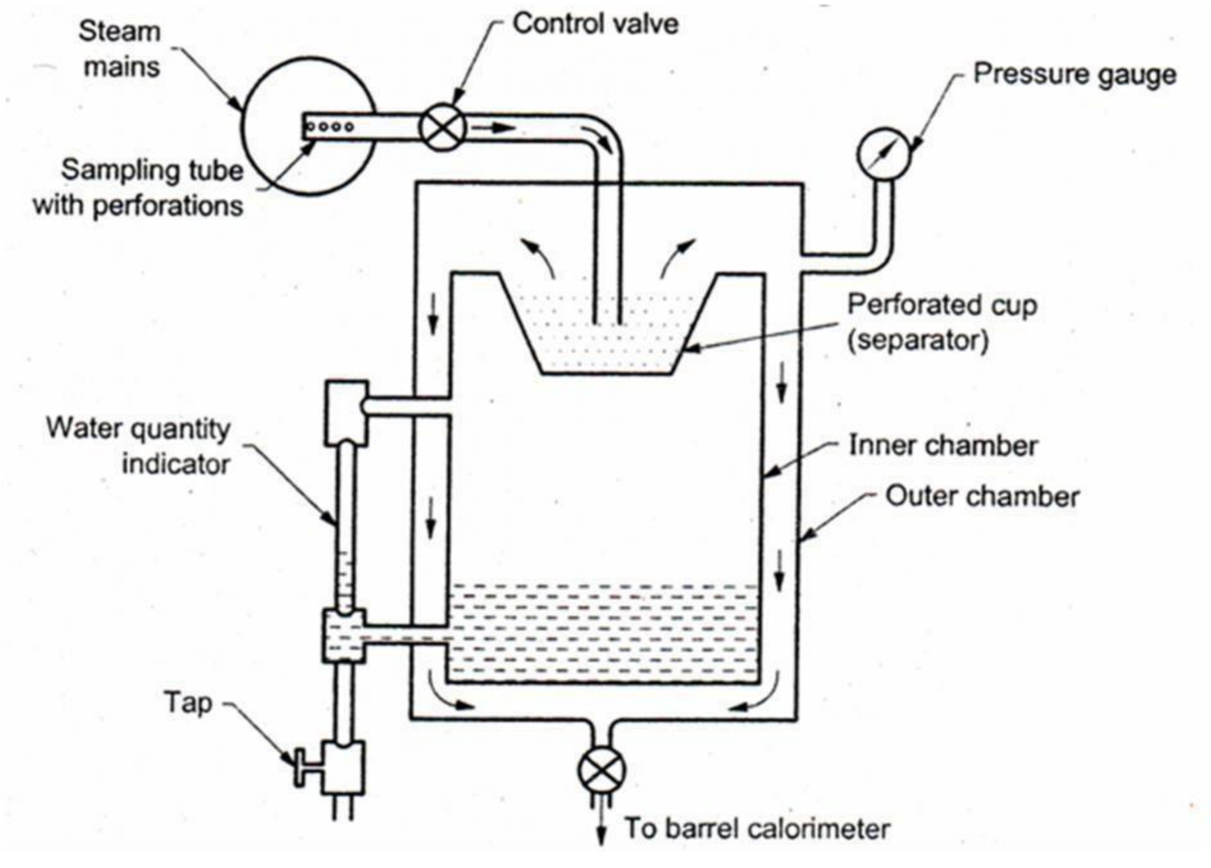


Fig. 4.5 Separating Calorimeter

Limitation

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

Throttling Calorimeter

Construction

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

Working

With full open steam stop valve, steam is allowed to throttle until steady pressure and temperature is reached. At steady state condition pressure before throttling (p1) and temperature after throttling is to be measured.

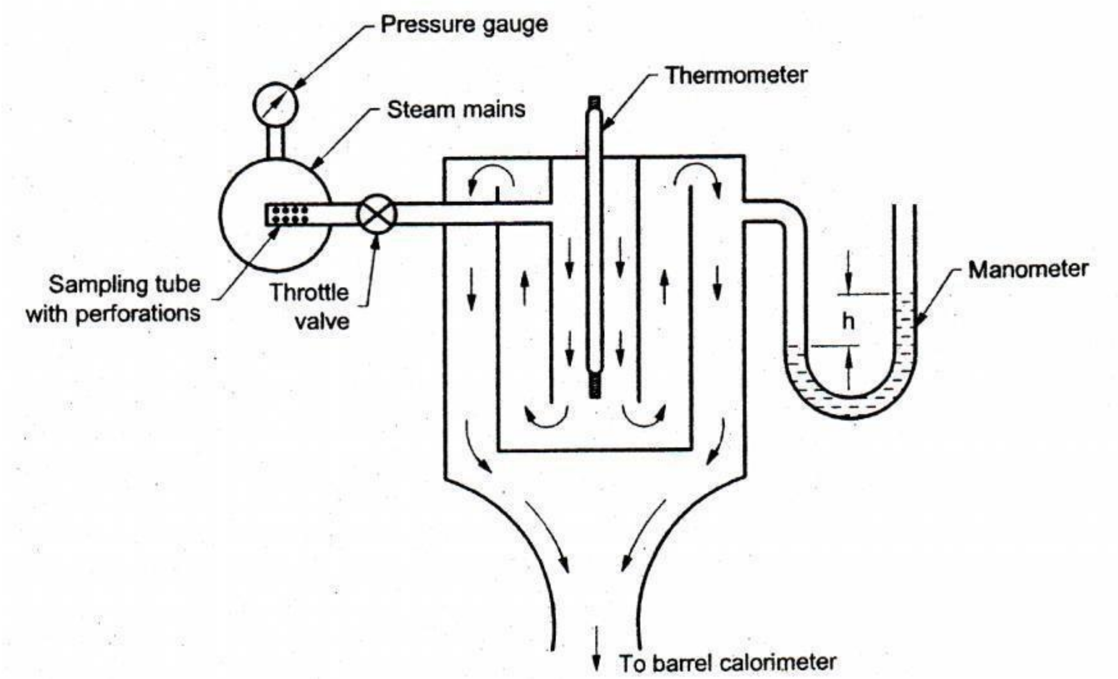


Fig. 4.5 Throttling calorimeter

Calculation

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

Limitation

Condition of steam after throttling must be superheated.

Combined Separating and Throttling Calorimeter.

It is already stated that the dryness fraction of the steam can be found by using throttling calorimeter only if the dryness fraction is greater than 0.95. When the dryness fraction is less than 0.9, then part of water is removed first passing the steam through separating calorimeter and then it is passed through a throttling calorimeter with a combined arrangement of separating and throttling calorimeter as shown in Fig. 5.3. Even load values of dryness fraction of steam can be easily determined.

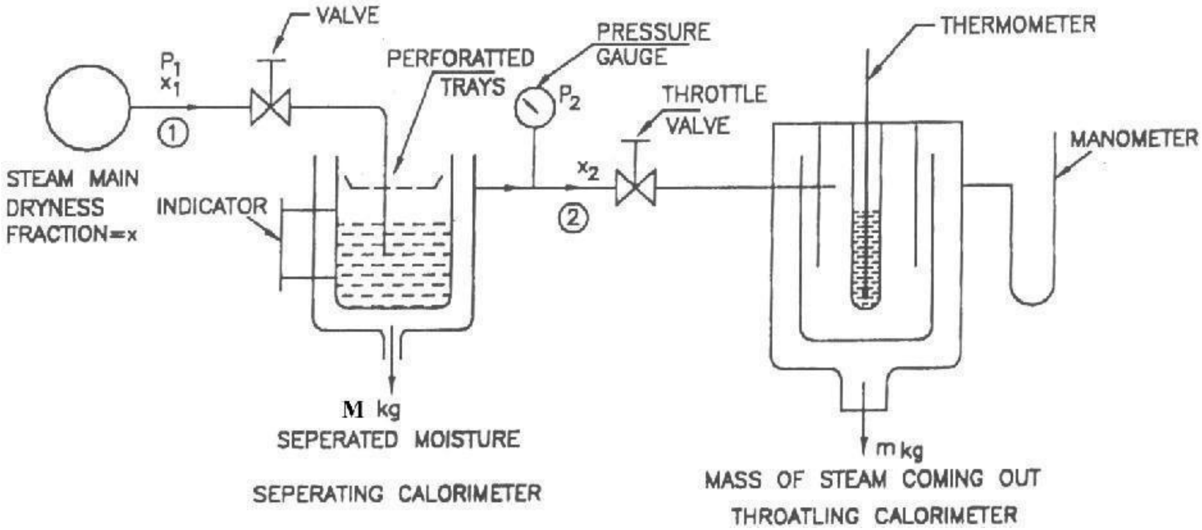


Fig. Combined separating and throttling calorimeter

Construction

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

Working

In a separating and throttling calorimeter, the steam from sampling tube is first passed through the separating calorimeter where it is partly dried up and then it is further passed on to the throttling calorimeter from where it comes out as superheated steam. The steam coming out from throttling calorimeter is condensed in a condenser and the mass of the condensate coming out of the condenser is recorded.

UNIT-III

INTERNAL COMBSUTION ENGINES, REFRIGERATION AND AIR-CONDITIONING

HEAT ENGINES

Thermal prime movers:

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

Sources of Energy (Heat):

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

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

ENGINE:

An engine is a device which transforms one form of energy into another form.

HEAT ENGINE:

Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine. Generally source of heat is combustion chamber or furnace where combustion of fuel takes place. Heat is continuously supplied to the medium from the combustion chamber for conversion into mechanical work. In addition to the above three elements, there is one cold body, at a lower temperature than the source is known as ***heat sink.***

Classification of Heat Engine:

Heat engine are divided into two broad classes:

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

1. External Combustion Engine:

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

2. Internal Combustion (IC) Engine:

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

Advantages of Heat Engines:

The advantages of internal combustion engines are:

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

The advantage of external combustion engines are:

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

DEFINITIONS:

Working substance:

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

Converting machines:

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

Reciprocating machine:

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

Rotary machine:

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

Jet machine:

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

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

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

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

HEAT ENGINE CYCLES:

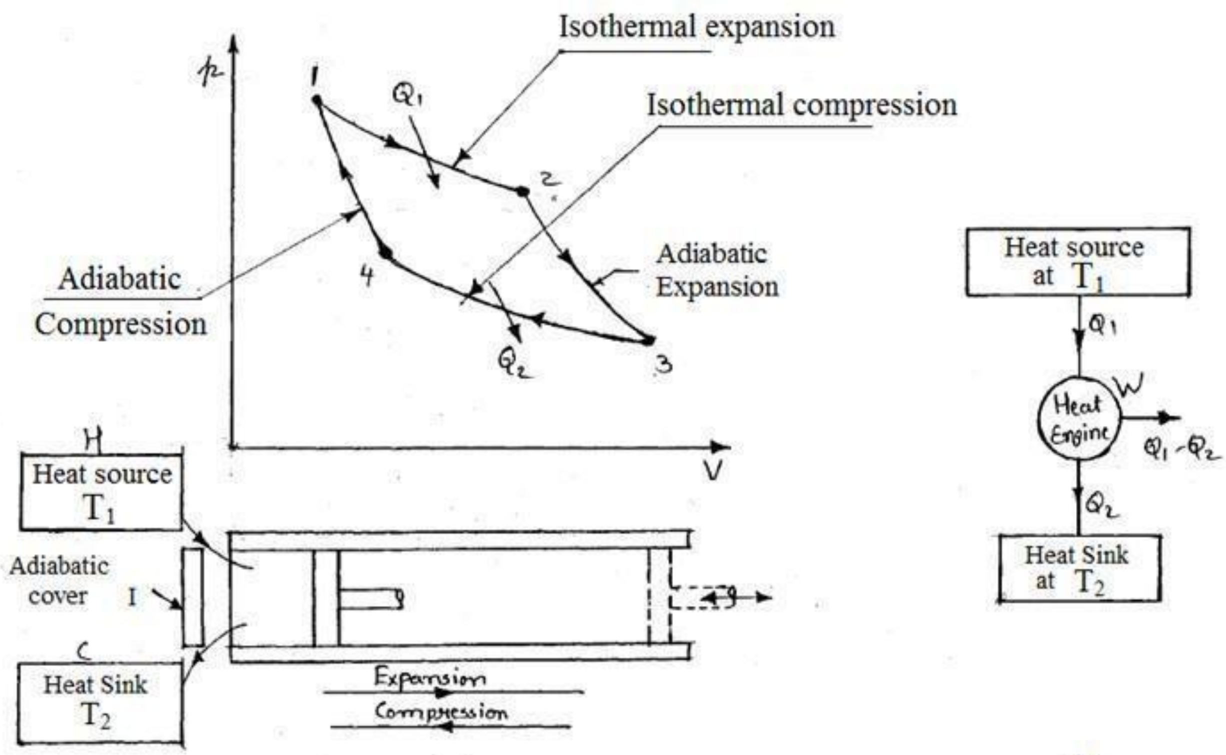
Following are the various heat engine cycles which will be discussed in detail in this chapter.

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

Carnot cycle Processes:

This cycle consists of four processes in the following order.

(1) Isothermal expansion,
(2) Adiabatic expansion,
(3) Isothermal compression,
(4) Adiabatic compression.



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

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

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

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

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

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

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

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

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

Assumptions made in the working of the Carnot Engine:

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

CARNOT VAPOUR CYCLE:

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

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

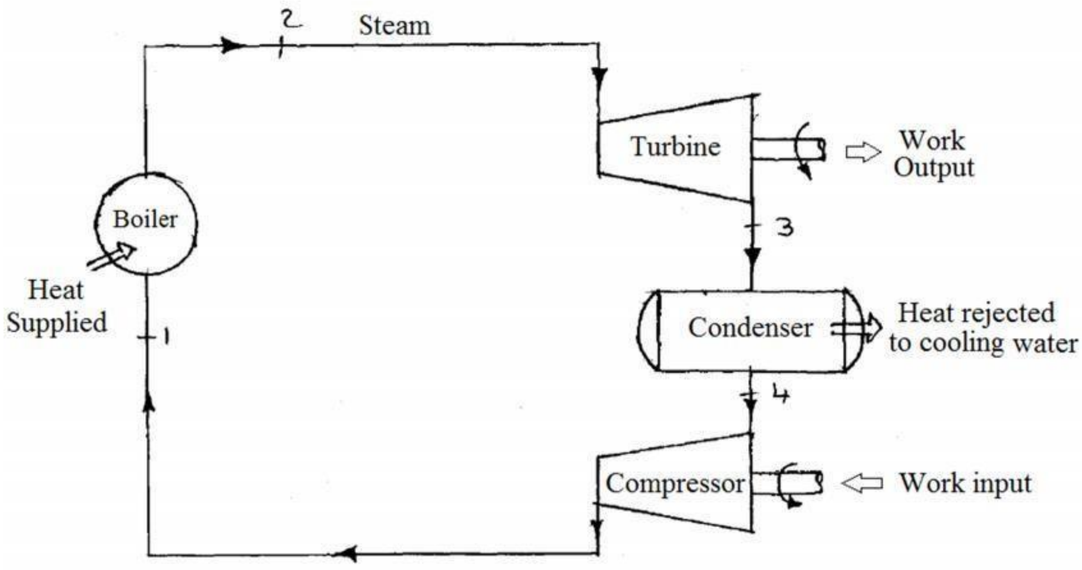


Fig. 3 Arrangement of Carnot vapour cycle

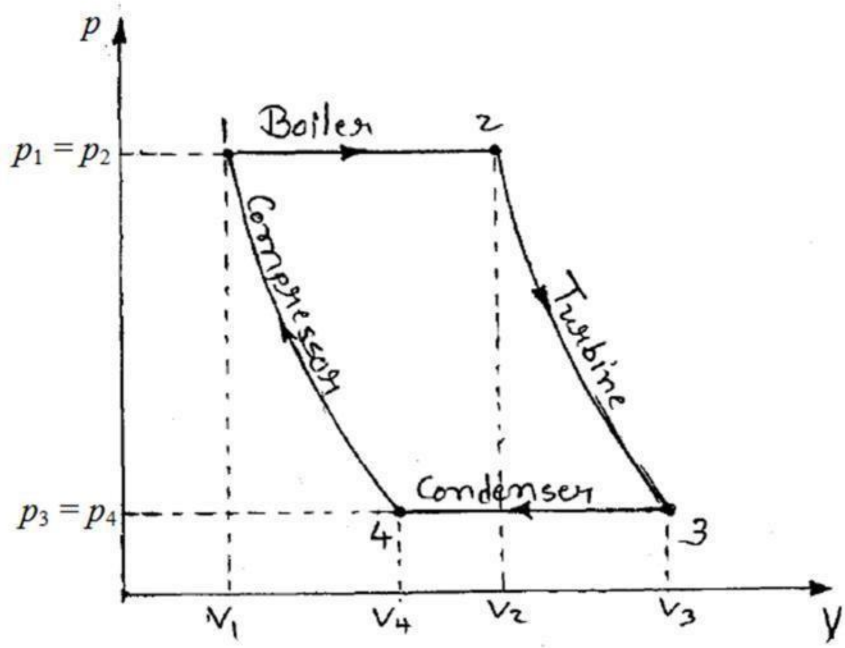


Fig. 4 p-V diagram of Carnot vapour cycle

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

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

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

RANKINE CYCLE:

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

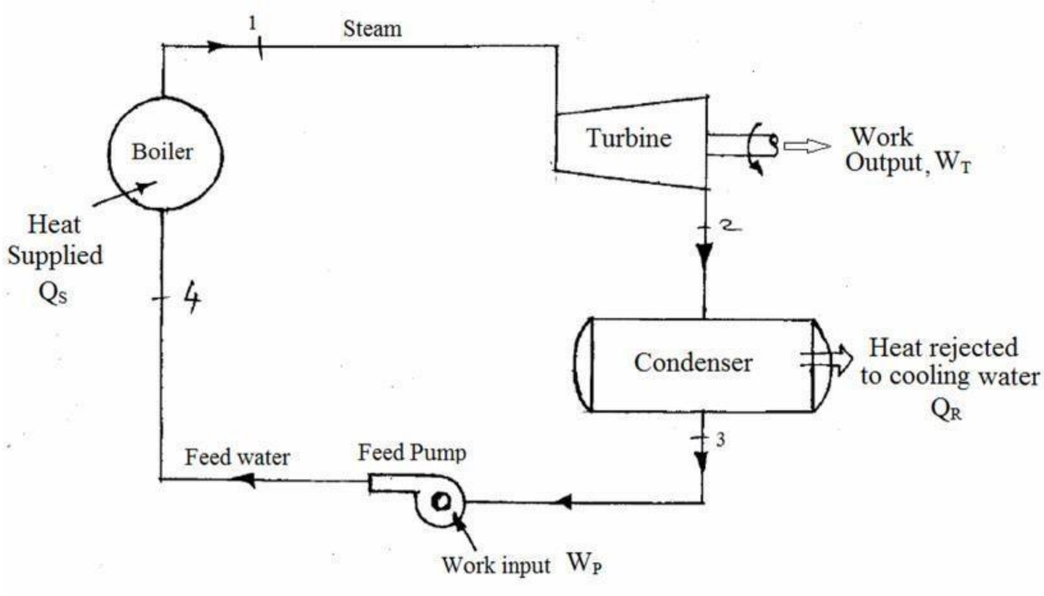


Fig. 5 Flow diagram of Rankine cycle

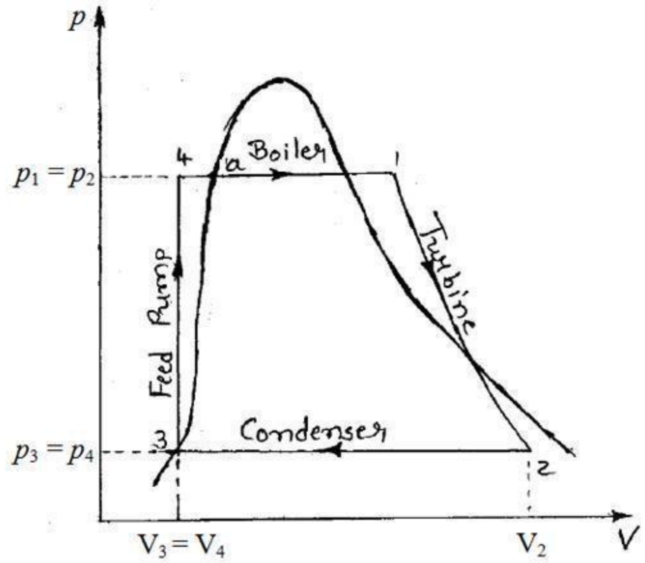


Fig. 6 p-V diagram of Rankine cycle.

The four main components of cycle are:

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

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

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

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

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

Difference between Rankine cycle and Carnot cycle:

(1) The exhaust steam from the turbine is not completely condensed in condenser in case of Carnot cycle; while in case of Rankine cycle it is completely condensed.
(2) The compressor is used in Carnot cycle to handle mixture of water and steam. In Rankine cycle pump is used in place of compressor, it has to handle only liquid.
(3) Superheating of steam is very difficult to achieve in Carnot cycle but there is a possibility of superheating of steam in Rankine cycle.

OTTO CYCLE:

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

Air standard efficiency:

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

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

Assumptions made for analysis of Air standard cycle:

(1) The working fluid is air.
(2) In the cycle, all the processes are reversible.
(3) The air behaves as an ideal gas and its specific heat is constant at all temperatures.

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Processes of Otto cycle:

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

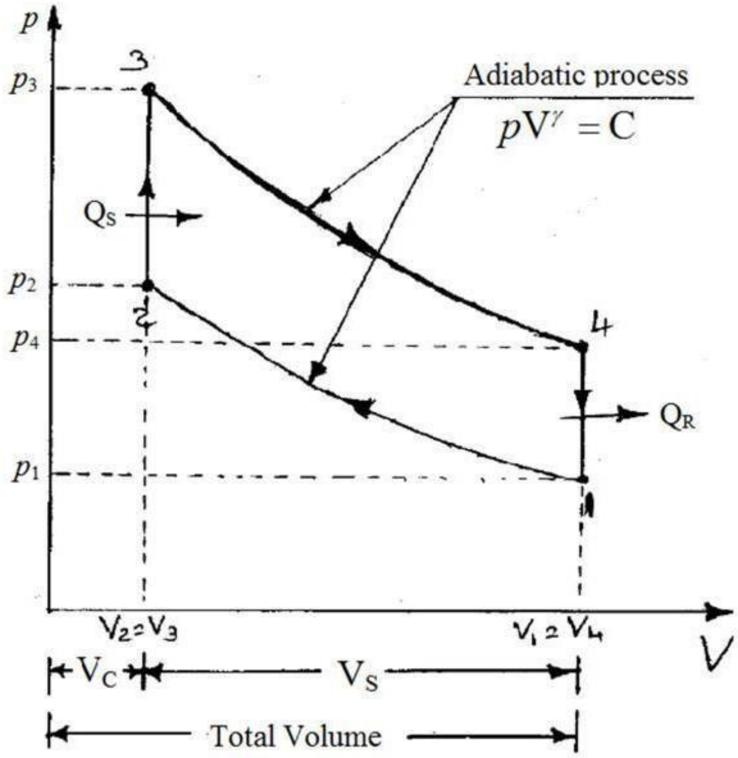

Fig. 7 p-V diagram for Otto cycle.

Consider „m" kg of air in the cylinder.

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

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

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

DIESEL CYCLE:

This cycle was discovered by a German engineer Dr. Rudolph Diesel. Diesel cycle is also known as ***constant pressure heat addition cycle.*** The diesel cycle consists of two reversible adiabatic process, a constant pressure process and constant volume process. (p-V) diagram of this cycle.

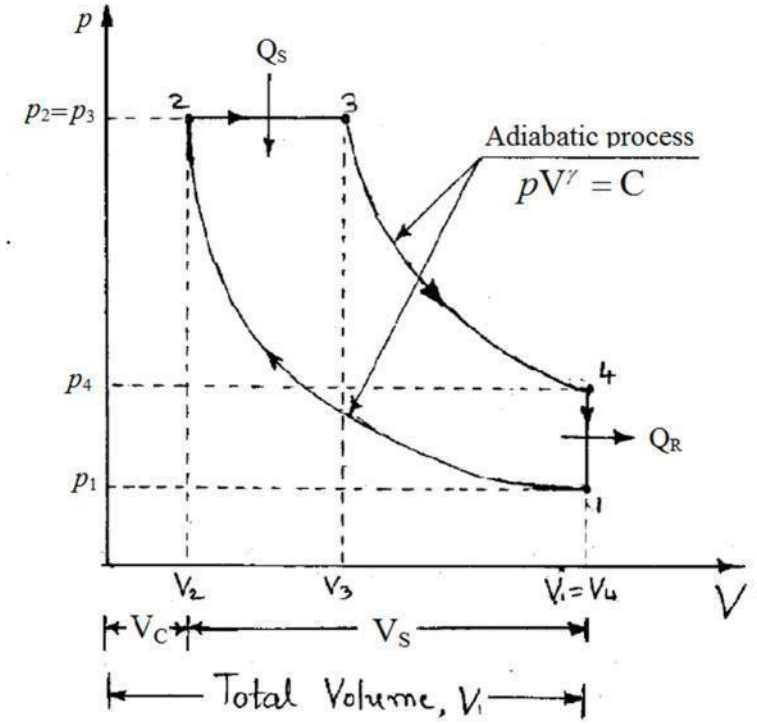

Fig. 9 p-V diagram for diesel cycle

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

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

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

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

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

Introduction

STEAM BOILERS

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

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

Classification of Steam Boilers

According to relative position of water and hot gases.

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

According to the axis of the shell

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

According to the method of firing

Externally fired boilers – furnace is located outside the shell.

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

According to the Method of Water circulation

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

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

According to the Pressure of steam

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

According to the mobility of boiler

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

According to the number of tubes in the boiler

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

Comparison between fire-tube and water tube boilers

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

General terms used in Steam Boiler

Cylindrical shell

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

Combustion chamber

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

Grate

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

Furnace

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

Fire Hole

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

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

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

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

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

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

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

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

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

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

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

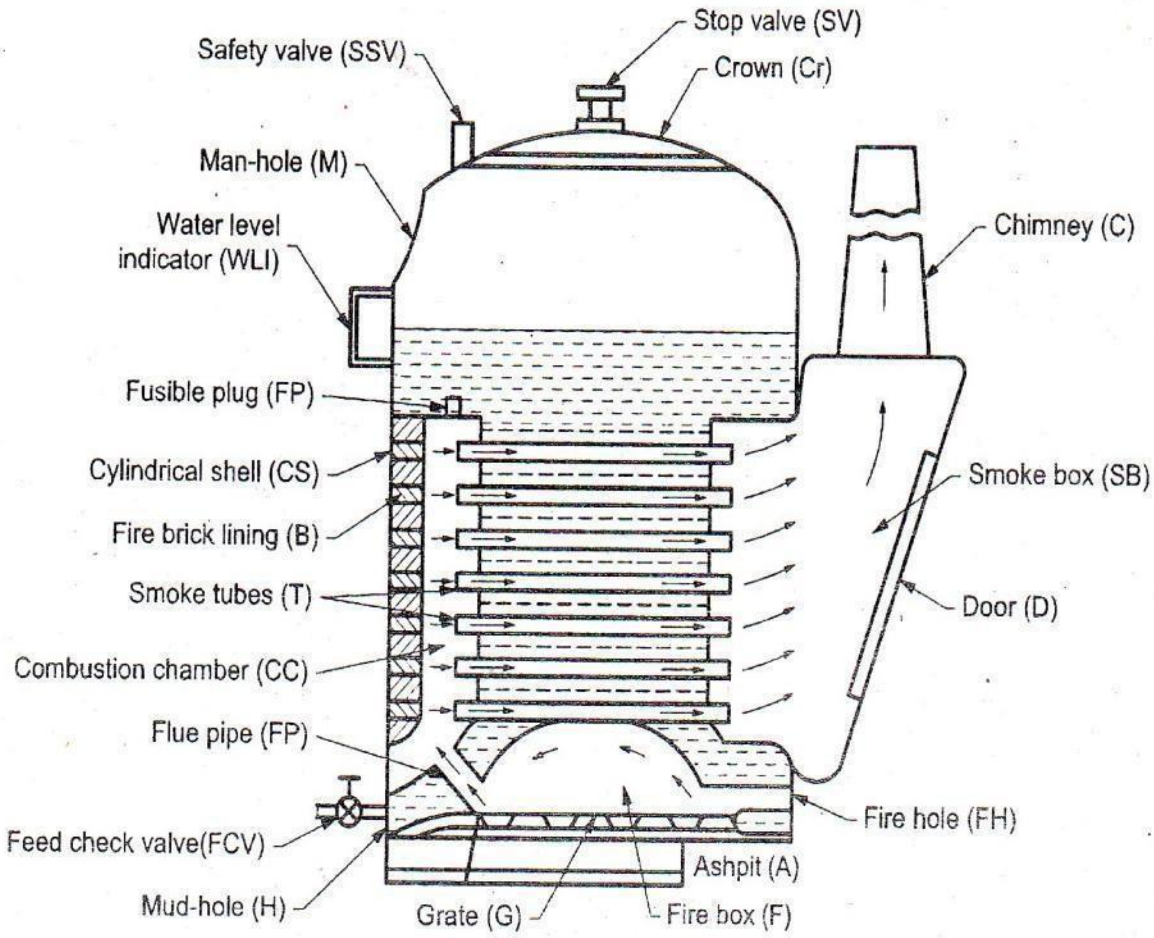

Fig. Cochran Boiler

Working

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

Advantages

1) It is compact and portable boiler therefore minimum floor area is required.
2) Initial cost of boiler is less
3) It can be moved and set up readily in different locations.
4) Quick and easy installation.
5) Any type of fuel can be used. (Coal or Oil)

Disadvantages

1) Steam raising capacity is less due to vertical design.
2) Water along with steam may enter the steam pipe under heavy loads sue to small steam space.
3) Efficiency is poor in smaller sizes.

Babcock and Wilcox water tube Boiler

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

Construction

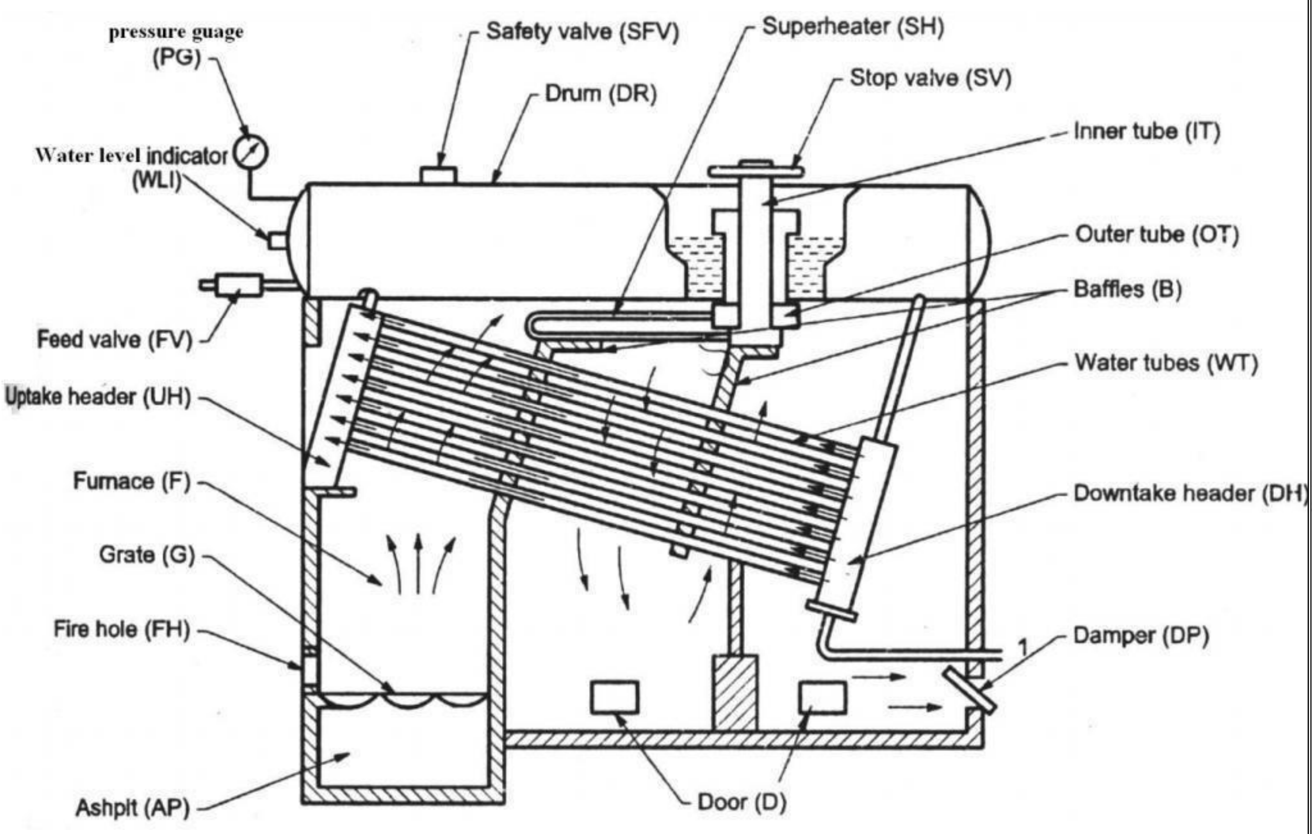

Fig. Babcock Wilcox Boiler

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

Working

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

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

Boiler Mountings & Accessories
List of Boiler Mountings & Accessories

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

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

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

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

Water level indicator

Function

It is an important fitting, which indicates the water level inside the boiler to an observer. It is a safety device, upon which correct working of boiler depends. This fitting may be seen in front of boiler, and are generally two in number.

Construction

It consists of three cocks and a glass tube. Stem Cock 1 keeps the glass tube in connection with the steam space. Water cock 2 puts the glass tube in connection with the water in the boiler. Drain cock 3 is used at frequent intervals to ascertain that the steam and water cocks are clear.

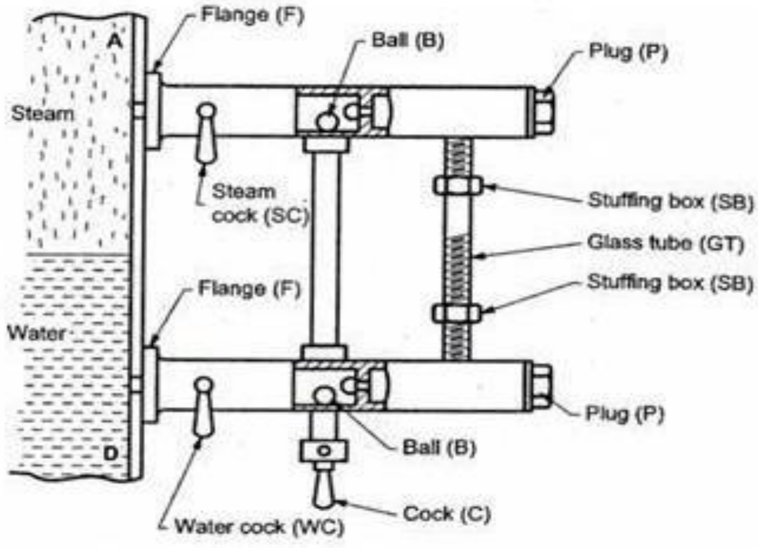

Fig. 6.3 Water Level Indicator

Working

In the working of a steam boiler and for the proper functioning of the water level indicator, the steam and water cocks are opened and the drain cock is closed. In this case handles are placed in a vertical position. The rectangular passage at the ends of the glass tube contains two balls. In case the glass tube is broken, the two balls are carried along its passages to the ends of the glass tube. It is thus obvious, that water and steam will not escape out. The glass tube can be easily replaced by closing the steam and water cocks and opening the drain cock.

Pressure Gauge

Function

It is used to measure the pressure of the steam inside the steam boiler. The pressure gauges generally used are of Bourdon tube type.

Construction

It consists of an elliptical elastic tube XYZ bent into an arc of a circle, as shown in Fig. 6.4. This bent up tube is called Bourdon‟s tube. One end of the gauge is fixed and connected to the steam space in boiler .The other end is attached by links and pins to a toothed quadrant. This quadrant meshes with a small pinion on the central spindle.

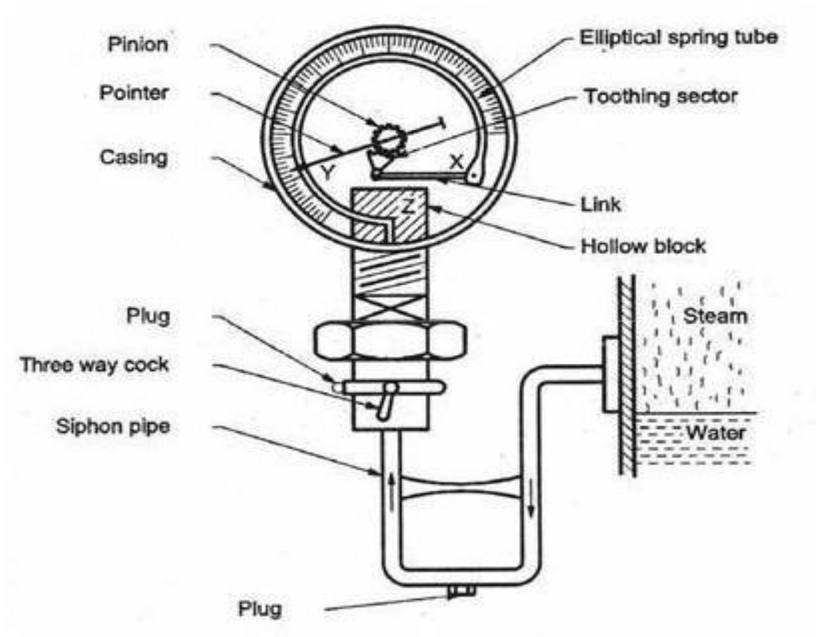

Fig 6.4 pressure gauge

Working

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

Safety Valves

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

Lever Safety Valve

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

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

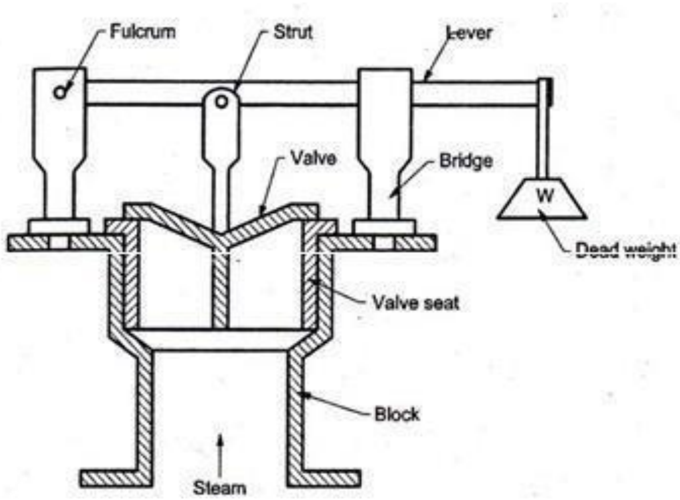

Fig 6.5 lever safety valve

Dead weight safety valve

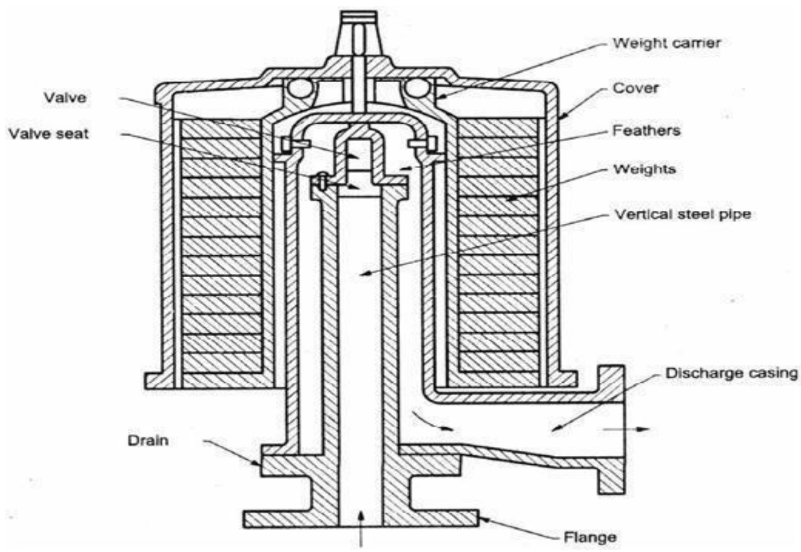

Fig 6.6 Dead weight safety valve

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

High steam low water safety valve

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

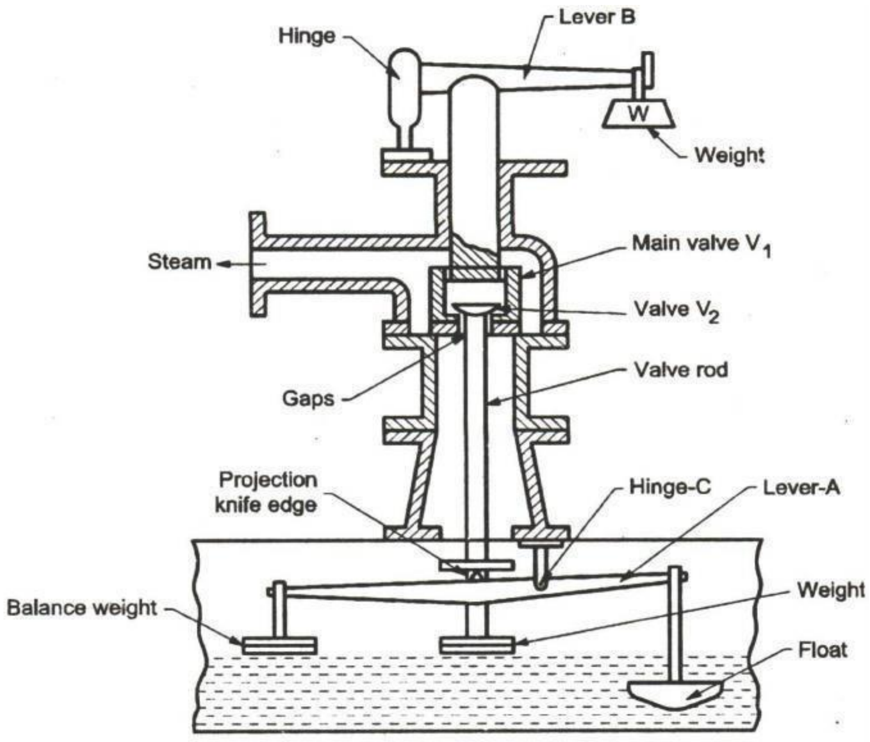

Fig. 6.7 high stem low water safety valve

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

Spring Loaded safety valve

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

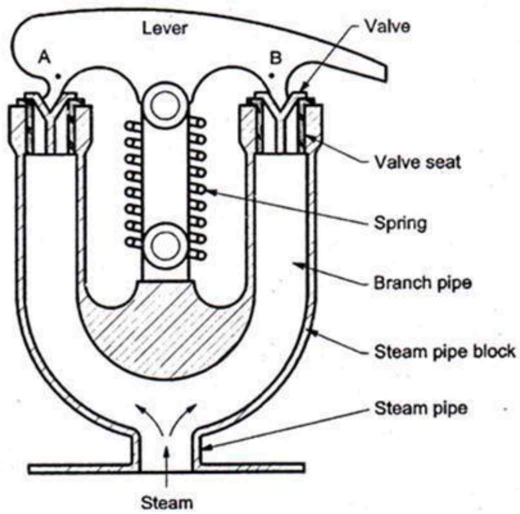

Fig. 6.8 Spring Loaded Safety valve

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

Steam stop valve

The body of the stop valve is made of cast iron or cast steel. The valve, valve seat and the nut through which the valve spindle works, are made of brass or gun metal. The spindle passes through a gland and stuffing box. The spindle is rotated by means of a hand wheel. The rotation of the spindle causes the valve to move up and down. Whenthe valve sits over the valve seat, the passage of steam is completely closed. The passage may be partially or fully opened for the flow of steam by moving the valve up, rotating the hand wheel.

Blow off cock

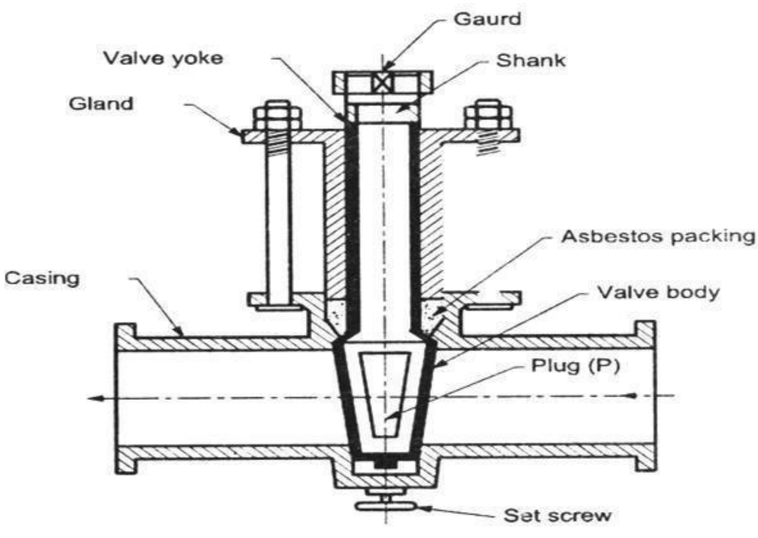

Fig. 6.11 Blow off Cock

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

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

Fusible Plug

Function

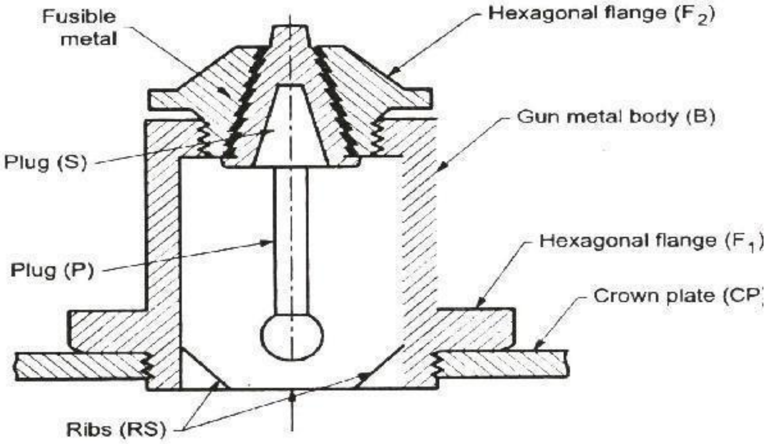

Fig. 6.12 Fusible Plug

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

Construction

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

Working

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

Boiler Accessories

Economiser

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

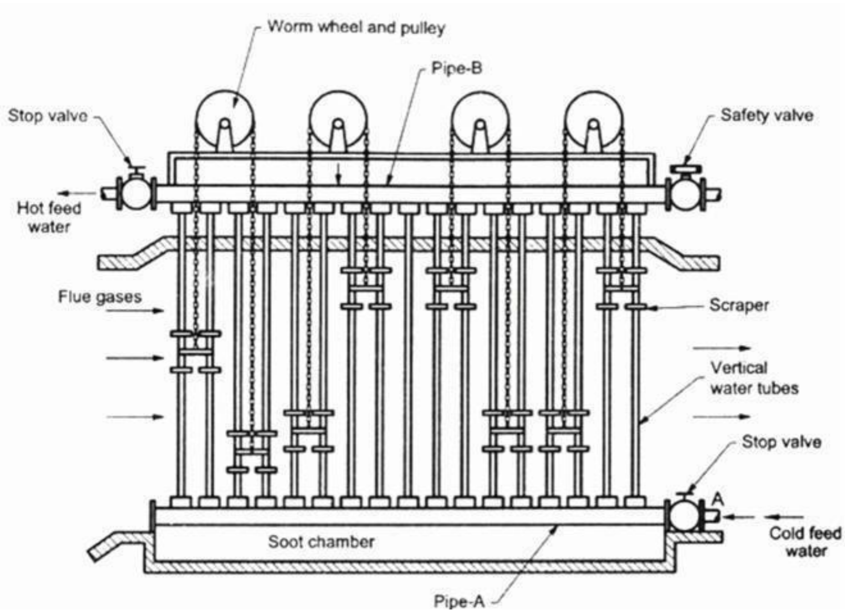

Fig. 6.13
Economiser

Construction and working

It is employed for boilers of medium pressure range unto about 25 bar. It consists of a large number of vertical cast iron pipes P which are connected two horizontal pipes, one at the top and other at the bottom. A is the bottom pipe through which the feed water is pumped into the economizer. The water comes into the top pipe B from the bottom pipe and finally flows into the boiler. The flue gases flows around the pipes in the direction opposite to the flow of water. Consequently, heat transfer to the surface of the pipes takes place and water is thereby heated. A blow off cock is provided at the back end of vertical pipes to remove sediments deposited in the bottom boxes. The soot of flue gases deposited on the pipes reducesthe efficiency of economizer. To prevent the soot deposit, the scrapers S move up and down to keep the external surface of pipe clean.By-pass arrangement of flue gases enables to isolate or include the economizer in the path of flue gases.The action of the superheater is as follows: The stop valve A is closed and stop valves B and C are in open position. The wet steam from boiler flows into right hand header via stop valve C. After superheating of steam in the tubes, it flows into the left hand header, from where it is withdrawn through the stop valve B. If the superheated steam is not needed, the stop valves B and C are closed and the wet steam is directly taken out from the boiler through stop valve A.

Internal Combustion Engine

Introduction

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

Diesel in the year 1892.

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

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

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

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

Classification of I.C. Engines

I.C. Engines may be classified according to,

a) Type of the fuel used as :

(1) Petrol engine (2) Diesel engine

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

b) Nature of thermodynamic cycle as :

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

(3) Duel or mixed cycle engine

c) Number of strokes per cycle as :

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

d) Method of ignition as :

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

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

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

e) Method of cooling as :

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

f) Speed of the engine as :

(1) Low speed (2) Medium speed

(3) High speed

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

g) Number of cylinder as :

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

h) Position of the cylinder as :

(1) Inline engines (2) V – engines

(3) Radial engines (4) Opposed cylinder engine

(5) Opposed piston engine

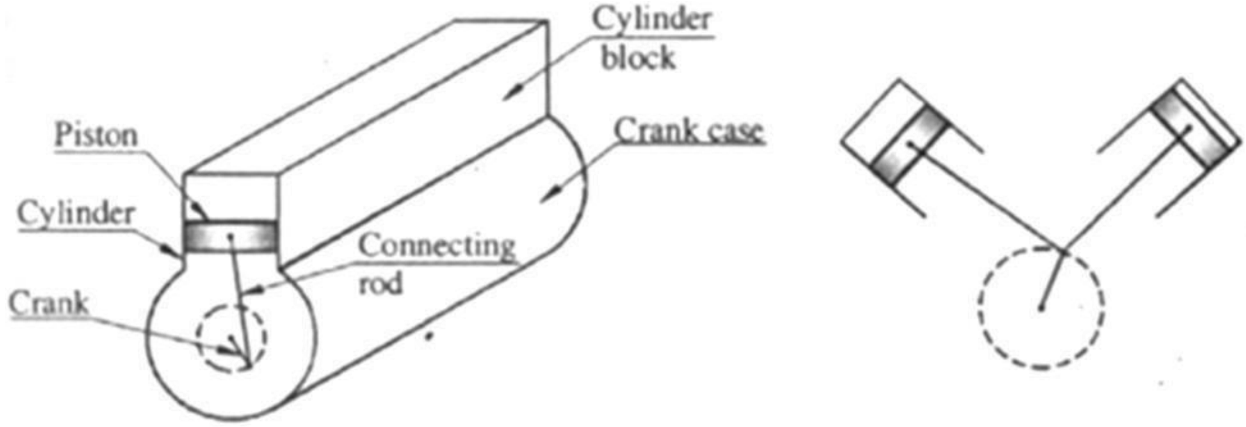

Fig. In line engine and V – engine

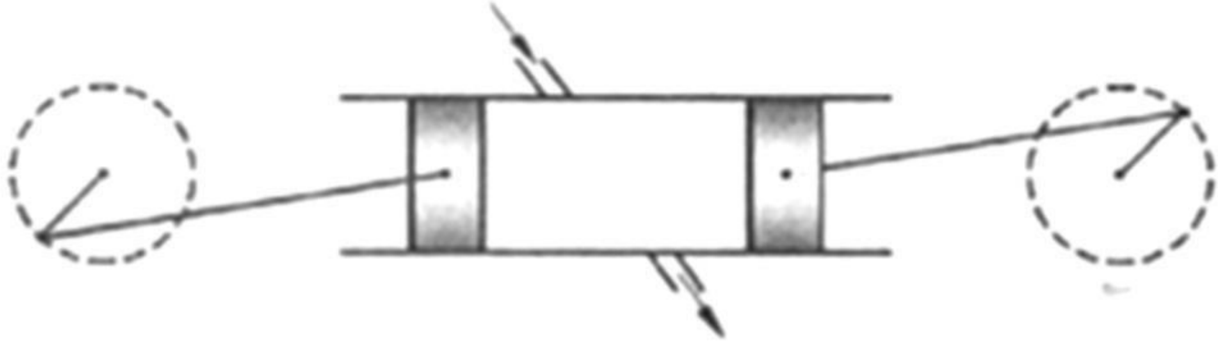

Fig. 7.2 Opposed piston engine

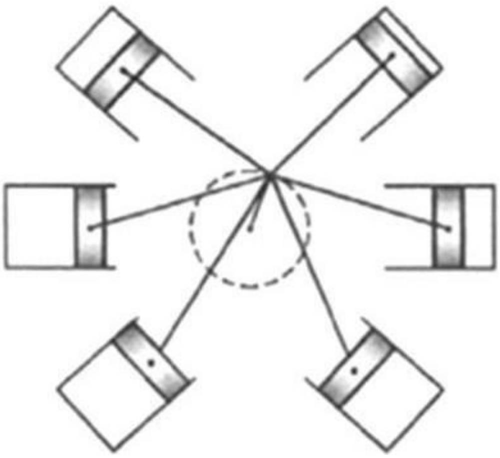


Fig. 7.3 Radial engine Fig. 7.4 Opposed cylinder engine

Engine details

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

Cylinder

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

Cylinder head

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

Piston

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

Piston Rings

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

Piston pin or Gudgeon pin

It is the pin joining small end of the connecting rod and piston. This is made of steel by forging process.

Connecting Rod

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

Crank and Crankshaft

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

Valves

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

Flywheel

It is a heavy wheel mounted on the crankshaft of the engine. It minimizes cyclic variation in speed by storing the energy during power stroke, and same is released during other stroke.

Crankcase

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

Carburetor

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

Fuel pump

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

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

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

(ii) Compression stroke

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

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

(iii) Power or Expansion stroke

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

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

(iv) Exhaust Stroke

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

Again the inlet valve opens and a new cycle starts.

Diesel four stroke cycle OR Four stroke Diesel engine OR Four stroke compression ignition (C.I) engine.

The diesel engines work on the principle of Diesel cycle, also called constant pressure heat addition cycle shown in Fig. The four stroke diesel engine cycle also consists of suction, compression, power, and exhaust strokes. Fig. 10 shows the working and construction of a four stroke diesel engine.

The basic construction of a four stroke diesel engine is same as that of four stroke petrol engine, except instead of spark plug, a fuel injector is mounted in its place as shown in Fig. 10. A fuel pump supplies the fuel oil to the injector at higher pressure.

(i) Suction Stroke

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

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

(ii) Compression stroke

During this stroke, both inlet valve and exhaust valve remain closed. The piston moves from BDC to IDC. As this stroke is being performed, the air in the cylinder will be compressed, so pressure and temperature of air increases.

The compression ratio of this engine is higher than petrol engine. Due to higher compression ratio, air will have attained a higher temperature than self ignition temperature of the diesel fuel.

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

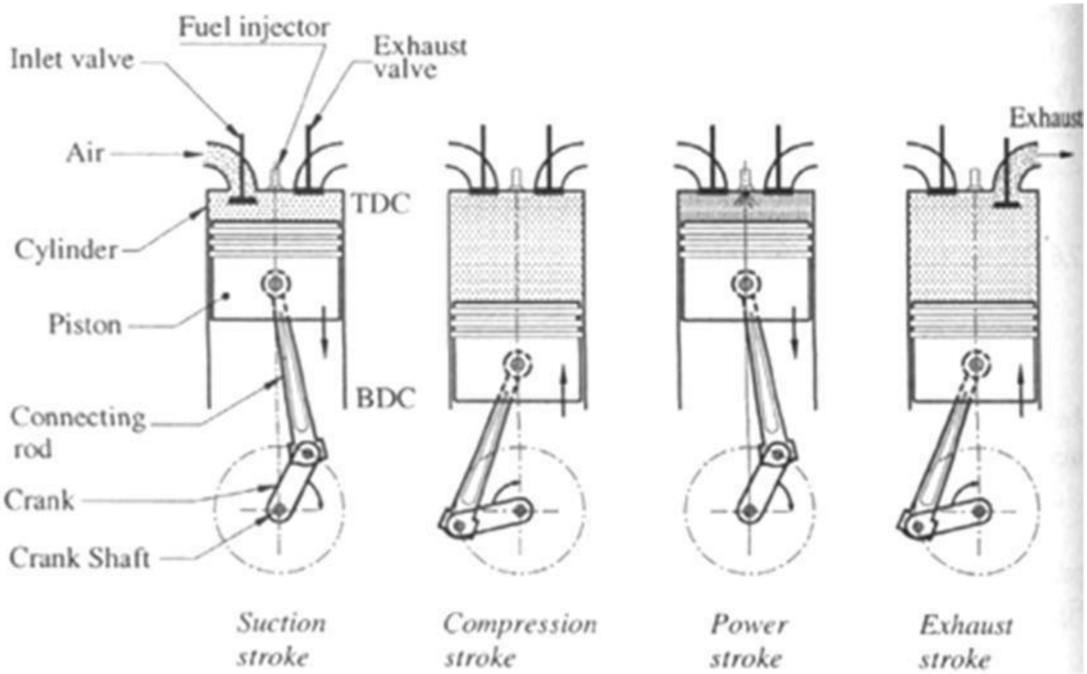

Fig. 7.9 Four stroke diesel engine

(iii) Power or Expansion stroke

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

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

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

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

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