MODULE 1

Properties, testing and inspection of engineering materials, Manufacturing of metals& alloys

Engineering Materials

Materials

- Over 70,000 different kinds and grades of engineering materials
- This number grows daily
- 1,000 different materials make up an automobile

CLASSIFICATION OF ENGINEERING MATERIALS

- Engineering materials
  - Metals and Alloys
    - Ferrous
      Eg:Cast iron, steel etc.
    - Non ferrous
      Eg:Copper,Zinc,Brass,Tin etc.
  - Polymers
    Eg:Rubber,
    Plastics etc.
  - Composites
    Eg:Cemented Carbide,RCC etc.
  - Ceramics
    Eg:Sand,
    glass,silica etc.

Metals & Alloys

- **Metals :** Elements which give up electrons to form metallic bonds
- Strength, opaque to light, lustrous, ductile, malleable, dimensional stability, good electrical and thermal conductivity.
- Crystalline in nature(Ordered arrangement of atoms)
- Castability,forgeability,machinability,weldability
- Metals are classified into two
- **Ferrous metal**: Principal constituent iron.Eg:Wrought iron, Cast iron, Steel
- **Non ferrous metal**: Do not possess iron as main constituent.Eg:Copper,Zinc,Tin
- **Alloy** is a mixture of two or more elements, with one being a metal.Eg.Brass,Bronze

Polymers

- Organic compounds consist of carbon + one or more other element such as hydrogen, oxygen, nitrogen and chlorine
- Long chain molecules formed by *polymerization*
- Basic building unit *monomer*
- Light in weight,soft,poor conductors of heat and electricity, corrosion resistance, formability
- Eg:Plastics,Rubber,Leather,Cotton etc.

Ceramics

- Compounds containing metallic and non-metallic elements
- They are frequently oxides, nitrides, and carbides.
- Brittle, high strength, chemically inert,hard,wear resistant, low thermal and electrical conductivities,refractory, non magnetic
- Eg:Clayproduct,glass,cement,refractories,abrasives

Composites

- Consists of two or more phases whose combination produces properties that are superior to its constituents
- Matrix + Reinforcement = composite

Eg:Cemented carbide, Reinforced cement concrete,Fibre glass reinforced plastic etc.

Factors in selection of Materials for Engineering Application

- Availability of the material
- Ease of handling
- Cost of the material
- Cost of processing
- Aesthetic
- Recycling
- Easiness in fabrication such as machinability, weldability,

  castability,forgeability etc.
- Capacity to meet service demand eg:proper strength, wear resistance, corrosion resistance etc.

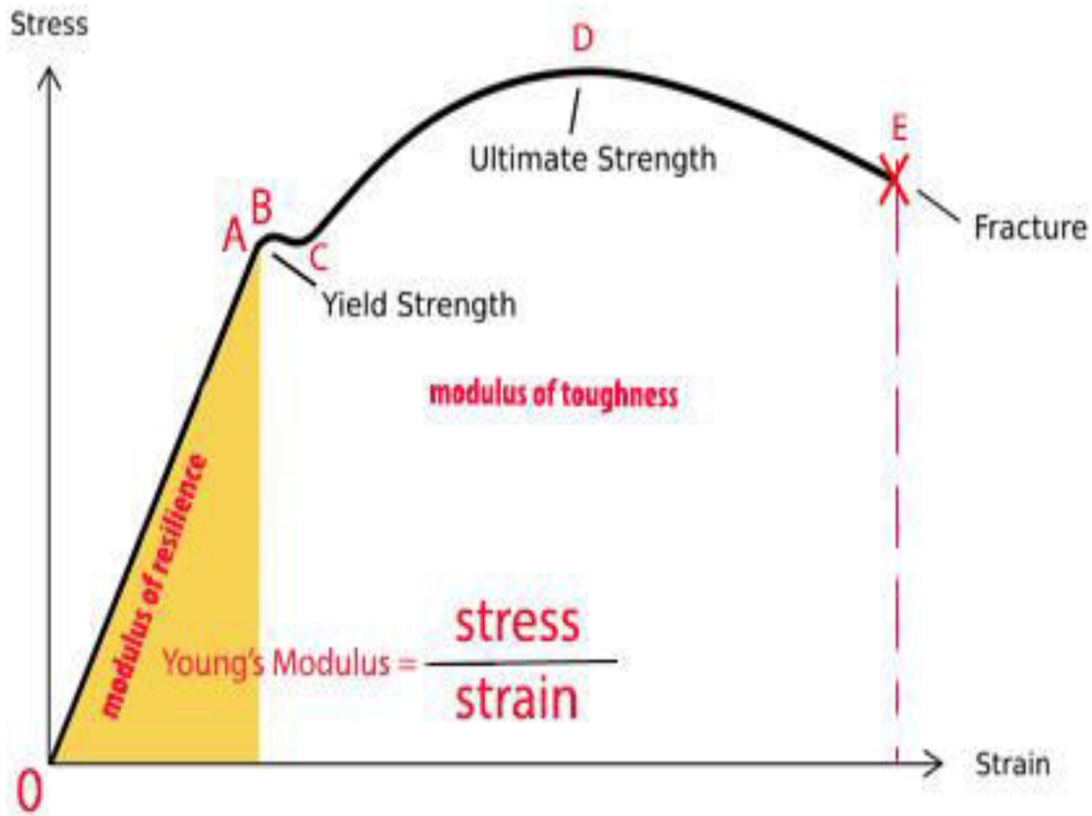
Mechanical properties

- Strength: Ability of material to withstand external load or force without failure
- *Tensile strength* :Ability of material to withstand tensile load (axial pull) without failure
- Tensile strength = $\frac{Max.tensile\ load}{Original\ Cr.sectional\ area}$
- *Compressive strength* =Ability of material to withstand compressive load (axial push) without failure
- Compressive strength = $\frac{Max.compressive\ load}{Original\ Cr.sectional\ area}$
- *Shear strength*: Ability of material to withstand tangential load without failure across resisting section
- Shear strength = $\frac{Max.tangential\ load}{Original\ Cr.sectional\ area}$

Mechanical properties

- ***Torsional strength*** :Ability of material to withstand twisting load with out failure across resisting section
- Torsional strength = $\frac{Max.twisting\ load}{Original\ Cr.sectional\ area}$
- ***Bending strength***: Ability of material to withstand breaking load by bending across resisting section
- Bending strength = $\frac{Max.\ bending\ load}{Original\ Cr.sectional\ area}$
- **Hardness**: Resistance to indentation(penetration),abrasion or scratching
- Desirable property for dies,punches,cutting tool
- **Toughness**: Ability of material to absorb energy during plastic deformation up to fracture (During impact or shock load)
- Indicated by area under stress strain curve up to fracture

Comparison of toughness and resilience



Mechanical property

- **Resilience:** Ability of material to absorb energy up to elastic limit
- Desirable property for spring materials
- Indicated by area under stress strain curve up to elastic limit
- **Brittleness:** Fracture with out much deformation
- Opposite to ductility
- Eg for brittle material: Cast iron, Glass
- **Ductility**: Under go deformation under tensile load without rupture
- This property enables wire drawing
- Measure of ductility are
- % reduction in area = $\frac{Reduction\ in\ cr.sectional\ area}{Original\ area}$ x 100
- % elongation = $\frac{Increase\ in\ length}{Original\ length}$ x 100
- Most ductile material: Gold

Mechanical properties

- **Malleability:** Under go deformation under compressive load with out rupture
- This property is useful in rolling of thin sheets
- **Elasticity:** Ability of a material to regain its original shape and size after removal of load

  Eg:Steel,rubber
- **Plasticity**: Ability of material to be permanently deformed (without fracture) even after the load is removed
- This property finds its use in forming, shaping and extruding operations of metals.

- **Creep:** Slow and continuous deformation of material with time under constant load
- Metals shows creep at high temperature where as plastic creep at low temperature
- Eg:Beams in the roof of building shows creep with time
- This property is considered in designing of boilers,IC engines, steam turbines etc.
- **Fatigue**: Failure of material caused due to cyclic or fluctuating loads.
- Occurs abruptly without showing any sign of failure
- This property is considered in designing of motor shafts, wire ropes, springs etc. subjected to cyclic loading

- **Stiffness**: Resistance of material to elastic deformation
- *Modulus of rigidity* is the measure of stiffness
- Materials which suffers less deformation under load have high degree of stiffness.
- This property is made used in spring balance and spring controlled measuring instruments

Electrical properties

- Resistance: Opposition to flow of electric current through a conductor. Unit: Ω
- R α $\frac{l}{A}$ or R = $\frac{\rho l}{A}$
- When l = 1 m and A = 1 m^2 R = ρ(Resistivity)
- I.e. Resistivity = Resistance of a material having unit length and unit cr.section.Unit: Ω-m
- Metals with high resistance are used in heating element and low resistance for long distance transmission lines
- Conductance: Property of material which allows passage of electric current through it easily.Unit:mho
- Conductivity: Conductance of material per unit volume
- Reciprocal of resistivity
- Unit :$(\Omega - m)^{-1}$ or mho/ m, Simens/m

Electrical properties

- Capacitor
- Device used to store electric charge
- Consists of two conducting surface separated by an insulator(dielectric)
- Capacitance: Property of capacitor to store electric charge when a potential difference exists between the terminals
- C = $\frac{Q}{V}$
- Unit: Farad(F)

Magnetic properties

- Magneto motive force(MMF):Force which produce magnetic flux in a magnetic circuit
- Similar to emf in electric circuit
- Reluctance: Opposition offered to magnetic lines of force in a magnetic circuit
- Similar to resistance in an electric circuit
- Unit:AT/ Wb
- Permeance:Reciprocal of reluctance.Unit:Wb/AT
- Similar to conductance in electrical circuit

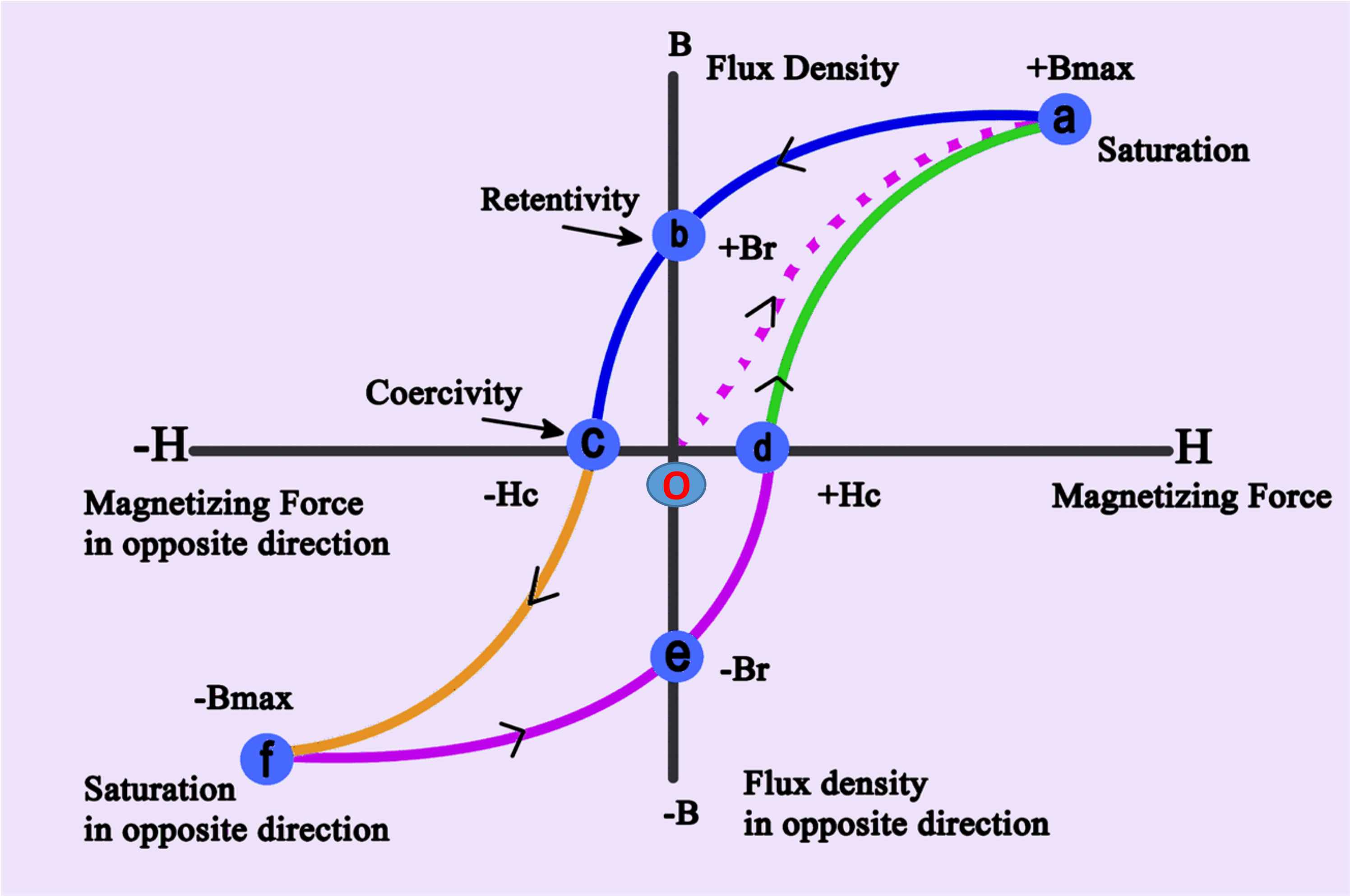
Magnetic hysteresis

B = magnetic flux density or magnetic induction

H = magnetising force or magnetic field strength

- Hysterisis:Lagging of B behind H
- When a ferro magnetic material is initially magnitised,B increases with H and follows curve oa
- When H is decreased, B will not decrease along ao but follows curve ab
- At point b ,H =0,but B ≠0,it has a value($+ B_r$) known as residual magnetism or retentively
- To demagnetise the material, magnetic field(H) is revered
- Value of H required to wipe off residual magnetism is called coercive force($- H_c$)
- Further increase of H in – ve direction, results in max. B,but in opposite direction(cf)
- Continuing this way curve feda is obtained
- Enclosed area is called hysteresis loop
- Energy is wasted in the form of heat for reversal of magnetism in the iron core of transformer(hysteresis loss)

Magnetic hysteresis



Thermal properties

- **Specific heat:** Amount of heat required to rise unit mass of substance by one degree Celsius
- Unit: J/Kg- K
- Thermal Conductivity: Ability of material to transmit heat through it
- Measure of how fast heat will flow through a material
- Unit: W/m-K
- Fourier law of conduction ,Q = - KA $\frac{dt}{dx}$

$\mathrm{Q} =$ rate of heat transfer , W

$\mathrm{A} =$ area normal to direction of heat flow, m^2

$\frac{\mathrm{dt}}{\mathrm{dx}} =$ temperature gradient ,°C/m

K= thermal conductivity , which is defined as the rate of heat transfer through unit thickness of material per unit area per unit temperature difference

- Unit : W/m-K

Thermal properties

- Thermal diffusivity: $\alpha = \frac{K}{\rho . C_p}$

K = thermal conductivity in W/m-K

ρ = density of material

C_p = Specific heat of material in $\frac{J}{Kg-K}$

- Ability to spread out heat to make temperature change

- Thermal resistance: Ability of material to withstand high temperature
- Material with high melting point has high thermal resistance
- Eg:Alumina,Zirconia,Tungsten

Chemical properties

- Corrosion resistance: Resistance to deterioration or decaying of metal by chemical or electrochemical reaction with its environment
- Corrosion degrade material properties and reduce economic value
- Acidity: Substance that gives hydrogen (H^+) ions or hydronium ions(H_3O^+) in aqueous solution

  $HCl + H_2O = H_3O^+ + Cl^-$
- Alakalinity:Substance that gives hydroxyl ions (OH^-) ions in aqueous solution

  $Na(OH) + H_2O = Na^+ + OH^-$

Physical properties

- Density:
- Amount of mass contained in unit volume of material
- Higher the density the heavier is the substance
- For water 1000 Kg/m^3
- $\rho = \frac{Mass}{Volume}$
- Unit: Kg/m^3
- Viscosity(dynamic viscosity): Property of fluid which offers resistance to the flow of one layer of fluid over another adjacent layer of fluid
- Unit of viscosity : Ns/m^2
- Kinematic viscosity, $\mu = \frac{Dynamic\ viscosity}{\rho}$
- Unit: m^2/s

- Specific gravity
- Ratio of density of a substance to the density of fresh water at 4°C
- $S = \frac{Density\ of\ substance}{Density\ of\ water}$
- No unit. For mercury 13.6
- Colour:
- Represents reflective properties of substance
- Colour of material is that colour which is reflected.Eg:Yellow colour of gold
- Porosity: Presence of small holes or vacant space
- Eg:Clay
- Melting point: Temperature at which material changes its state from solid to liquid at standard atmospheric pressure

Material testing

- Purpose of material testing is to
- check chemical composition
- suitability of material for particular applications
- find out mechanical properties (ductility, toughness etc.)
- determine data such as stress values, for design purpose
- determine surface and sub-surface defects

Classification of Mechanical tests

1. *Destructive Tests:* specimen or the component is destroyed and cannot be reused.

   Eg. Tensile test, hardness test, impact test, fatigue test, creep test, etc.

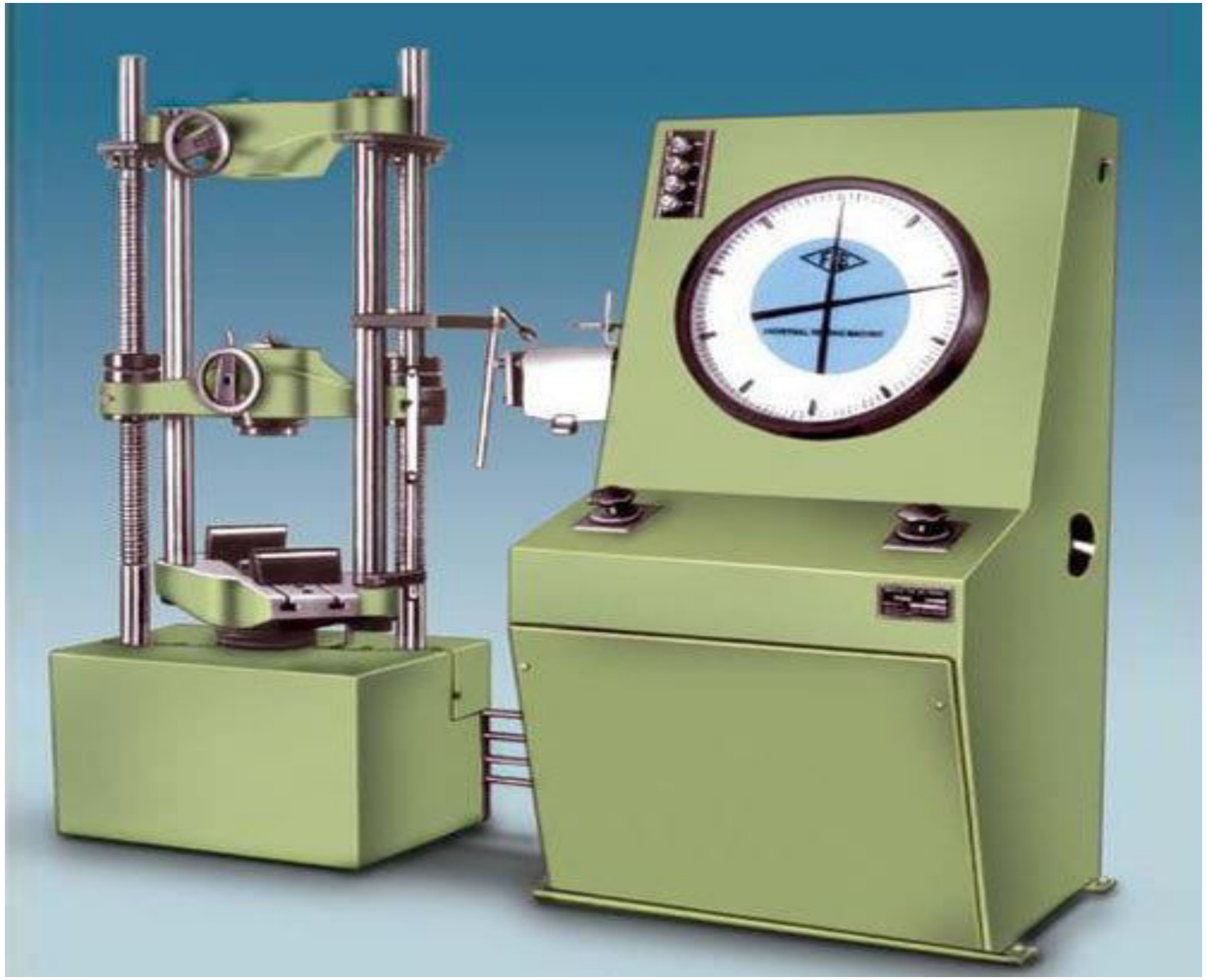
2. *Non-Destructive Tests:* The specimen is not destroyed and can be used after the test.

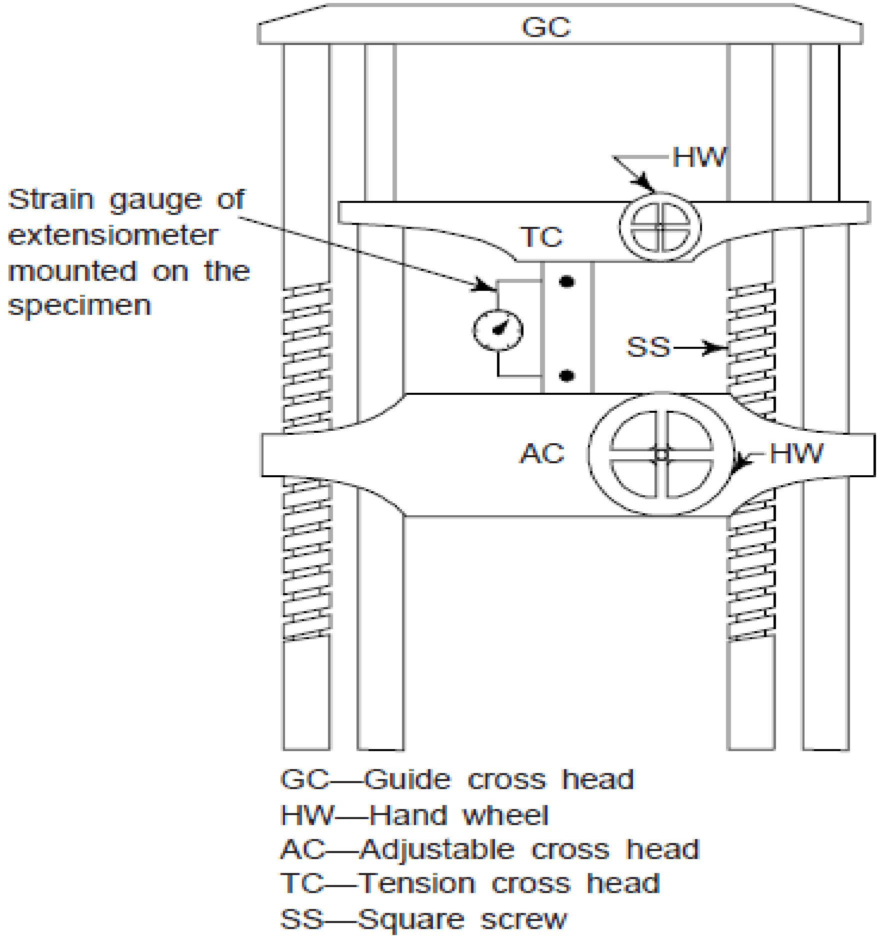
   Eg: Liquid Penetrant Test (LPT), Radiographic Test (RT), Ultrasonic Testing(UT

Tensile test

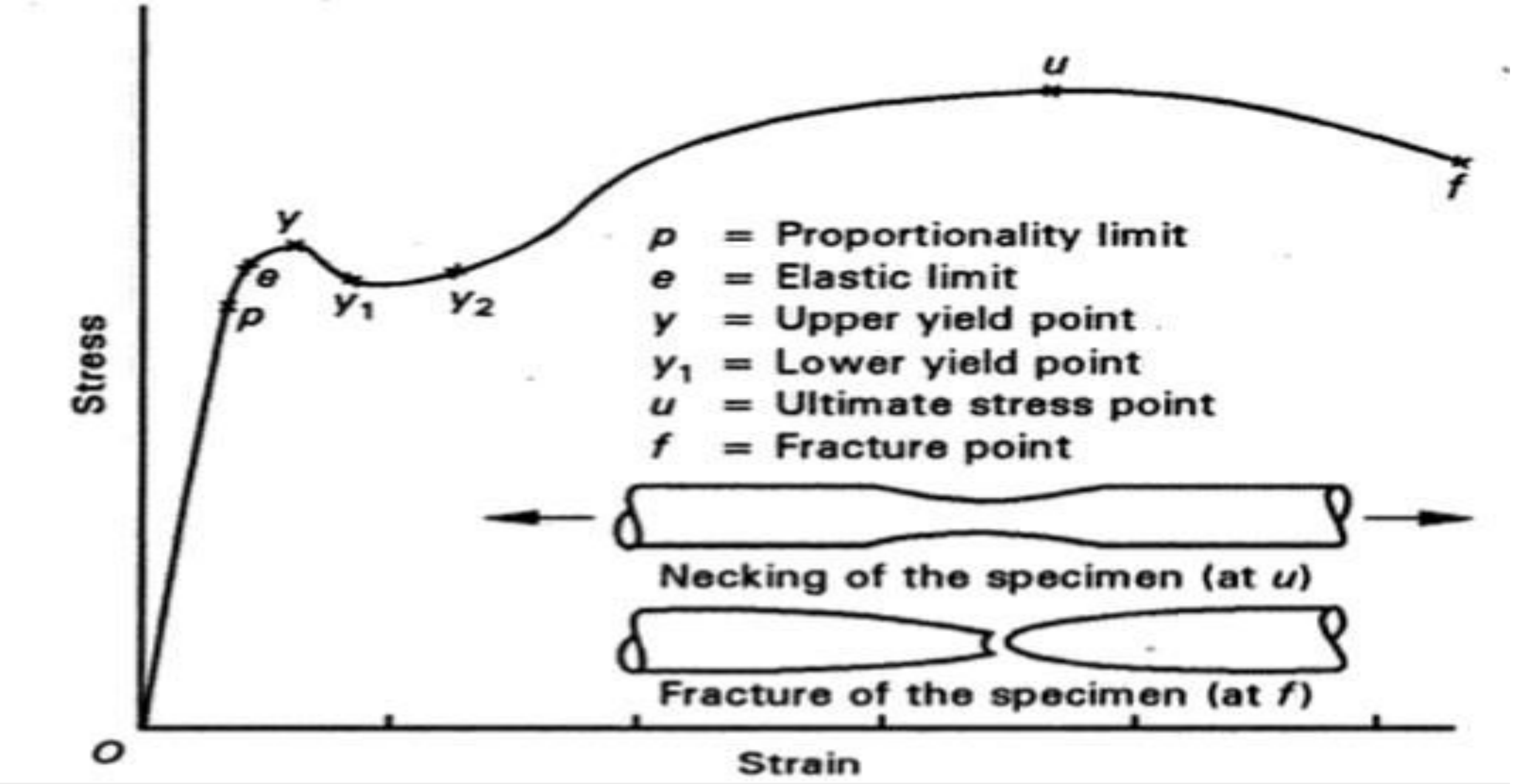
- *To determine tensile properties such as tensile strength, yield strength, percentage reduction in area and modulus of elasticity.*
- Test is carried out in UTM(Universal testing machine)
- Specimen is held in the jaws of machine after marking gauge length
- Pull load is applied gradually(usually hydraulically)
- This causes specimen to elongate and finally fracture
- Magnitude of the load is measured by measuring unit.
- Elongation is measured by an extensiometer attached to machine
- Stress strain graph is plotted from above data

Universal testing machine

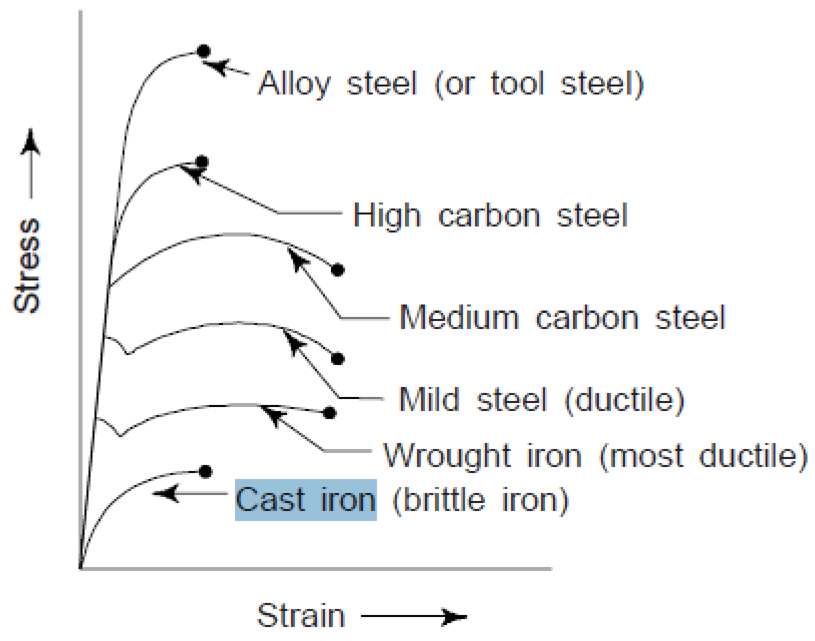




Stress strain curve for ductile material(Mild steel)



Stress strain curve for different materials



Brittle material: Breaks without significant plastic deformation

Tensile test

- *Proportional Limit*: *Stress* ∝ *Strain* (linear relation ship) up to this point. Hook's law obeyed.
- Elastic Limit: Material regain its original shape when unloaded
- Elastic stress = $\dfrac{Elastic\ load}{Original\ cross\ section\ area} = \dfrac{P_e}{A_0}$
- *Yield Point*: Strain increases more quickly than stress
- Yield Strength = $\dfrac{Yield\ load}{Original\ cross\ section\ area} = \dfrac{P_y}{A_0}$

Tensile test

- Ultimate stress :Maximum load that can withstand without failure
- Ultimate Strength = $\frac{Ultimate\ load}{Original\ cross\ section\ area} = \frac{P_u}{A_0}$
- Breaking point: Point at which material breaks.
- Breaking stress = $\frac{Breaking\ load}{Original\ cross\ section\ area}$ (less than ultimate stress)
- % reduction in area = $\frac{Reduction\ in\ cr.sectional\ area}{Original\ area} = \frac{A_0 - Af}{A_0}$ x 100
- % elongation = $\frac{Increase\ in\ length}{Original\ length} = \frac{L_f - L_0}{L_0}$ x 100
- *Young's Modulus of elasticity* (*E* or *Y*) = $\frac{Stress\ at\ any\ point\ within\ elastic\ limit}{Strain\ at\ that\ point}$

Compression test

- Tested in UTM
- Opposite of tensile test
- For testing brittle material like cast iron, concrete etc.
- Specimen placed between table and adjustable cross head
- Push load is applied

Hardness test

- Brinell hardness test
- Vickers hardness test
- Rockwell hardness test

Brinell hardness test

- Test consist of pressing hardened steel ball of diameter (*D = 10 mm)* into the surface of specimen by a gradually applied load *P*
- Specimen is placed on anvil
- Hand wheel is rotated so that specimen along with anvil contact the ball.
- Apply the desired load for 10-15 seconds
- Diameter of indentation 'd' made on the specimen is measured by using a microscope

$$\mathrm{BHN} = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

Brinell hardness testing

Advantages

- Simple to conduct test
- BHN can be correlated with tensile strength of material

Disadvantages

- Area of indentation more, affect surface quality
- Cannot be used for very hard material (ball gets flattened) and thin materials(thin sheets bulge/destroyed)

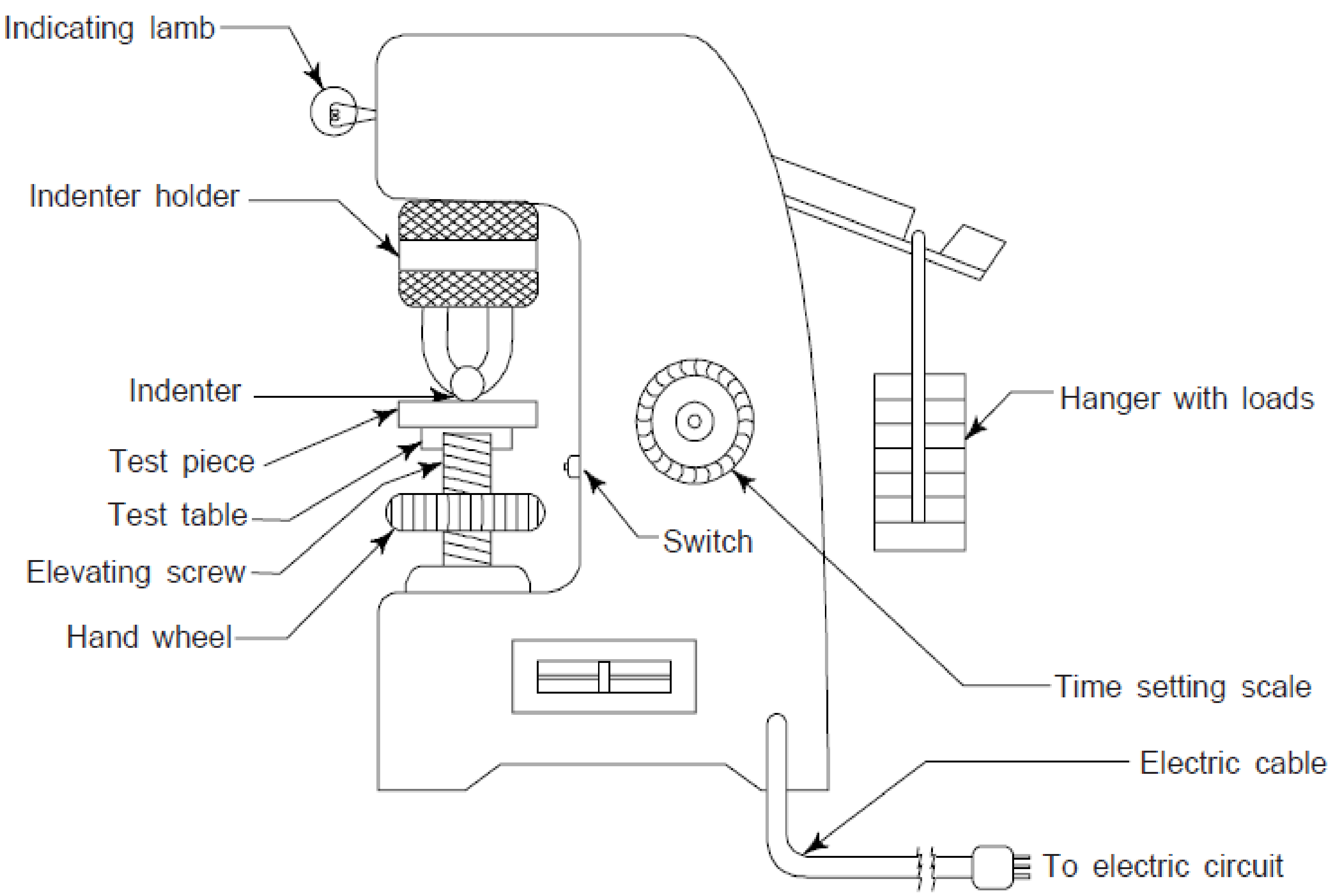


Fig. 8.30 Brinell hardness testing machine

Vickers hardness testing

- Test similar to Brinell hardness testing
- A diamond square based pyramid indentor with 136° angle between opposite faces is used.
- Load varies from 5 kg to 120 kg in steps of 5 Kg
- The specimen is placed on the anvil, which is then raised to indentor
- Load is applied and then removed
- Indentor makes square impression
- Diagonal of impression is measured
- Used for the determination of hardness of very thin and very hard materials

$$\mathrm{VPN} = \mathrm{DPN} = \frac{2P \sin \theta/2}{d^2}$$

Rockwell hardness testing

- Testing machine is simple to operate and does not require microscope
- Free from personal errors and also faster.
- Surface polishing of the specimen is not required.
- Compared to Brinell hardness testers, this test requires much smaller penetrators and loads.
- There are nine scales on the dial *A* to *H* and *K*, but B-scale C scale are widely used
- B-scale uses 1.58 mm diameter ball indenter to record the hardness of soft metals
- C-scale uses diamond cone indenter with 120° cone angle and 0.2 mm tip radius to record the hardness of hard materials

Rockwell hardness testing

Working of machine

- The test specimen is placed on the machine's test table
- The test piece is raised up against the indenter and a minor load 10 kg is applied till the needle on the dial reads zero
- Now, major load of 100 kg (for B-scale) or 150 kg (for C-scale) is applied
- Withdraw the major load and lower the test piece
- Hardness of material is read directly from machine

Impact test

- Capacity of a material to resist suddenly applied load before it fractures is called its impact strength.
- This test is an indicator of toughness of material
- Test is performed on impact testing machine
- Two types of test – charpy and izod
- Charpy test(beam test):
- Specimen is 10 x 10 mm cross section,55 mm length and has a V-notch 2 mm deep of 45° included angle at its centre
- Specimen placed horizontally as a simply supported beam
- Specimen is hit behind the V - notch
- Izod test(cantilever test):
- Specimen is 10 x 10 mm cross section and 75 mm length and has a *V*-notch 2 mm deep of 45° included angle.
- Specimen is held vertically as a cantilever beam
- Specimen with V notch facing the pendulum will be hit above the V notch

Specimen for Izod and charpy test

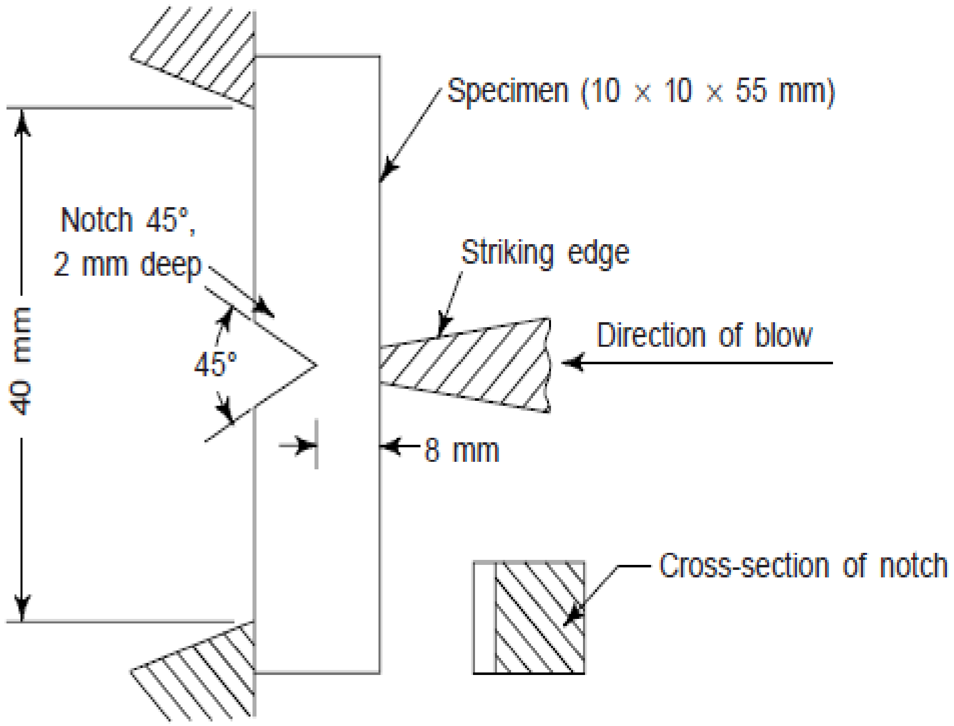


Fig. 8.34 Specimen for Charpy test

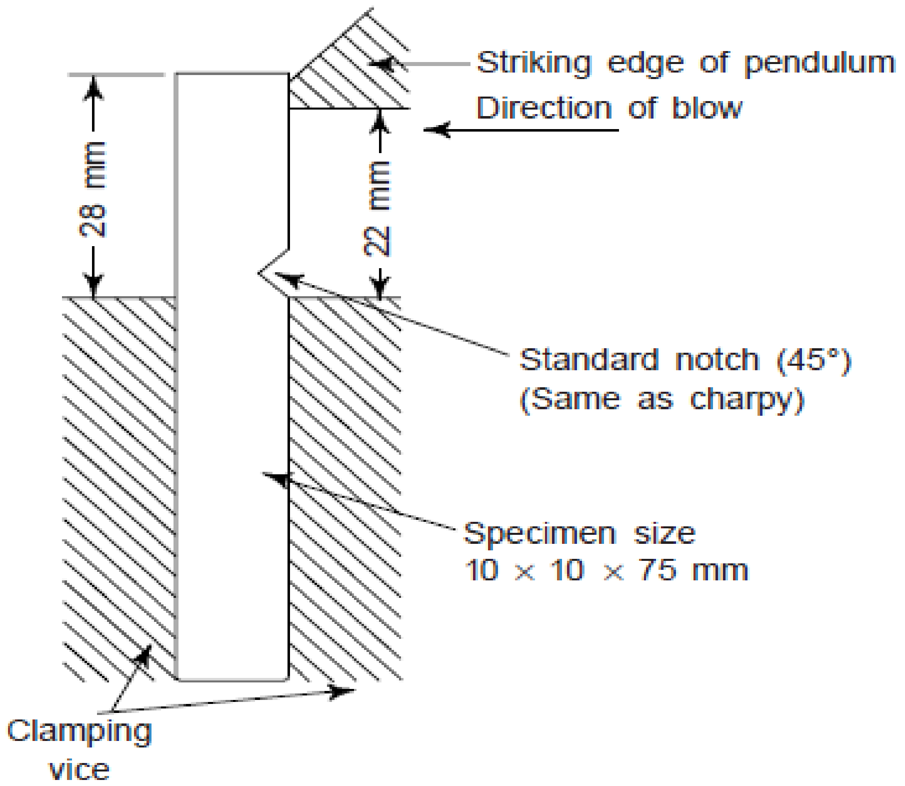
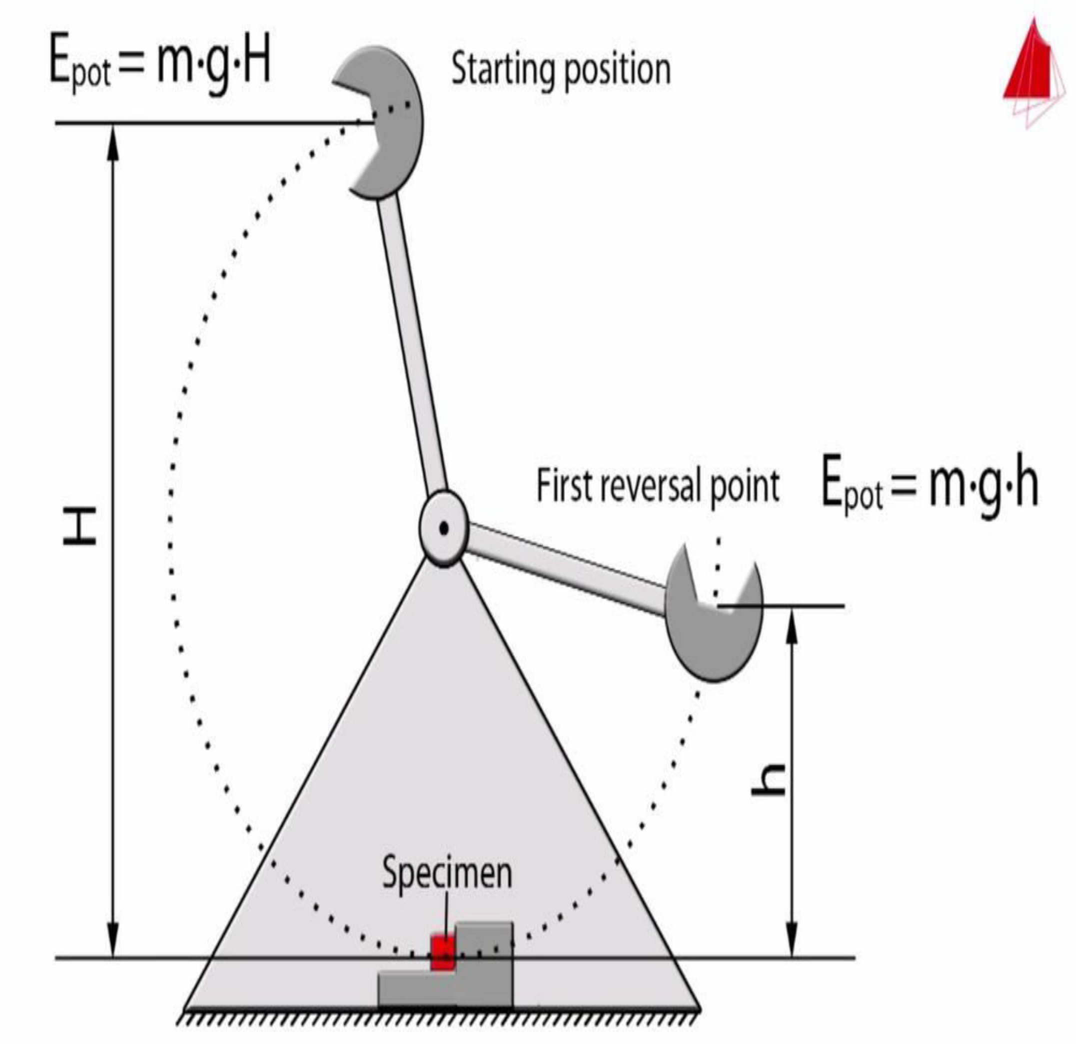


Fig. 8.33 Cantilever beam of Izod test

Impact test

- A pendulum having a weight at one end is raised to a height ‘h’ from where it is released
- Pendulum strikes the specimen placed at the base
- A portion of energy possessed by pendulum is used to break the specimen, so pendulum will rise to a lower height (h') on the opposite side than its initial height (h)
- The energy required to break the specimen ,E = W(h-h ') Joules



Fatigue test

- Test is conducted on a rotating beam fatigue testing machine
- Specimen is loaded in pure bending and rotated with the help of motor
- The surface of specimen is subjected to alternate tensile and compressive stress
- A counter records the number of cycles the specimen withstand before it beaks
- A number of specimen of same material are tested under different load
- Number of cycles ‘N’ at which fracture occurs is determined
- Results are plotted in S-N curve

Fatigue test

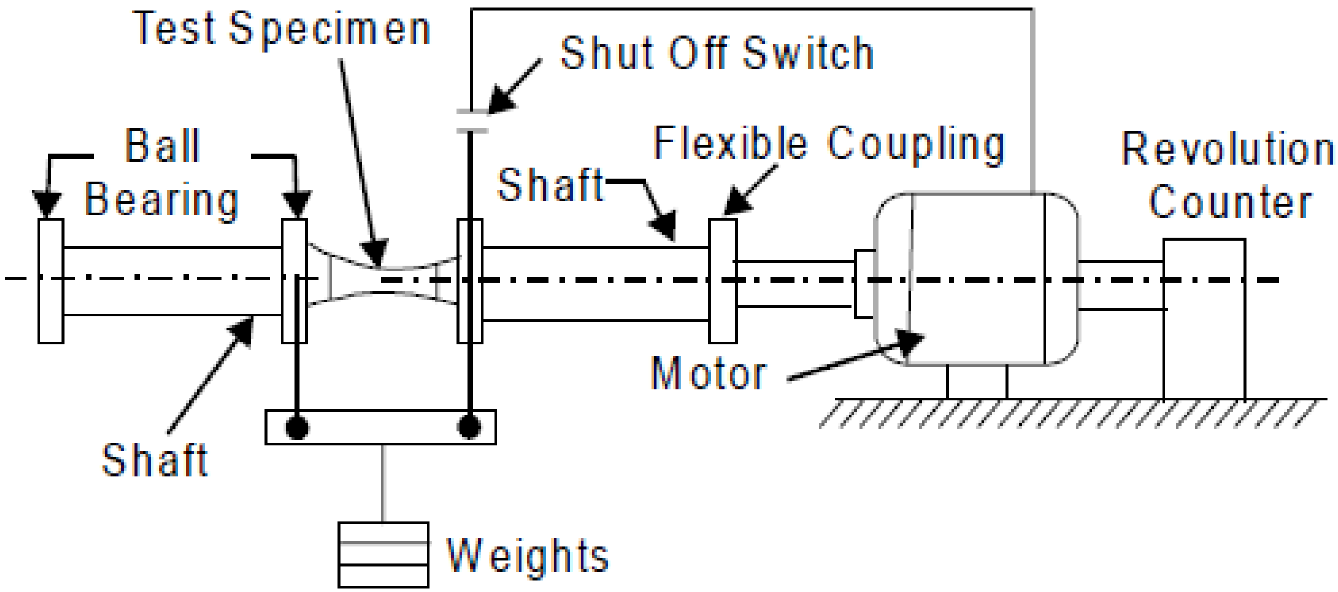


Fig. 7.11 Schematic fatigue test setup

Fatigue test

- The number of revolution required to produce fracture increases as the stress decreases.
- After some tests a limit is reached when the stress is not sufficient to break the specimen after infinite number of revolutions(10^7 cycles)
- This safe stress which does not cause specimen to break is called *endurance limit or fatigue limit*

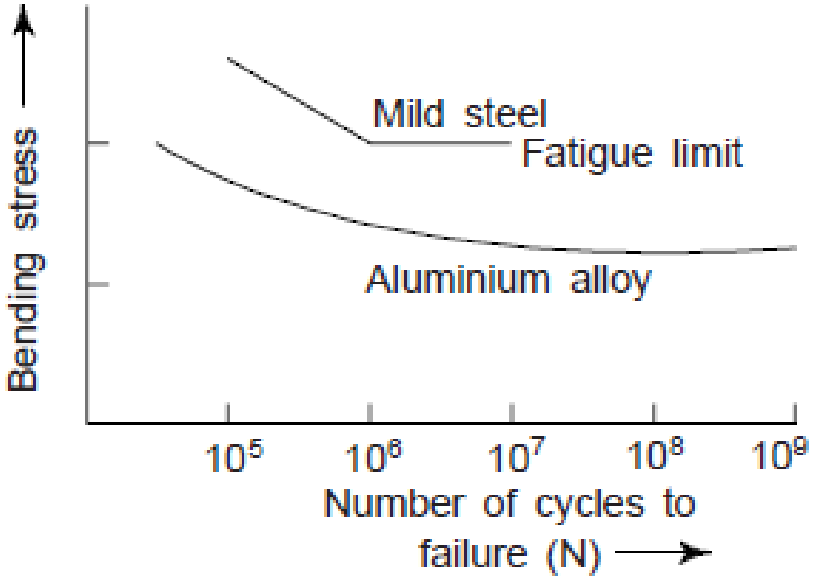
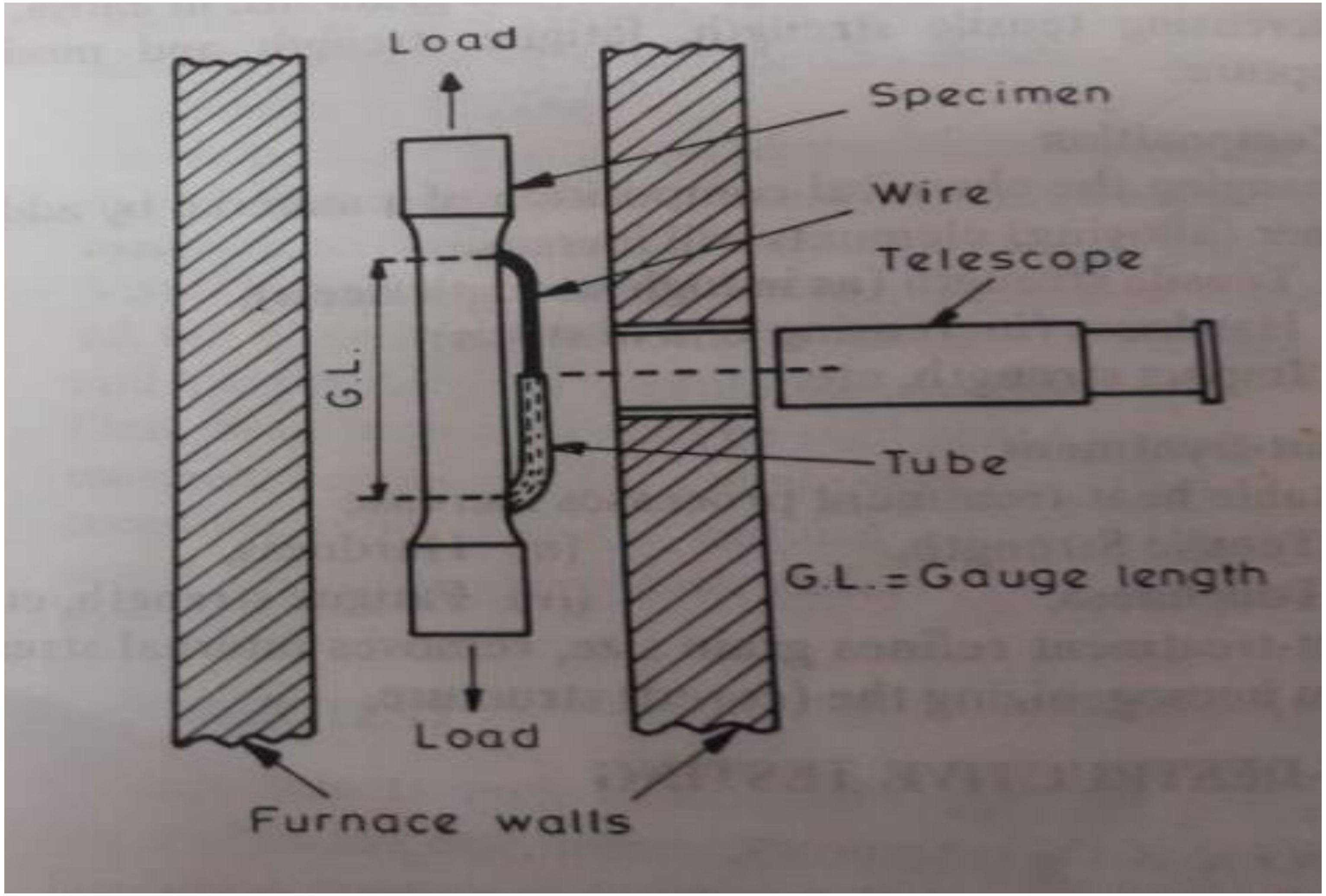


Fig. 8.16 S-N Diagram

Creep test

- Specimen to be tested is kept in an electric furnace at high temperature and a constant load is applied
- A platinum wire is spot welded to one end of its gauge length and a platinum tube at other end
- Platinum wire slides inside the tube. Elongation can be measured on a scale inside the telescope
- Four or five specimen are tested at each temperature under different load
- Elongation vs time curve are plotted for each specimen

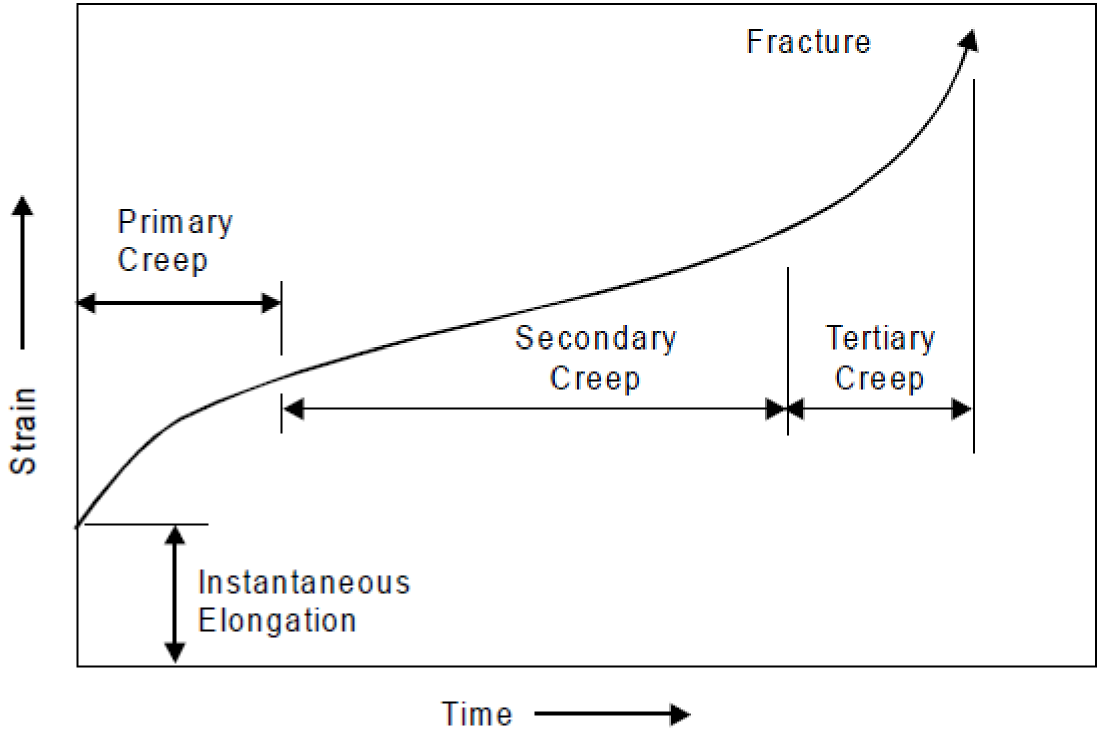
Creep test



Load
Specimen
Wire
Telescope
G.L.
Tube
G.L. = Gauge length
Load
Furnace walls

Creep

- Primary creep: After initial rapid elongation, the creep rate decreases
- Secondary creep: Constant creep rate. Longest duration of the three modes.
- Tertiary creep : Increase in creep rate up to failure



Non destructive testing

1. Liquid(Dye) penetrant test

- Detects flaws that are open to surface eg.cracks,laps,porosity etc.
- Used for the inspection of ferrous & non ferrous metals,ceramics,plastiscs and glass
- Surface of the material is properly cleaned
- Spray colour penetrant on the surface
- After allowing sufficient penetration time, excess penetrant is removed
- Developer(absorbent powder) is then applied to revel the flaws by absorbing penetrant from these flaws
- If fluorescent penetrant is used, surface must be examined under ultra violet light to see the presence of defects

Liquid penetrant test

- Clean
- Spray penetrant
- Waiting time
- Carefully clean off excess penetrant
- Spray developer
- Wait and watch

Radiography

- Use of X-rays and γ- rays to check internal defects like blow holes, slag inclusion, gas porosity etc. in welding, forging and casting

Principle

- X-rays or γ- rays are passed through metals being examined and a picture is obtained in a photographic film
- Intensity of rays coming out of object depends on density of object
- Presence of internal defects will change the intensity of radiation and the defect will appears as either light or dark areas in the film

X-ray radiographic procedure

- X-rays are produced in x-ray tube
- Metallic component to be tested is exposed to X-rays
- A cassette containing X-ray film is placed behind the casting perpendicular to X-rays
- Defects like porosity, cracks etc. has lesser density than sound metal
- They transmit X-rays better than sound metal and appears darker in X-ray film
- Defects like inclusion has high density and appears lighter in X-ray film

X-ray radiography

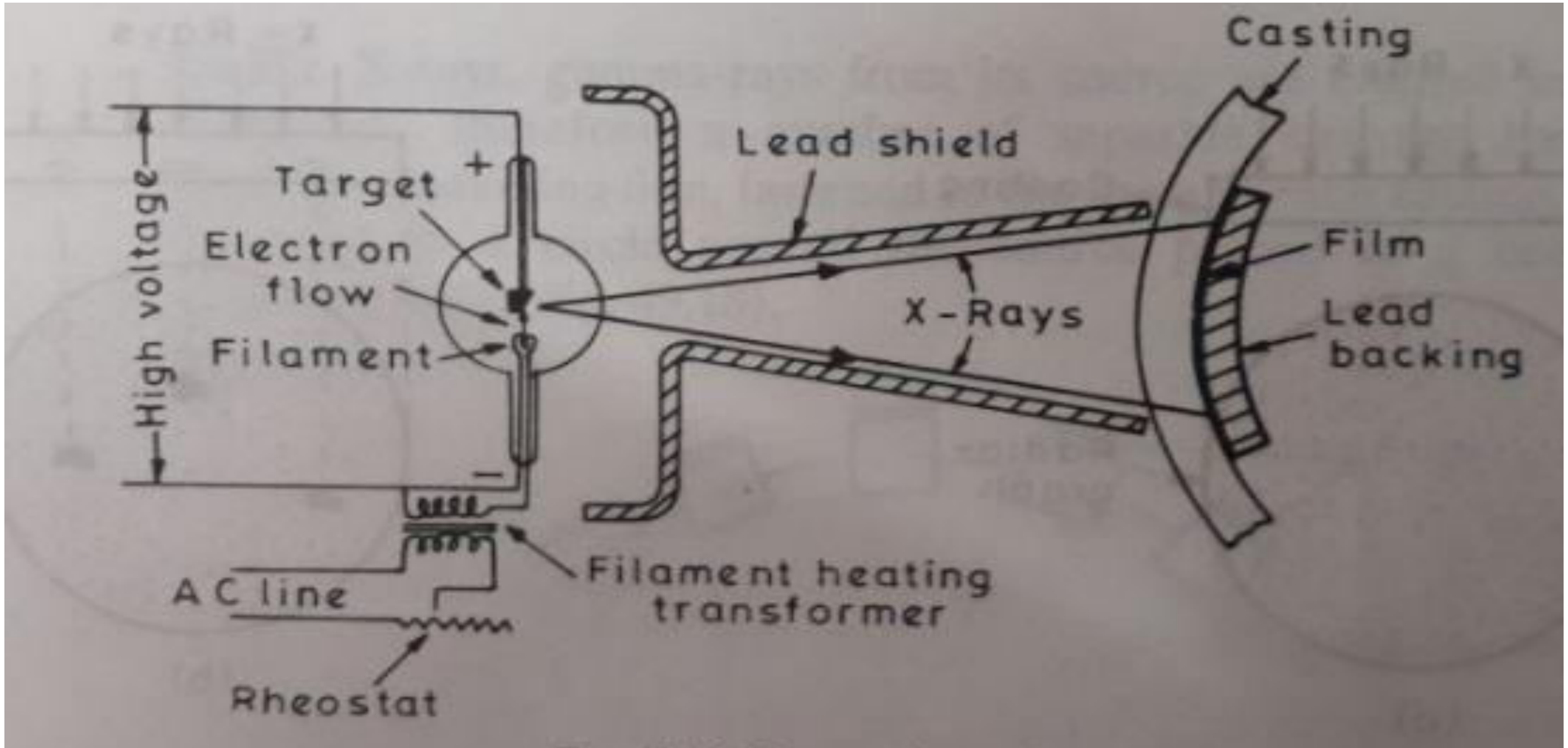


Fig. 49.16. X-ray radiography.

γ- ray radiography procedure

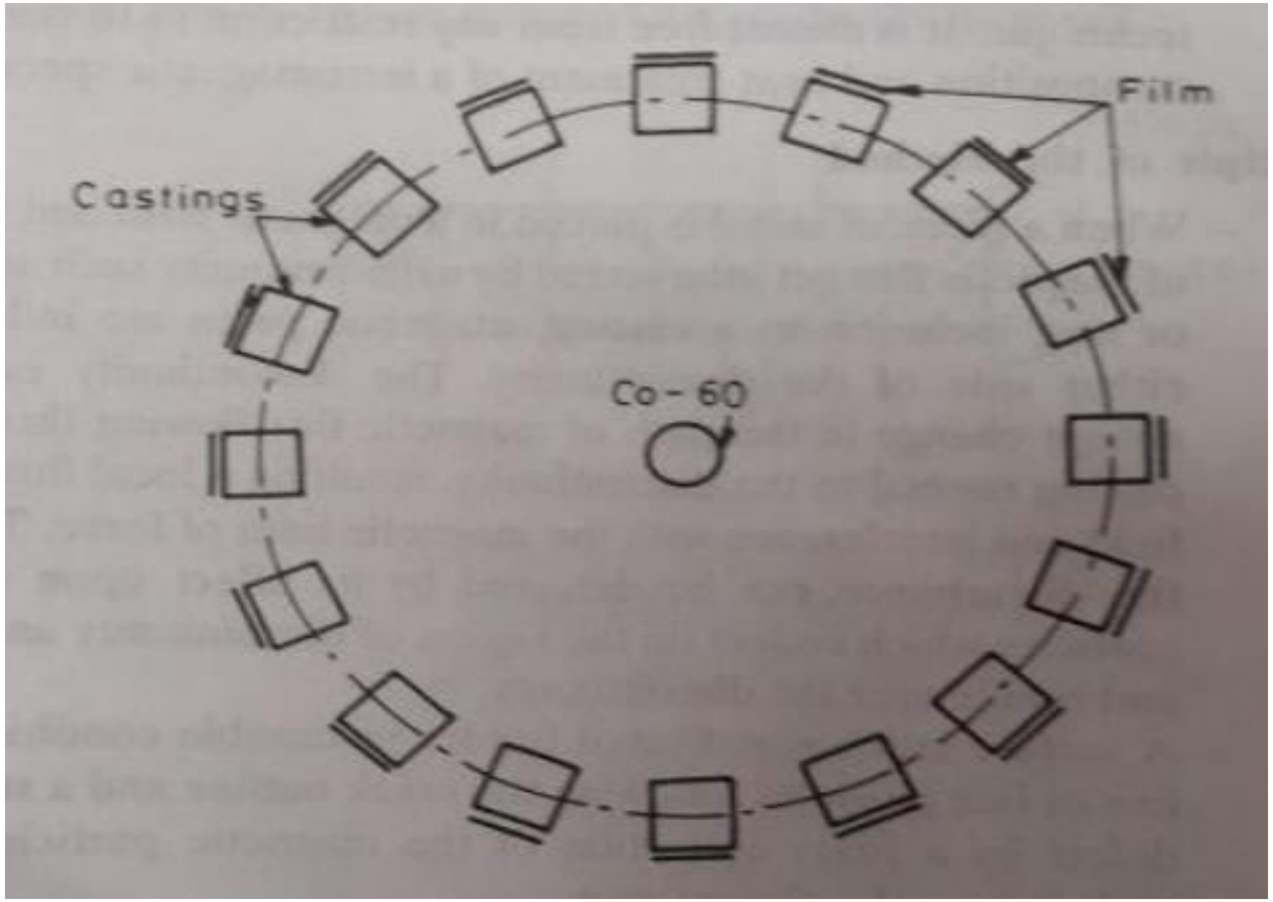
Difference between γ- rays and X-rays

- γ- ray are used for check defect in thicker castings
- Less scattering, gives better result for casting of varying thickness
- X-rays gives better result for casting of uniform thickness
- X-rays better than γ- ray for small defects in casting less than 50 mm
- γ- ray technique takes longer time
- γ- ray technique can inspect number of component at a time

γ – radiography procedure

- γ- rays are emitted from radioactive substance a such as radium, radon, cobalt 60
- Radioactive substance is sealed in containers and placed at centre
- Number of separate castings are arranged around radioactive substance in a circle
- Cassette containing film is placed behind each casting
- Developed film will reveal the presents of defects as in X-rays

γ – radiography



Ultrasonic inspection

- Used to locate defects such as shrinkage cavities, internal cracks, porosity and inclusions in ferrous & non ferrous metals, plastic and ceramics
- High frequency ultrasonic (sound) waves (20 KHz and 20 MHz) is applied to the test piece from transmitter probe
- It strikes the upper surface of casting and makes a sharp(peak) or pip(echo) at left side of CRO screen
- If the test piece is free from cracks the wave will strike bottom surface get reflected and indicated by a pip (echo) towards right side of CRO screen
- If any defect exists between top and bottom surfaces, the input waves strikes the defect get reflected and reaches receiver probe taking less time
- It is indicated by a pip echo on CRO screen before back echo(reduced echo)
- Location and size of defect is found out with a distance time scale provided on CRO

Ultrasonic inspection

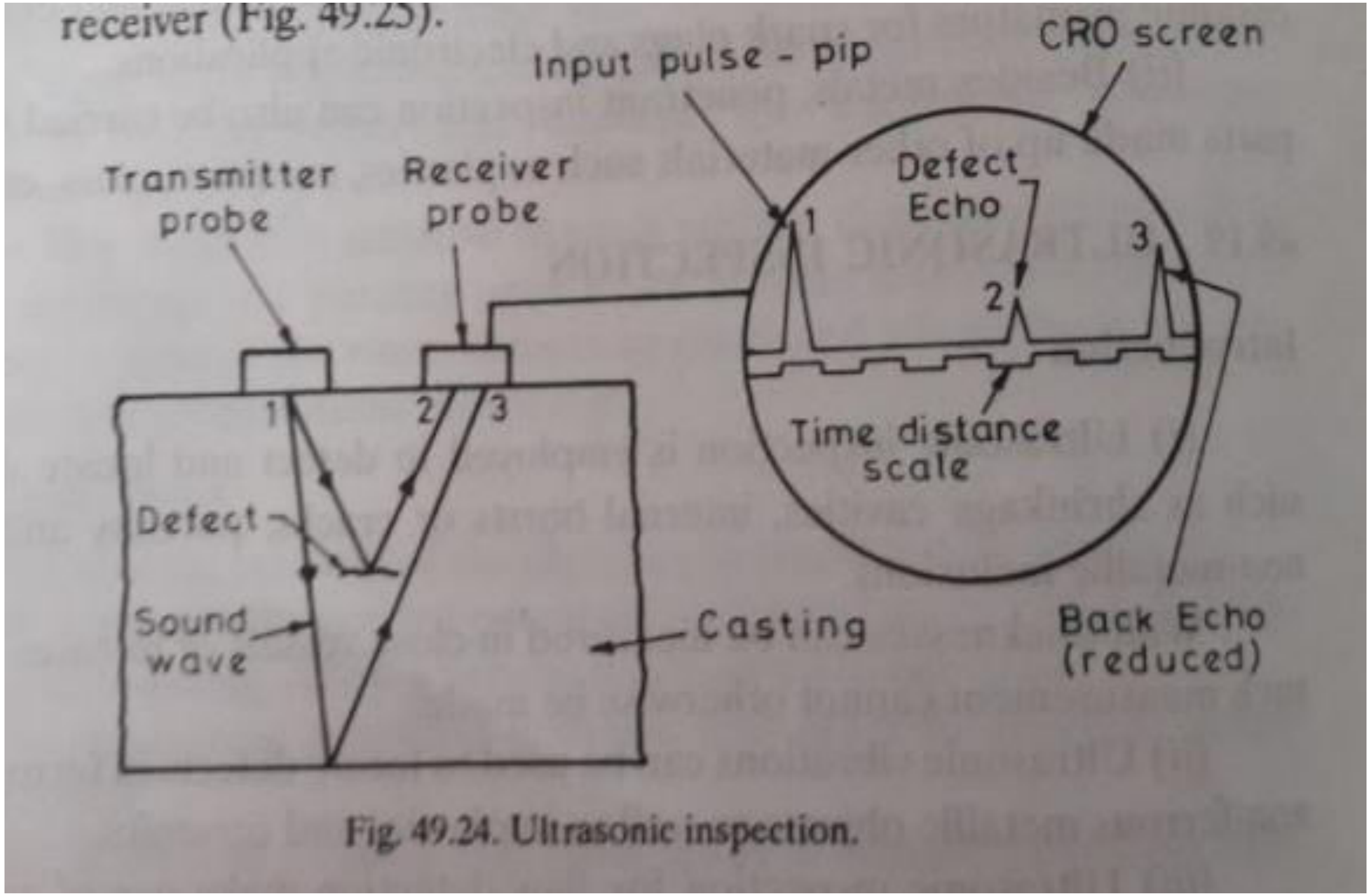


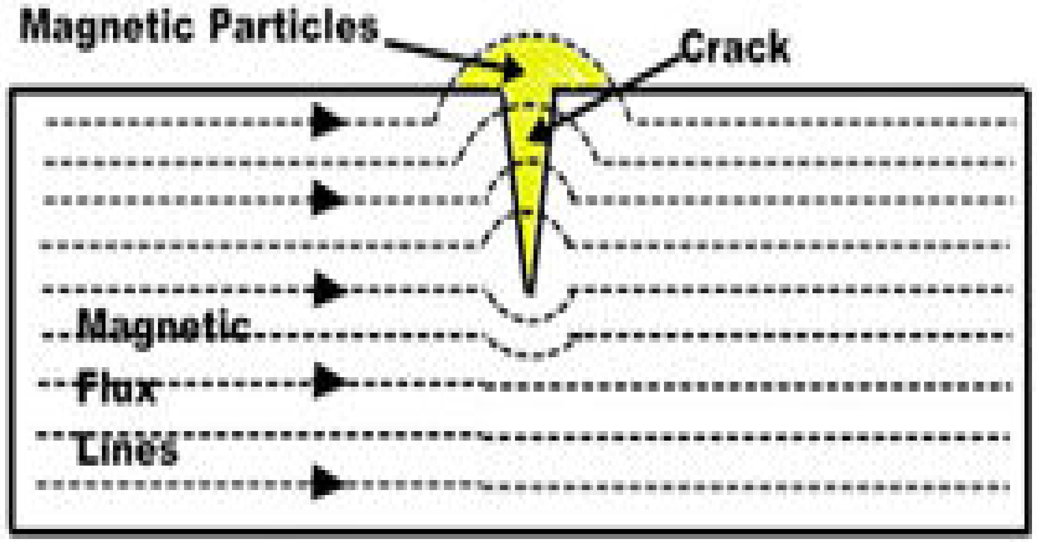
Fig. 49.24. Ultrasonic inspection.

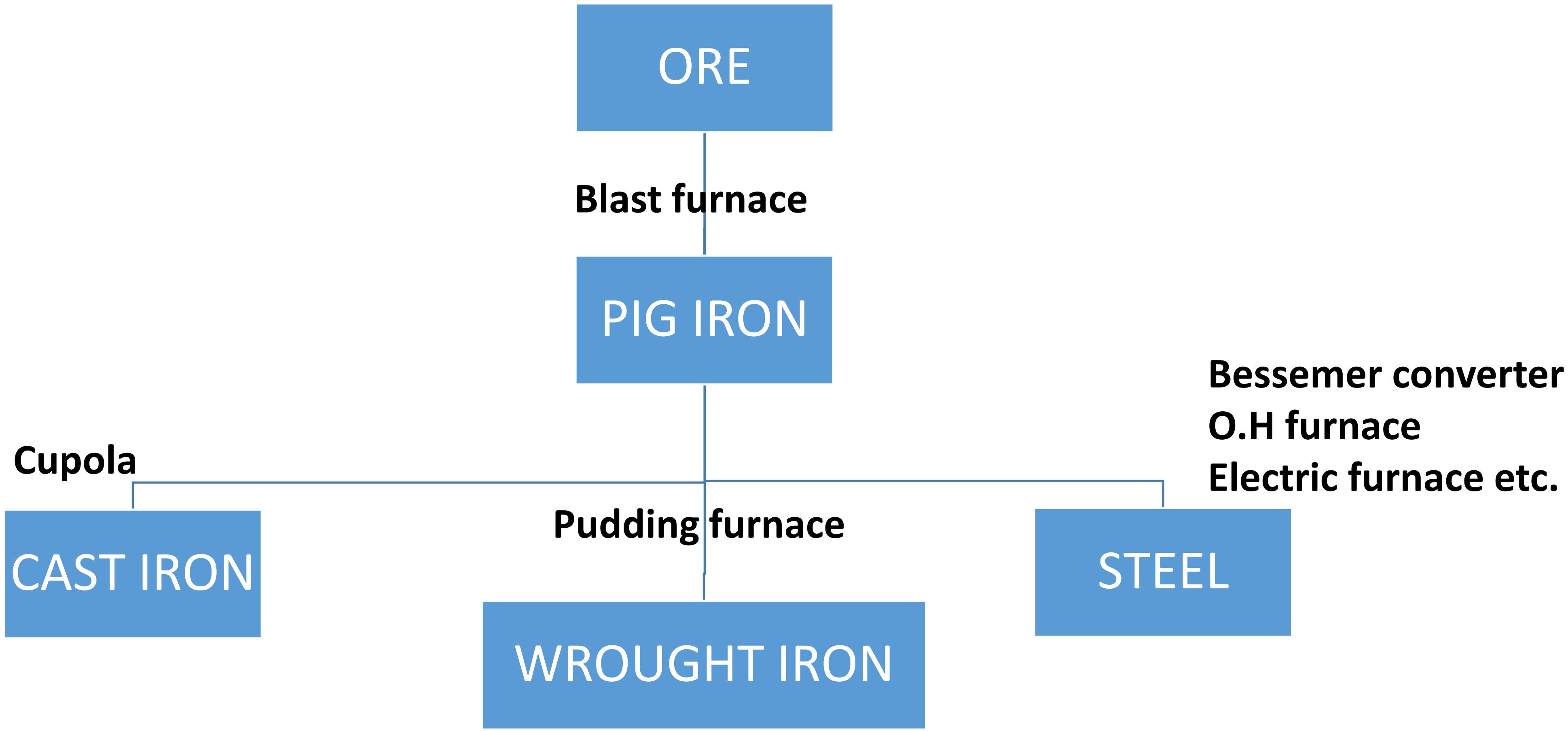
Ultrasonic inspection

Ultrasonic inspection

- Application:Inspection of large casting and forging for internal soundness
- Inspection of locomotive axles and wheel pins for fatigue cracks
- Limitation
- Sensitive to surface roughness. Initial machining required
- In complex castings waves reflected from corners give false indication of defect
- Advantages
- Fast and reliable
- Low cost, high speed of operation
- Locating defects in metal object is more sensitive than radiography
- Small cracks and defects are easily detected

Magnetic particle inspection




ORE
Blast furnace
PIG IRON
Bessemer converter
O.H furnace
Electric furnace etc.
Cupola
Pudding furnace
CAST IRON
STEEL
WROUGHT IRON

Cast iron

- Contain 2 to 4.5 % carbon
- Contain small amount of silicon,sulphur,manganese,and phosphorus
- Low melting point
- Brittle material – cannot be used for parts subjected to shock
- Low cost, good casting characteristics, high compressive strength, wear resistance, excellent machinability

Types of cast iron

1. Grey cast iron

- contains 2.5-3.8% C, 1.1-2.8% Si, 0.4-1% Mn, 0.15% P and 0.10% S.
- carbon is present in the form of graphite flakes.
- when fractured it gives grey color
- lowest melting point among ferrous alloys.
- high fluidity and hence it can be cast into complex shapes and thin sections
- machinability better than steel.
- high resistance to wear
- high vibration damping capacity

Application of grey cast iron

- Machine tool structures such as bed, frames, column etc.
- Gas or water pipes for under ground purposes.
- Man holes covers.
- Piston rings.
- Rolling mill and general machinery parts.
- Cylinder blocks and heads for I.C. engines.
- Frames of electric motor.

2. White cast iron

- Carbon is in the form of iron carbide(Cementite), the hardest constituent of iron. So its white colour
- Formed by quick cooling of molten iron
- Contains 2 – 2.5 % C, .85 – 1.2 % Si, 0.1 - 0.4Mn, 0.18% P and 0.10% S.

Properties

- Abrasive wear resistance
- Extreme hard. Difficult to machine
- Good castability
- **Applications**
- For producing malleable iron castings.
- For manufacturing parts which require a hard, and abrasion resistant surface such roller for crushers, wearing plates etc.

3. Malleable cast iron

- Formed from white cast iron by suitable heat treatment process (annealing)
- Annealing convert combined carbon in white cast iron into graphite nodules or temper carbon
- Three types of malleable cast iron - Black heart(BM) and white heart (WM) and Pearlitic (PM)
- Contains 2-3% C, 0.6-1.3% Si, 0.2-0.6% Mn, 0.15% P and 0.10% S.

Properties

- good ductility and malleability
- high yield strength
- medium cost
- good machinability and castability
- good wear resistance and vibration damping capacity.

Application

- Automobile parts
- Agricultural implements.
- Electrical line hardware.
- Conveyor chain links.
- Gear case.
- Crankshaft.
- Hinges, door keys, spanners
- Thin walled components of sewing machines and textiles machine parts.

4. Nodular Cast Iron (Ductile iron or spheroidal graphite)

- produced by adding magnesium to molten iron
- graphite appears as nodular or spheroidal form
- contains 3.2-4.2% C, 1.1-3.5% Si, 0.3-0.8% Mn, 0.08% P and 0.2% S.

Properties

- good machinability
- high fluidity, good castability,strength,toughness
- wear resistance
- good damping capacity
- weldability
- pressure tightness

Application

- Tractor parts
- Paper industries machinery.
- Internal combustion engines.
- Power transmission equipment.
- Earth moving machinery.
- Valves and Fittings.
- Steel mill rolls and mill equipment.
- Pipes.
- Pumps and compressors
- Construction machinery

STEEL

- an alloy of iron and carbon
- Carbon up to 2 %(commercially 1.5 % C)
- Carbon exist in the form of iron carbide and ferrite
- Other elements like silicon, sulphur, phosphorus and manganese are also present
- Types of steel
- Plain carbon steel (un alloyed)
- Alloy steel

Plain carbon steel(Un alloyed steel)

- Contains up to 1.5% carbon

1. Low carbon steel

- Dead mild steel: Contain .05 to .15 % C
- Mild steel contain 0.15 to 0.30%.
- Soft,ductile,low tensile strength, easily worked and welded
- Used for making nuts,bolts,steel wire, sheets, rivets, screws, pipe, nail,chain,body work for car and ships etc.

2. Medium Carbon Steel

- Contain carbon from 0.30 to 0.60%.
- It can be forged, welded, machined.
- It is ductile, malleable, absorb sudden shocks
- Used for making Axles, Connecting rods, Crankshafts, Agricultural tools, gears, fasteners etc.

3. High carbon Steel

- Contain carbon from 0.60 to 1.5 %
- It is used for parts requiring strength,hardness,wear resistance
- Used for making hacksaws, hammers, cold chisels,punches,dies, taps, drills, razors, machine tools etc.

Alloy steel

- For improving the properties of plain carbon steel, certain alloying elements are added in it
- Common alloying elements added to steel are *nickel, chromium, cobalt, manganese, molybdenum, silicon, vanadium, tungsten, copper, aluminium.*
- *The purposes of alloying steels are :*
- Improve corrosion resistance
- Improve machinability ductility, toughness ,hardness, strength
- Better wear resistance
- Improved cutting ability
- Grain size control

Effects of alloying elements in steel

- **Nickel:**
- improves strength,elasticity,ductility,toughness,resistance to corrosion
- Lessens distortion in quenching
- Lowers the critical temperatures of steel and widens the range of heat treatment
- Nickel alloy steel containing 36 % nickel is known as invar. Used in pendulum of clock and precision measuring instruments
- **Chromium**
- improves strength, hardness, wear resistance, corrosion and heat resistance
- **Tungsten**
- Increases red hardness, wear resistance, shocks resistance and magnetic properties
- Retain hardness and toughness at high temperature.
- Used in tools, dies, valves, taps and permanent magnets.

Effects of alloying elements in steel

- **Vanadium**
- improves tensile strength, elastic limit, ductility, toughness, hot hardness, fatigue resistance. Strong deoxidiser.
- **Manganese**
- improves the strength and hardness of steel.
- used as deoxidiser and desulphuriser
- **Molybdenum**
- increases hardness, wear resistance, thermal resistance
- Reduces temper brittleness

Effects of alloying elements in steel

- **Cobalt**
- refine grains.
- improves red hardness, toughness, strength and heat resistance
- Increases residual magnetism and coercive magnetic force
- **Copper**
- improves resistance to corrosion.
- **Aluminium**
- good deoxidiser, it helps promoting nitriding
- **Silicon**
- Improves hardness,strength,oxidation resistance
- Acts as a deoxidizer
- Increases magnetic permeability and reduce hysteresis loss

High speed tool steel

- Used for cutting metals at higher speed
- Operate at cutting speeds,2 to 3 times more than carbon tool steel
- Retains hardness up to 600˚C

1. 18-4-1 High speed steel

- contains 18% tungsten, 4% chromium and 1 % vanadium, 0.8 carbon and remaining iron
- Used for lathe, planer and shaper tools, drills, milling cutters, punches etc.

2. Molybdenum high speed steel

- Contains 6% Mo, 6% W, 4% Cr, 2% V, 0.8% C and remaining Fe.
- excellent toughness and cutting ability.
- cheaper than other types of steels used for drilling and tapping tools.

3. Cobalt based high speed steel

- Contains 12% Co, 20% W, 4% Cr, 2% V, 0.8 carbon and remaining iron
- Used for heavy cutting operation at elevated temperature. Also known as *super high speed steel*

stainless steel

- Alloy steel which are high resistance to corrosion, high strength, ductility
- Chief alloying element chromium
- Other alloying elements includes nickel,molybdenum,silicon, copper etc.

1.Austenitic stainless steel

- Contain 18%Cr and 8%Ni (Commonly called 18/8 steel)
- Carbon less than 0.2%
- Excellent corrosion resistant, nonmagnetic and very ductile
- Hardened by cold working
- Application: air craft engine parts, cooking utensils, furnace and heat exchanger parts, milk cans, kettles etc.

Stainless steel

2. Ferritic Stainless steel

- Contains 12 to 27 % chromium, C less than 0.1 %
- Magnetic and corrosion resistance but are less ductile than austenite
- Hardened by cold working ,not heat treatable
- Application: Furnace parts,Interior decorative work, cooking utensils,Jet engine parts,Screws and fittings etc.

3.Martensitic Stainless steel

- Chromium up to 18 %.Carbon 0.1 to 1 %
- Hardened by heat treatment
- High strength,hardness,fatigue strength, ductility, moderate corrosion resistance
- Application: cutlery and surgical tools,instruments,valves,springs

Magnetic steel

- High Cobalt steels having 15 to 40% Co, 0.4 to 1 % C, 1.5 to 9% Cr, W up to 10 % are called magnetic steel
- Used in making permanent magnets for magnetos, loud speakers and other electrical machines.
- An important permanent magnet alloy is

  Alnico :contains 60% Iron, 20% Nickel, 8% Cobalt and 12% Aluminium.

BIS specification of steel

1.Steel designation on the basis of mechanical properties

1.Symbol Fe followed by minimum tensile strength in N/mm^2

or

Symbol FeE followed by minimum yield strength N/mm^2

2.Special characteristics such as method of deoxidation,weldability guarantee, surface condition etc.

Eg:Fe 470 W - Minimum tensile strength 470 N/mm2 with fusion welding quality

Steel designation on the basis of chemical composition

1.Plain carbon steel(un alloyed steel)

XCYZ

X – 100 times the average % of C
C – carbon

Y – 10 times average % of Mn

Z – special characteristics

Eg: 35 C 10 G – Steel with average .35 % C,1% Mn,guaranteed hardenability

2.Carbon tool steel (Unalloyed tool steel)

XTY

X and Y have same meaning as above

T – Tool steel

Eg:72 T 5 – Unalloyed tool steel with .72 % C and .5% Mn

Steel designation on the basis of chemical composition

3.Low and medium alloy steel(alloying element not exceeding 10 %)

1 st symbol – 100 times average % of C

2 nd,4th,6th symbol – Elements

3rd ,5th ,7th symbol – % elements multiplied by factor as follows

Elements	Multiplying factor
Cr,co,Ni,Mn,Si,W	4
Mo,Al,V,Pb,Cu,Ti	10
P,S	100

Last symbol – Special character

Eg:24 Cr 4 Mo 2 G – Steel containing 0.24% C,1% Cr,0.2% Mo and guaranteed hardenability

Steel designation on the basis of chemical composition

4.High alloy (more than 10% alloying element)

Eg: X 10 Cr 18 Ni 9 S3

X – High alloy steel

10 – 0.10 % C

Cr 18 – 18 %

Ni 9 – 9% Ni

S3 – pickled condition

Steel designation on the basis of chemical composition

5.High alloy tool steels

Eg:XT 98 W6 Mo 5 Cr 4 V1

XT – High alloy tool steel

98 – 0.98 % C

W 6 – 6 % Tungsten

Mo 5 – 5 % Molybdenum

Cr 4 – 4 % chromium

V1 – 1% vanadium

Non ferrous metals

Copper,Aluminium,Nickel,Zinc,Tin,Lead

Copper

- most widely used non ferrous metal in industry
- soft, malleable and ductile metal with a reddish-brown appearance.
- a good conductor of heat & electricity
- non-corrosive under ordinary condition
- easily machined,welded,brazed,soldered
- used for making electric cables and wires for motor winding, electric transmission etc.
- making cooking utinsils,radiator elements, refrigerator tubes etc.

Copper alloys

1. Brass

- Copper and Zinc alloy(50 % Cu and 50% Zinc)
- Greater strength than copper, but poor conductor of heat &electricity
- Non corrosive, easily machinable, soldered
- Non magnetic
- Types of brass

a. Yellow Brass or Muntz Metal

- Contains Cu = 60%,Zn = 40%
- high strength ,high hot workability
- Used for making bolts, rods, tubes,valves,fuses,taps, condenser tubes, ship sheathing etc

Copper alloys

b.Nickel brass(Germen Silver)

- Contains 60% Cu,35 %Zn,5 % Ni
- Good strength, corrosion resistance
- Silvery white appearance
- Used for making valves, plumb fittings, automobile fittings, musical instruments
- Other common brass are Cartridge brass, Leaded brass,Admirality brass, Naval brass

Copper alloys

2. Bronze

- alloy of copper (75 to 95%) and tin (5 to 25%)
- better strength & corrosion resistance than brass
- hard , resists surface wear
- shaped or rolled into wire, rods and sheets
- Costlier
- Antifriction or bearing properties
- Used for making hydraulic fitting, utensils,bearings,bushes,rods,wires etc.

Copper alloys

- Types of bronze

a. Bell metal

- Contain 15 to 20 % tin
- Hard,brittle,wear resisting but are sonorous(capable of giving ringing sound)
- Used for making bells

Gun metal

- Contain 88 % Cu,10% Sn,2% Zn
- It is known as gun metal because previously it was used for making guns due to its strength
- Used for casting boiler fittings,bearings,glands etc.
- Other common bronzes are Phosphor bronze, Silicon bronze, Beryllium bronze, Manganese bronze, Aluminium bronze

Nickel alloys

- Monel metal
- Contains 68 % Ni,29% Cu and 3 % other constituents like Fe,Mn,Si,C
- Strong, ductile and tough
- Superior to brass and bronze in corrosion resistance
- Used for making propellers, pump fittings, condenser tubes, turbine blades, sea water exposed parts, chemical and food handling plants
- Inconel
- contains Ni = 76 %,Cr = 15% and rest iron
- high resistance to corrosion and oxidation at elevated temperatures
- can be casted, forged, cold drawn
- Welded by both arc and gas welding methods
- Used for making exhaust manifold for air craft and spring which have to with stand high temperature and corrosion

Nickel Alloys

- Nichrome
- Consist of 65% Ni,15% Cr,rest iron
- High resistivity, resistance to oxidation creep resistance
- Used for making heating elements
- Nimonic
- Contains Cr = 75 % Ni,20 % Cr,2 titanium rest Co,Mo,Al & Fe
- Ability to operate under intermittent heating and cooling condition
- used for making gas turbine engines

Tin alloys

Babbitt metal

- Contains Sn = 88%,antimony = 8%,Cu = 4%
- excellent antifriction properties and sufficient mechanical strength.
- easily casted
- expensive because of high tin content
- **Applications**
- used for making bearing metal subjected to high pressure

Solder

- 60 % tin + 40 % lead

Aluminium and its alloys

- Pure aluminium has silvery colour and lusture.
- Ductile, malleable and very good conductor of heat and electricity.
- Very high resistance to corrosion than the ordinary steel
- alloyed with other elements like copper, magnesium, zinc, manganese, silicon and nickel to improve various properties
- Duralumin

Cu = 4 %,Mn & Mg each = .5 %,Al = 94%

- High strength after age hardening,formability,electrical conductivity, Non magnetic
- Application: turbine blades, parts of I.C engines

Aluminium and its alloys

Y –alloy

- Copper aluminium alloy
- Al = 92.5%,Cu = 4%,Ni =%,Mn= 1.5%
- High creep strength(than duralumin)
- Piston, cylinder head, air craft engines

Hindalium

- Aluminium and magnesium alloy
- Produced as rolled product in 16 gauge, for anodized utensils manufacture

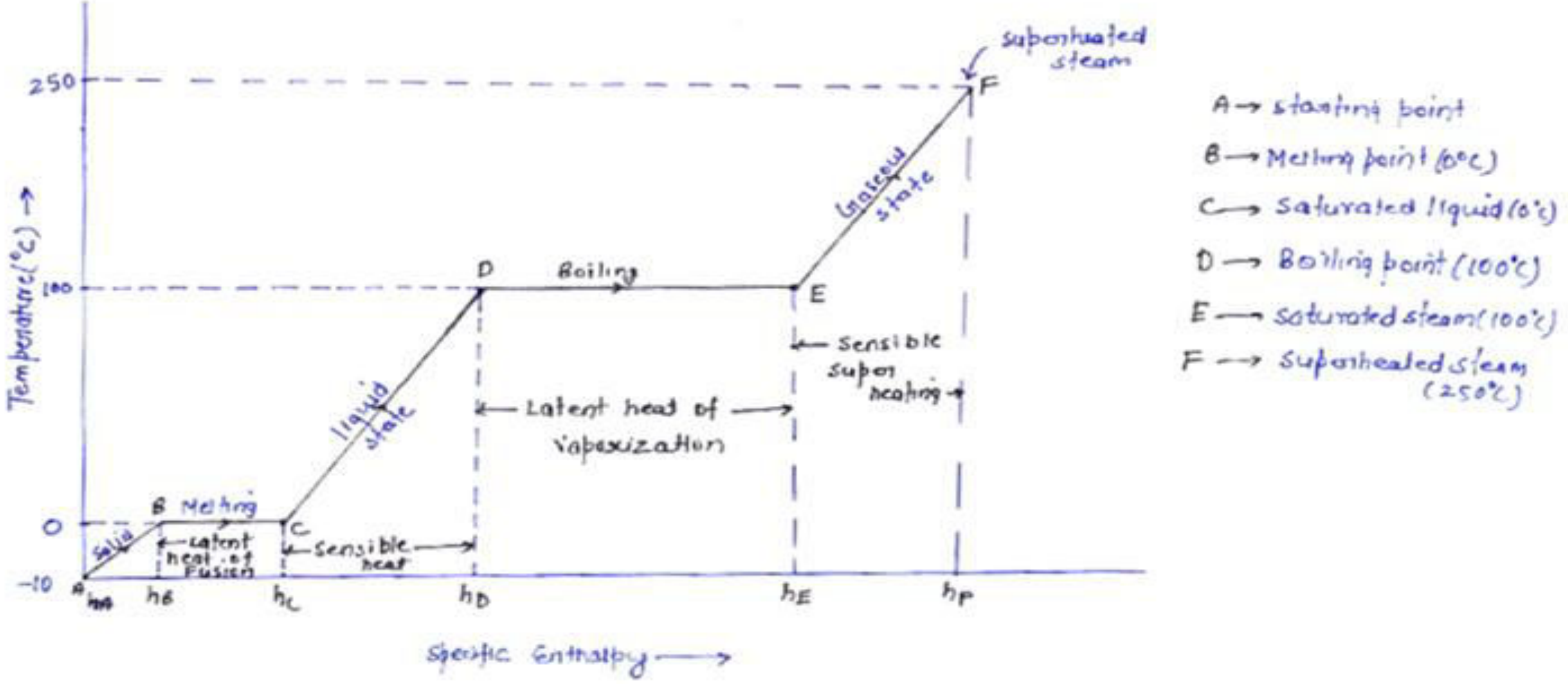
Magnalium

- Al = 85 to 95%,Cu= 2%,Mg= 1 to 5%,Ni,Sn,Fe,Mn,Si = altogether 2%
- light in weight and good mechanical properties
- Used for aircraft and automobile components

MODULE 2

Steam generators, steam engines

Formation of steam



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Formation of steam

AB : The heating of water upto boiling temperature or saturation temperature (t_s)

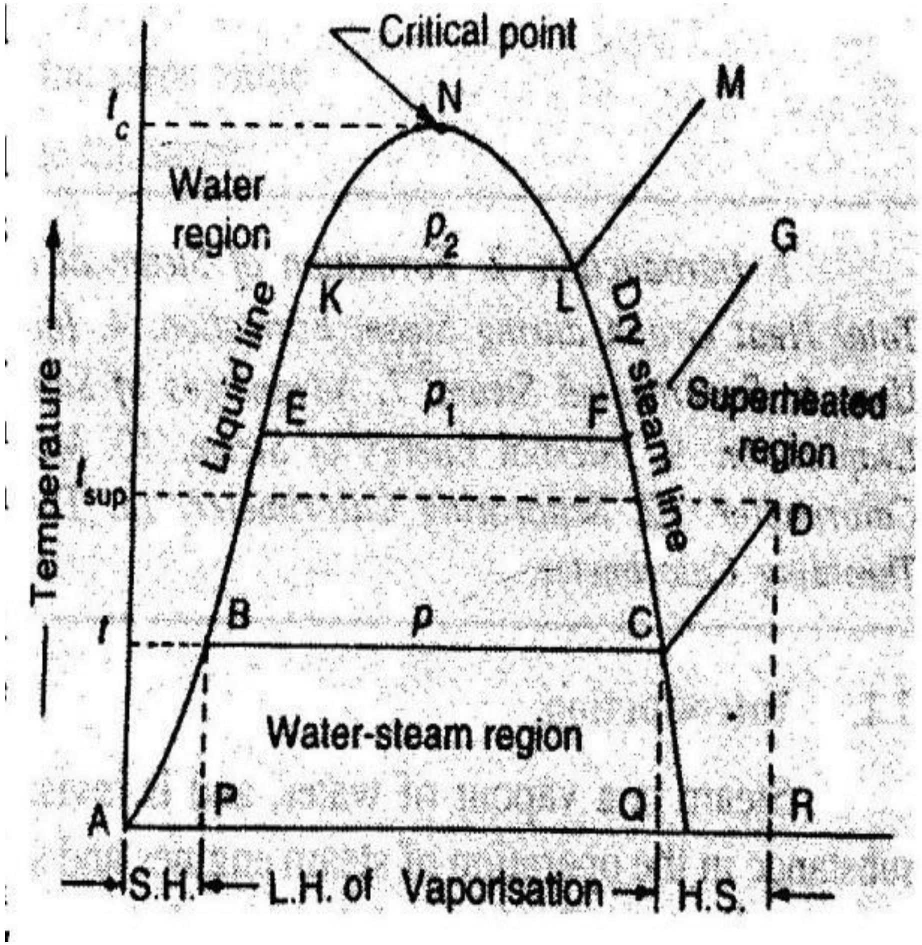
AP – Sensible heating, liquid heat or total heat of water.

BC: Change of state from liquid to steam

PQ : Latent heat of vaporization.

CD: Super heating process

QR:Heat of super heat



Wet, Dry and super heated steam

- **Wet steam**: Steam which contains moisture or water particles in suspension. It is the state between saturated water and saturated steam
- **Dry steam(Dry saturated steam):**When wet vapour is heated until it does not contain moisture or water particles
- **Super heated steam**:when dry steam is heated at constant pressure, its temperature increases and steam at this stage is called super heated steam
- Dryness fraction = $\frac{mass\ of\ dry\ steam}{mass\ of\ wet\ steam}$
- *Mass of wet steam* = mass of dry steam + mass of water particles in suspension
- Dryness fraction is denoted by ‘x’.For dry steam value of x is unity

Important terms

Saturated State: A state at which a phase change begins or ends
Saturation Temperature: Temperature at which phase change (liquid-vapour) begins or ends at a given pressure; $T_{sat} = T_{sat}(P)$

Saturation Pressure: It is the pressure at which phase change begins or ends at a specified temperature. $P_{sat} = P_{sat}(T)$

Saturated Liquid: It is the substance at T_{sat} which is fully liquid (no-vapour).

Saturated Vapour: It is the substance at T_{sat} which is fully vapour (no-liquid).

Subcooled liquid: If the temperature of the liquid (T) is less then T_{sat} then the liquid is called sub-cooled liquid.

Superheated vapour: If the temperature of the vapour (T) is greater than T_{sat} then the vapour is called superheated vapour.

STEAM GENERATORS(BOILERS)

- A device used for generating steam from water by application of heat
- Thermal energy released by combustion of fuel is used to make steam

Uses of steam

- Power generation in steam engines or steam turbines
- Heating residential and industrial buildings(air conditioning)
- Industrial processes in the sugar mills, chemical and textile industries.
- Operation of ship and locomotives
- Supply hot water for buildings
- Operation of power hammers, pile driving machines, hoisting rigs

Classification of boilers

- **Position of axis**

  a)Horizontal boiler: Axis of boiler is horizontal. Example:- Lancashire boiler, Locomotive boiler, Babcock and wilcox.

  b) Vertical boiler: Axis of boiler is vertical. Example:-Simple vertical, Cochran boiler,LaMount, Benson.

- **Tube content**

  a) Fire tube boilers:- Hot gases produced by combustion of fuel pass through tubes which are surrounded by water. Example: Simple vertical, Cochran, Lancashire, Locomotive, Cornish

  b) Water tube boiler:- Water passes through the tubes and hot gases surrounding the tubes. Example:- Babcock and Wilcox boiler, La Mont boiler,Stiriling boiler,Yarrow,Loeffler.

Classification of boilers

- **Position of furnace**

  a) Externally fired boilers:- Furnace is placed outside the boiler shell. Generally water tube boilers are externally fired. Example:- Babcock and Wilcox boiler.

  b) Internally fired boilers:- Furnace is placed inside the boiler shell. Generally fire tube boilers are internally fired. Example:- Lancashire, Cochran boiler.

- **Method of water circulation**

  a) Natural circulation boilers:- Water flow take place naturally, by density difference of water (natural convection). Example:- Lancashire, Babcock and Wilcox boiler.

  b) Forced circulation boilers:- Water flow takes place by a pump. Example:- Benson boiler, LaMont boiler, Velox boiler.

Classification of boilers

- Pressure rating

  a) High pressure boiler:-Produce steam above 80 bar pressure. Example:- Babcock and Wilcox boiler

  b)Low pressure boiler:- Produce steam below 80 bar pressure. Example:- Cochran and Cornish boiler.

- Use and application

  a) Stationary boiler:- These are used in power generation or process heating in industries.

  b) Mobile boiler:- These are used in marine and locomotive engines

- Numbers of tubes in the boiler
- a) Single tube boiler:- Only one fire or water tube. Example:- Cornish boiler.
- b) Multi-tube boiler:- Two or more fire or water tubes. Example:- Locomotive, Cochran, Lancashire, Babcock and Wilcox boiler.

Comparison between Fire tube and Water tube boiler

Sl No.	Particulars	Fire-tube boilers	Water-tube boilers
1	Position of water and hot gases	Hot gases inside the tube and water out side the tubes	Water inside the tubes and hot gases out side the tubes
2	Mode of firing	Internally fired	Externally fired
3	Rate of steam production	Lower(9000 Kg / hr.)	Higher (500000 Kg/hr.)
4	Construction	Difficult	Simple
5	Transportation	Difficult	Simple
6	Treatment of feed water	Not so necessary	Necessary to prevent scale formation
7	Operating pressure	Limited to 16 bar	High pressure as 100 bar
8	Floor area	More	Less
9	Shell diameter	Large for same power	Small for same power

Comparison between Fire tube and Water tube boiler

Sl No.	Particulars	Fire-tube boilers	Water-tube boilers
10	Overall efficiency	Low(85 %)	High (92%)
11	Accessibility	Parts are not accessible for cleaning ,repair, inspection	Parts are more accessible
12	Chances of explosion	Less	More
13	Operating cost	More	Less
14	Suitability	Not suitable for large power plant	Suitable for large power plant
15	Requirement of skill	Less skill for efficient and economic working	More skill and careful attention

Boiler Terms

- **Shell**. Consists of one or more steel plates bent into a cylindrical form and riveted or welded together.
- **Grate**. Platform in the furnace upon which fuel is burnt and it is made of cast iron bars. The bars are so arranged that air may pass on to the fuel for combustion.
- **Furnace(Fire box)**. It is a chamber formed by the space above the grate and below the boiler shell, in which combustion takes place.
- **Water space and steam space**. Volume of the shell that is occupied by the water is termed *water space.* Entire shell volume less the water and tubes (if any) space is called steam *space.*
- **Mountings.** The items such as stop valve, safety valves, water level gauges, fusible plug, blow-off cock, pressure gauges etc. are termed as *mountings* and a *boiler cannot work safely without them.*
- **Accessories**. The items such as super heaters, economisers, feed pumps etc. are termed as *accessories* and they form integral part of the boiler. They *increase the efficiency of the boiler.*

Cochran Boiler

- It is a vertical, multi tubular, fire tube, internally fired, natural circulated ,and low pressure boiler.
- It consists of a cylindrical shell with hemispherical top. Furnace is also of hemispherical shape
- The grate is placed at the bottom of the furnace and ash pit is located below the grate
- The water is supplied to the boiler through feed check valve
- Coal is fed into the grate through fire door and burnt
- The ash formed is collected in ash pit

- The hot gases from furnace(fire box) enters combustion chamber through flue pipe(smoke pipe) .
- This hot gases enters into horizontal fire tubes(flue tubes) to the smoke box and finally discharged to atmosphere through chimney
- Smoke box is provided with door for cleaning the flue tubes and smoke box
- Hot gases while passing through flue tubes transfers heat to water surrounding the tube
- The water gets converted to steam and accumulate in the steam space at the top of the shell
- This steam is taken to the steam supply pipe through steam stop valve

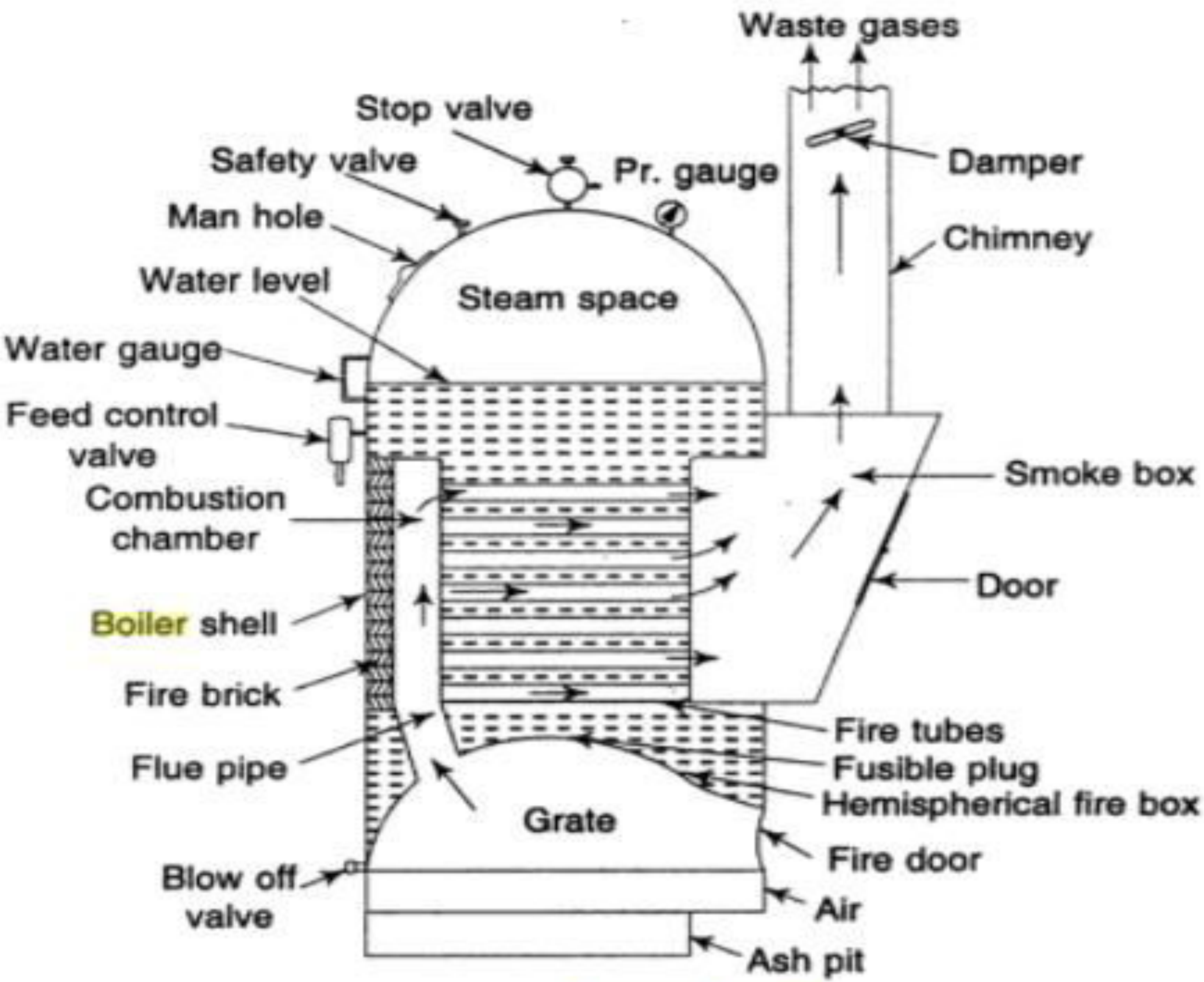


Fig. 1.1 *Cochran boiler*

Components:

1. Hemispherical shell
2. Flue pipe
3. Combustion chamber
4. Smoke box
5. Chimney
6. Grate
7. Ash pit
8. Fire door
9. Furnace
10. Feed check valve
11. Pressure gauge
12. Water gage
13. Safety valve
14. Steam stop valve
15. Blow-off cock
16. Fusible plug

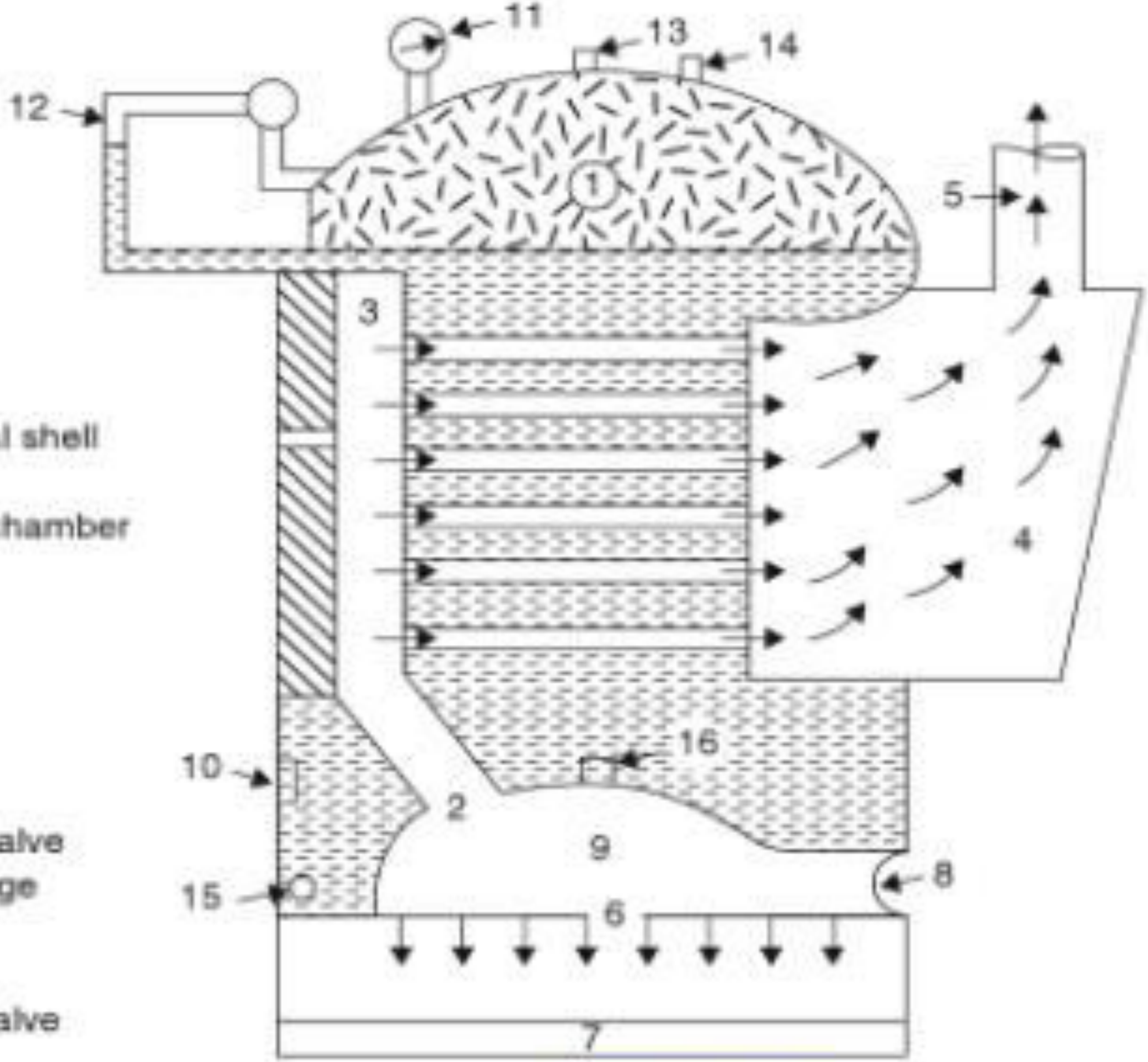
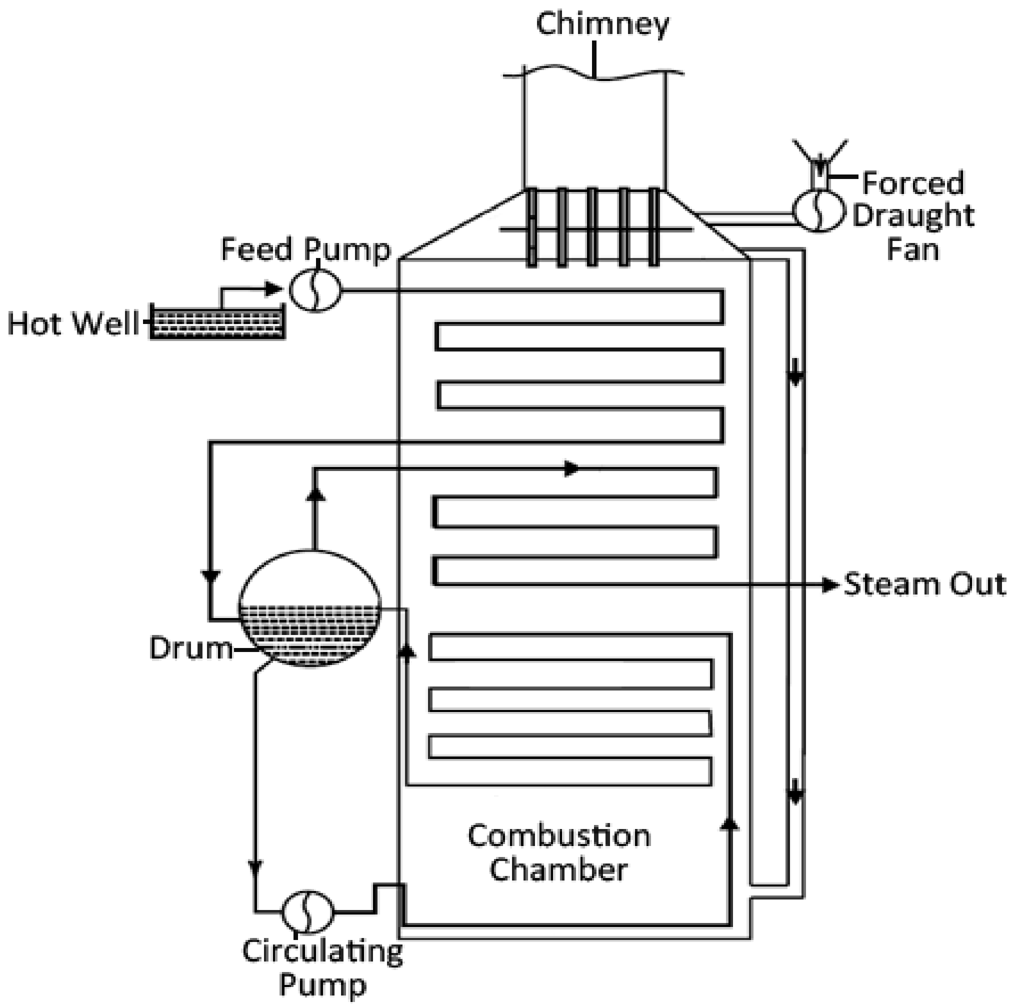


Figure 4.10 Cochran Boiler

La mount boiler



La mount boiler

- It is a high pressure, water tube, forced circulation boiler
- Forced circulation is maintained by centrifugal pump driven by steam turbine by using steam from boiler
- Feed pump forces water through economiser where it is heated by waste gas before going to chimney
- The heated water enters the steam-water drum(steam separating drum) where water is drawn by circulating pump and sent through evaporator
- Evaporator adds heat to water and part of it evaporates and become steam
- A mixture of steam and water enters the drum from evaporator
- The unevaporated water together with heated feed water goes for recirculation
- The steam formed goes through super heater and gets super heated
- Super heated steam is supplied to prime mover

La mount boiler

- The flue gases from furnace first pass through evaporator,then through super heater and finally through economiser and air preheater
- By this process most of the heat of flue gas are extracted before it goes through chimney

Advantage of high pressure boilers

- Forced circulation ensures positive circulation and increase evaporative capacity(50 Ton /Hr.)
- Compact- Less floor space required
- Scale formation is reduced due to high velocity water
- Uniform heating, no overheating problem, no thermal stresses
- Pressurised combustion- increase rate of firing of fuel and heat release
- Heat of combustion better utilised by small dia. tubes in large nos.
- Rapid starting from cold condition
- Can produce high pressure and high temperature steam

Boiler Mountings

- Fittings provided on the boiler for safe and proper functioning.
- Important boiler mountings are
  - Water level indicator
  - Pressure gauge
  - Safety valves
  - Stop valve
  - Blow off cock
  - Feed check valve
  - Fusible plug

Hopkinson's Water level indicator(Water gauge)

It indicates the level of water in the boiler.

- It consists of a gauge glass 'G' which is connected to steam and water space through two horizontal hollow castings 'A' and 'B'
- When steam cock 'S' and water cock 'W' are opened, gauge glass indicates the level of water
- Cock 'D' is used to drain water to prevent sediment deposit
- Two ball are provided. One to stop the water and other to stop the steam
- Both balls move to end passage as shown by dotted(ball) to stop the flow of water and steam when gauge glass is broken

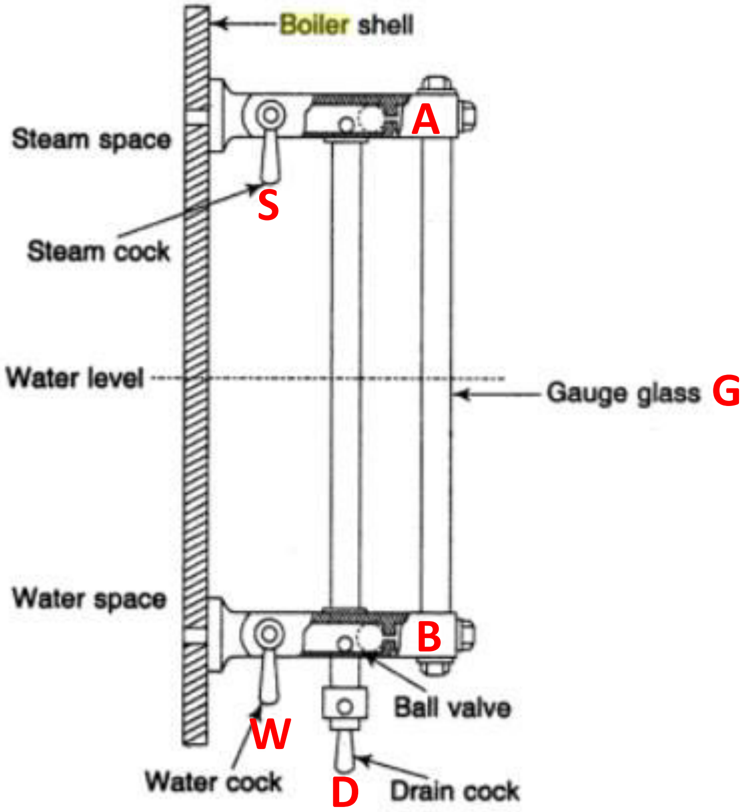


Fig.1.1(a) *Water level indicator*

Pressure gauge

Indicates the steam pressure

- It consists of an elliptical tube

 (Bourdon tube) bent in the form of circular shape

- One end of tube is connected to steam space and other end is connected to sector through link
- When high pressure steam enters the tube, it tends to straighten and move outward
- Movement of tube is magnified by a pinion and sector arrangement which rotates a pointer

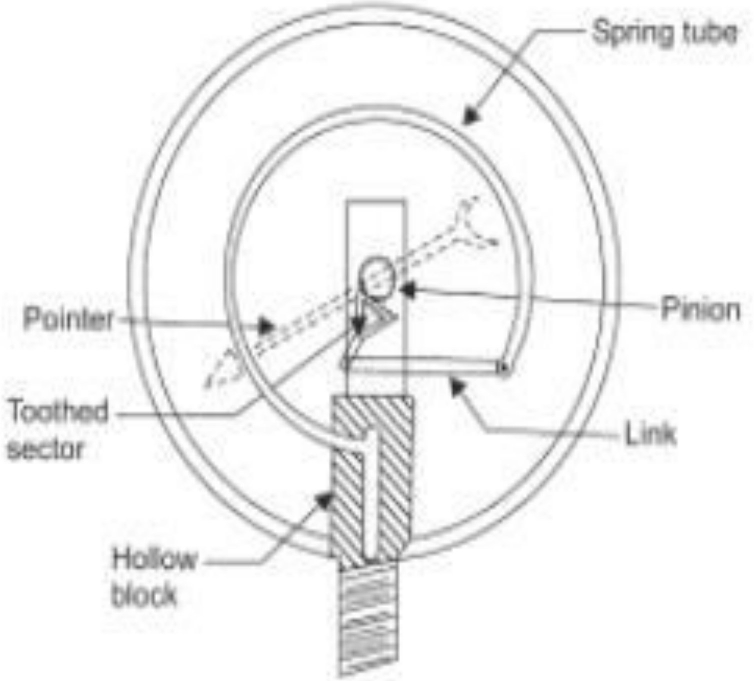


Fig. 3.23: Pressure gauge

Fusible plug

Put off fire in the furnace of boiler when water level in the boiler falls below unsafe limit and prevents explosion due to overheating of furnace plate

- A hollow gun metal plug 'A' is screwed to gun metal body.
- A solid copper plug 'B' is kept in the hole of 'A'
- A fusible metal holds the plug 'A' and 'B' together
- Under normal working condition, fusible plug is covered with water and fusible metal does not reach its melting point
- When water level in boiler falls below safe limit, the fusible plug gets over heated
- The fusible metal melts and copper plug falls down
- Steam and water rushes into the furnace and put off (stop) the fire

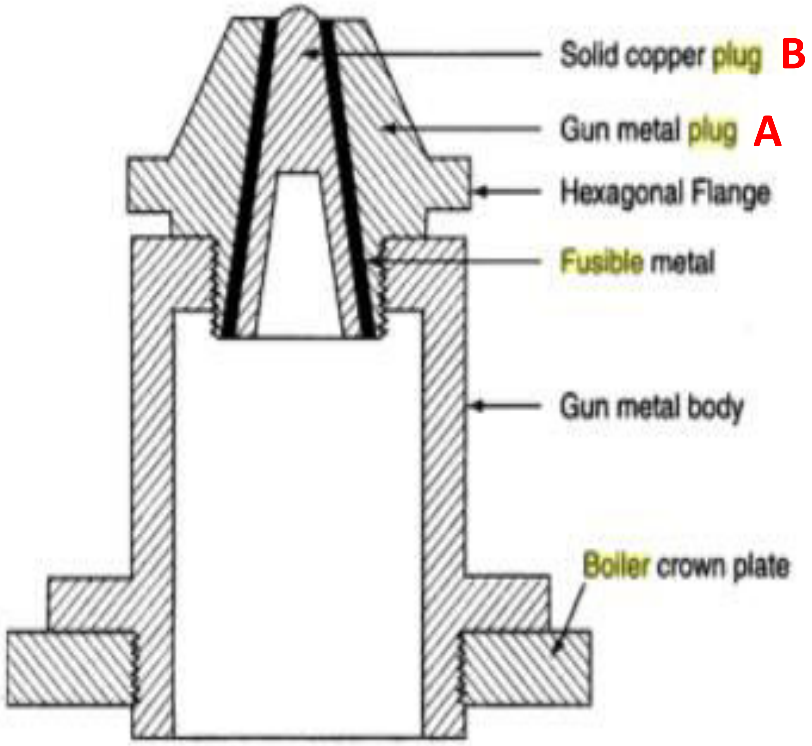


Figure 7 Fusible plug.

Steam Stop valve

To stop or allow the flow of steam from boiler to steam pipe

- It consists of a valve body having two flanges
- One flange is bolted to boiler at highest portion of steam space and other is connected to steam outlet pipe
- A valve rest on valve seat.
- The valve is connected with spindle so that it can carry the valve when raised or lowered
- Spindle pass through a gland in stuffing box to prevent leakage of steam
- A hand wheel is fitted at the top of spindle
- When hand wheel is rotated the valve will move up or down to allow or stop the flow of steam to steam out let pipe

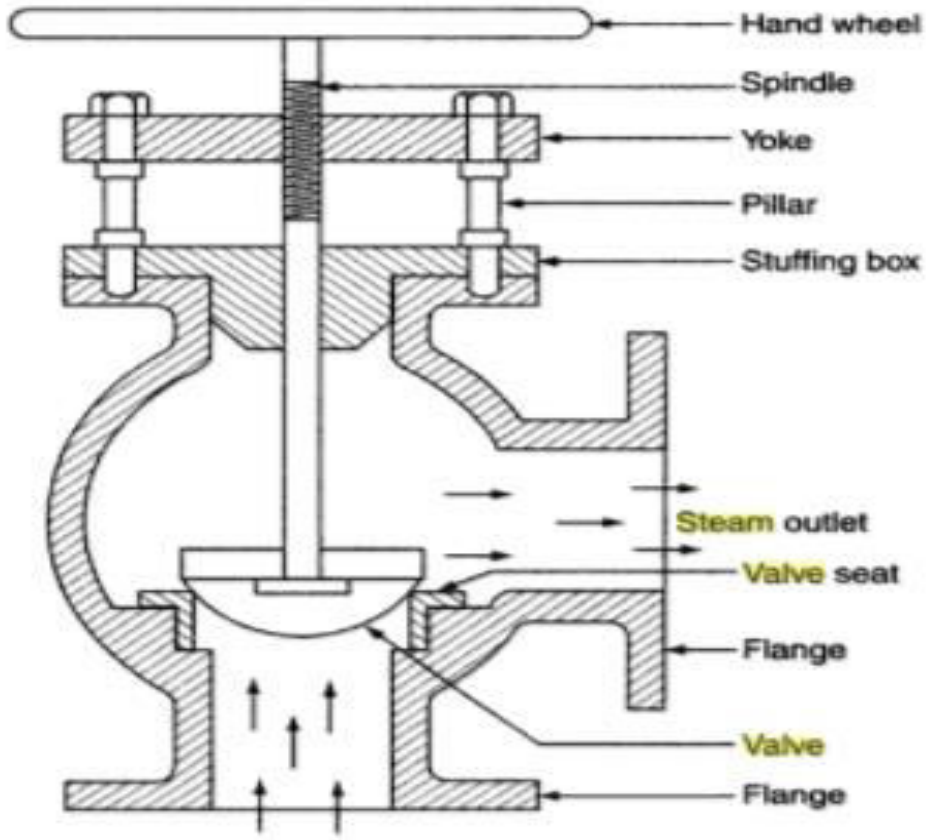


Figure 8 Steam stop valve.

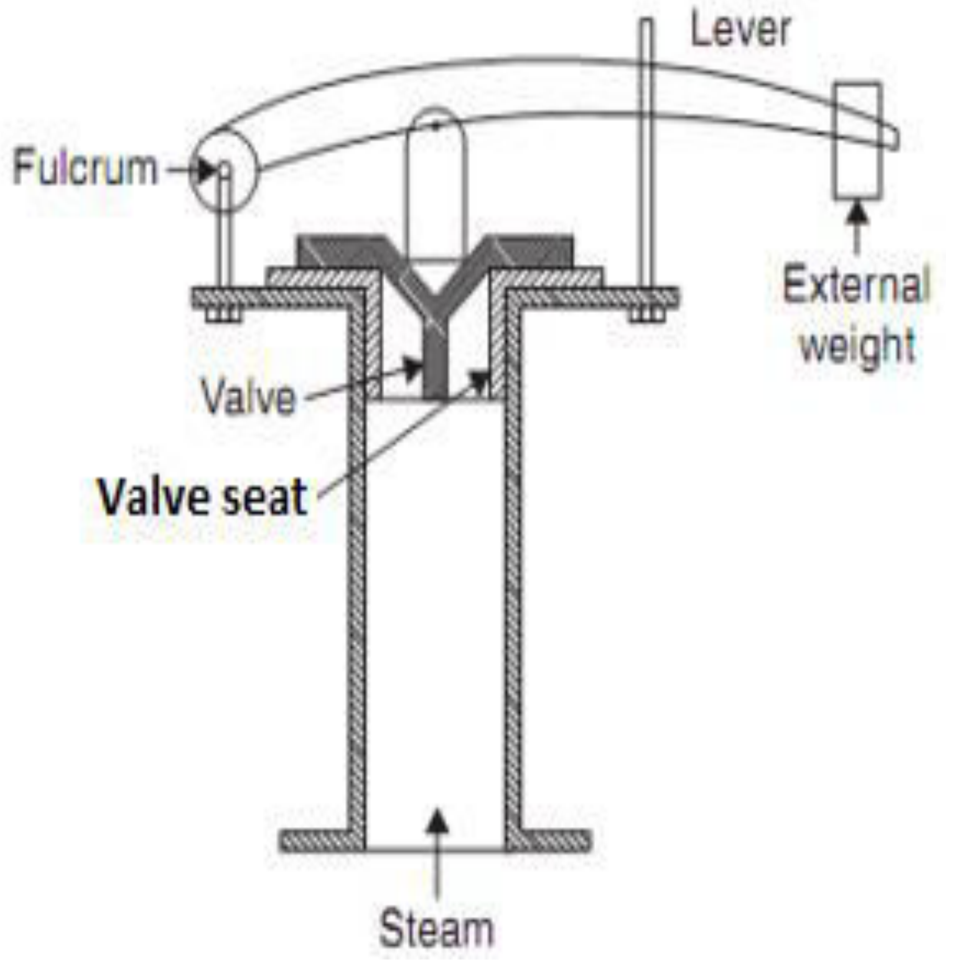
Safety valve

Blow off the steam when the pressure of steam inside the boiler exceeds working pressure

- *Following are the safety valves used in boiler*
- *Lever safety valve*
- *Dead weight safety valve*
- *Spring loaded safety valve*
- *High steam and low water safety valve*

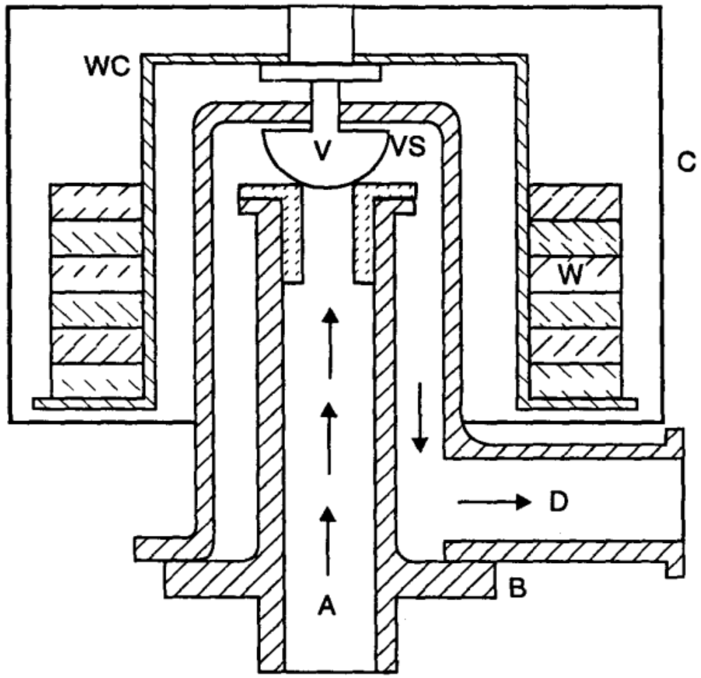
Lever safety valve

- It consists of a valve body(made of cast iron) fitted to steam space of boiler
- A valve *(made* of gun metal) rests on the valve seat (made of gun metal) which is screwed to the valve body.
- The valve is held by a lever hinged at one end and carries a weight at other end
- When the pressure of steam exceeds the safe limit, upward force of steam raises the valve from its seat
- Steam escapes till the pressure falls back to normal value
- Valve then return to its normal position



Dead weight safety valve

- It consists of a vertical pipe with a flange at its bottom fitted to boiler shell
- At top of pipe valve seat is fixed on which valve rest
- Valve support a weight carrier in which dead weights are placed
- Dead weight keeps valve in its seat under normal working pressure
- Valve as well as weight are lifted when pressure exceeds working pressure and steam is discharged



A = Cast iron pipe
B = Bottom flange
V = Gun metal valve
W = Cast iron weights
WC = Weight carrier
D = Discharge pipe
VS = Gun metal valve seat
C = Cover plate

Rams bottom Spring loaded safety valve

- It has two separate valves and seating
- A lever is placed over the valves by means of two pivots
- The lever is attached to a spring at its middle
- The lower end of the spring is attached to the valve body.
- Thus the valves are held tight to their seats by the spring force.
- Pressure of steam act on valve through steam chest
- When steam pressure exceed designed pressure ,valve open against spring force and steam escapes out

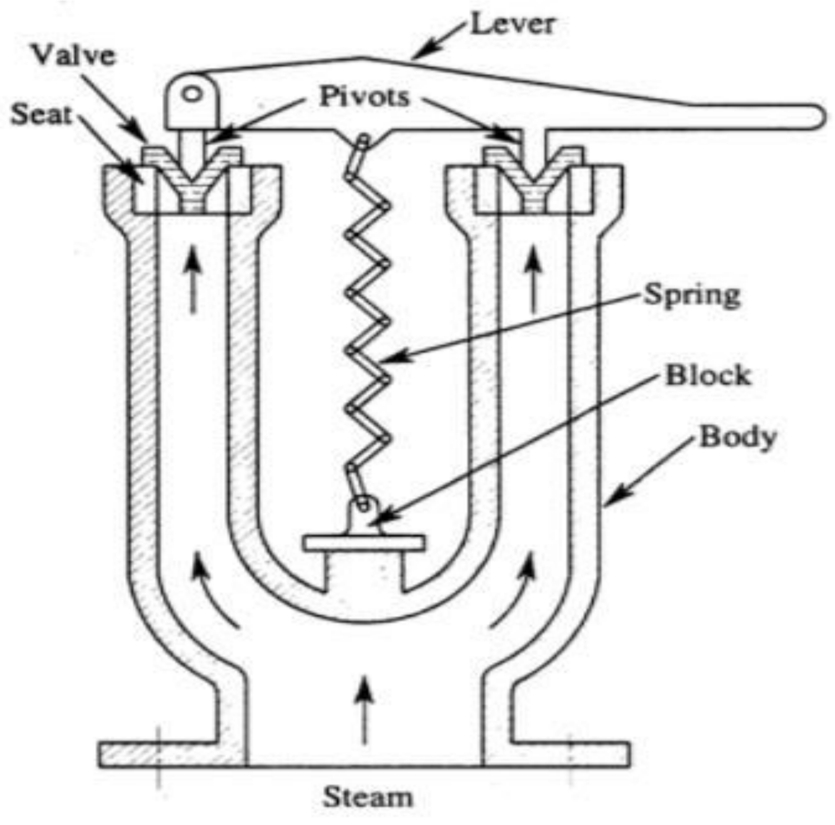


Fig. 7.8 *Spring loaded safety valve*

- **Feed check valve**: It is a non return valve used to supply water to boiler under high pressure.
- **Blow off cock**:It is fitted at the bottom of boiler. It is used to discharge mud, scales, sediments etc. accumulated at bottom of boiler

Boiler Accessories

- **Devices** *required for proper functioning and to increase efficiency steam power plant.* Commonly used boiler *accessories* are
- Feed pumps
- Injector
- Economiser
- Air preheater
- Superheater
- Steam separator
- Steam trap

Line diagram of boiler plant

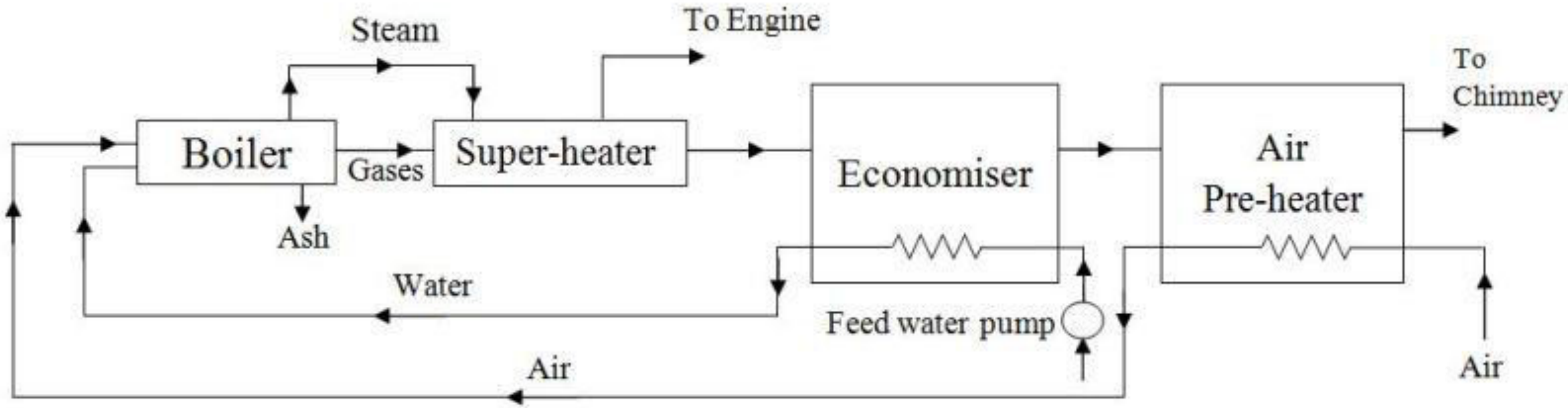


Fig- Schematic diagram of a boiler plant

Super heater

Increases temperature of saturated steam without raising its pressure

This is done by passing steam generated from boiler through a set of tubes placed in the path of flue gas

- Shows a sugden’s super heater (used in Lancashire boiler)
- It consists of two steel headers to which U tubes(super heater tubes) are attached
- Steam from boiler enters and leaves the header as shown by arrows
- Damper is provided to control flow of flue gases over the U tube
- Damper position is shown when super heater is in action
- When damper is vertical flue gases directly pass to bottom flue
- When steam is taken from boiler directly to steam pipe Valves V1 and V2 closed and V3 is open
- When super heater is in action valve V3 closed and V1 and V2 is open

Super heater

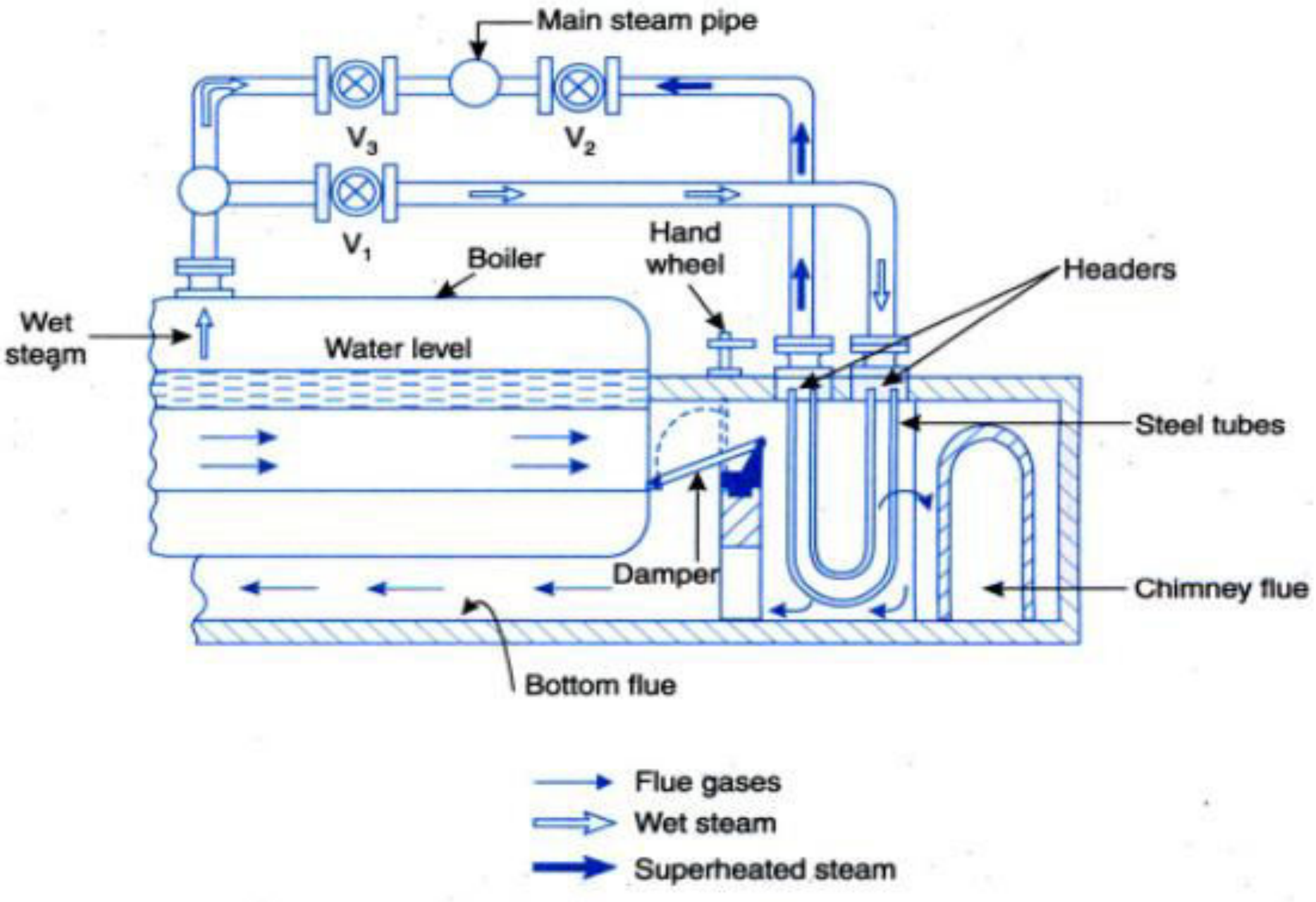


Fig. 12.19. Sugden's superheater.

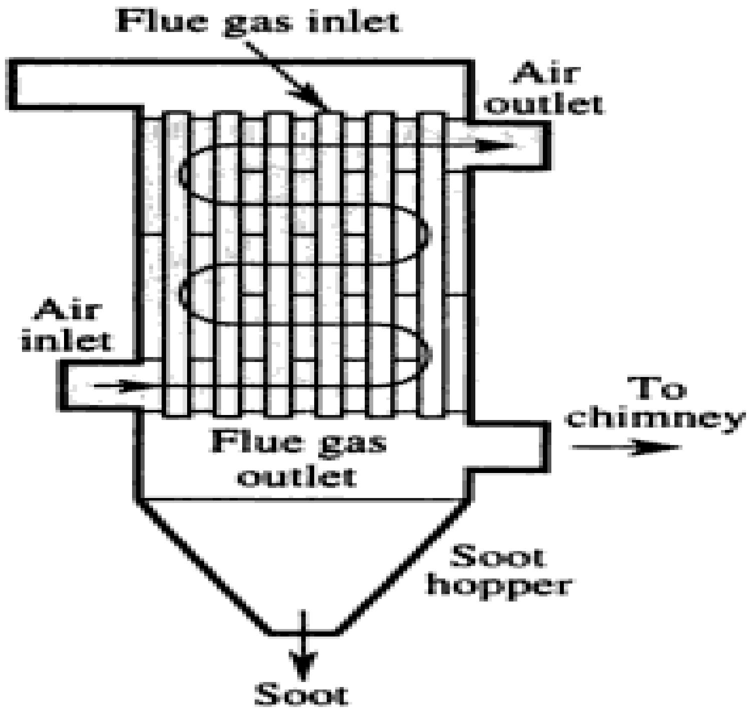
Advantages of super heated steam

- Steam consumption of steam turbine /engine reduced
- Losses due to condensation of steam in steam pipe is reduced
- Eliminates erosion and corrosion of turbine blades(due to absence of moisture)
- Increase overall efficiency of plant
- Saves fuel

Air preheater

Increases the temperature of air before it enters the furnace by using heat of flue gas

- It is installed between economiser and chimney
- Shows a tubular type air preheater
- Hot flue gases flows inside the tube and transfers heat to air flowing in opposite direction
- Air flow in zig zag path by providing baffles
- This ensures better heat gain from flue gas
- Soot and other particles carried by flue gases are collected at bottom and removed



Advantage of using Air preheater

- Low grade fuel can be used for combustion
- Better combustion with less soot, smoke ash
- Increase in evaporative capacity due to high furnace temperature
- Increase overall efficiency of plant

Economiser or Feed water heater

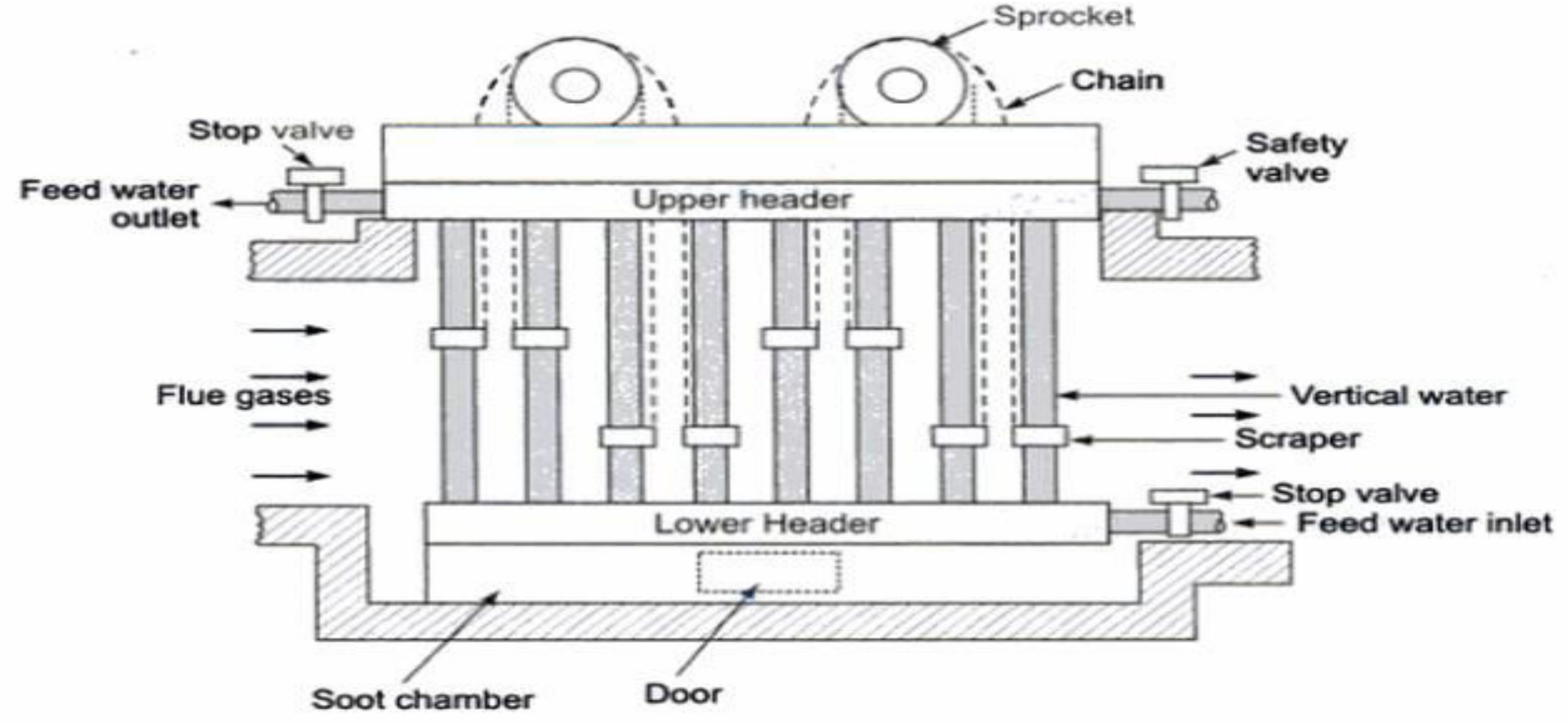


Fig. 18.13 *Green's economiser*

Economiser

It is a device used to heat feed water by utilizing heat of exhaust flue gas

- Feed water from feed pump enters the bottom header
- From there water passes through vertical tubes and reaches upper header
- From upper header water enters the boiler
- Water while flowing inside vertical tubes gain heat from flue gases which passes over vertical tubes
- Soot deposited over vertical tube are cleaned by scrapes moving up and down
- Soot collected in soot chamber are removed periodically
- Stop valves are provided on bottom and top headers to control feed water entering and leaving economizer
- Safety valve is provided to secure pipe from excessive pressure of flowing water

Advantages of Economiser

- Saves fuel
- Increase evaporative capacity of boiler
- Increase overall efficiency of the plant
- Dissolved air and CO_2 are removed by preheating feed water thus reduces pitting and corrosion
- Reduces the emission of soot and fly ash through chimney
- Feed water entering boiler is hot. So no thermal stresses due to unequal expansion. Increases boiler life

Feed pump

- Feed pump used is double acting reciprocating type ,run by steam engine
- Pump has two set of suction valves(S1 and S2) and delivery valves (D1 and D2)
- When piston moves to right, pressure inside the chamber **A** falls and **B** rises.
- Suction valve S1 and delivery valve D2 opens. Suction valve S2 and delivery valve D1 remain closed
- Water enters chamber A and discharged from chamber B
- When the piston returns (moves to the left), pressure inside the chamber **B** falls and **A** rises.
- Suction valve S2 and delivery valve D1 opens. Suction valve S1 and delivery valve D2 remain closed
- Water enters chamber B and discharged from chamber A
- The operations are repeated.

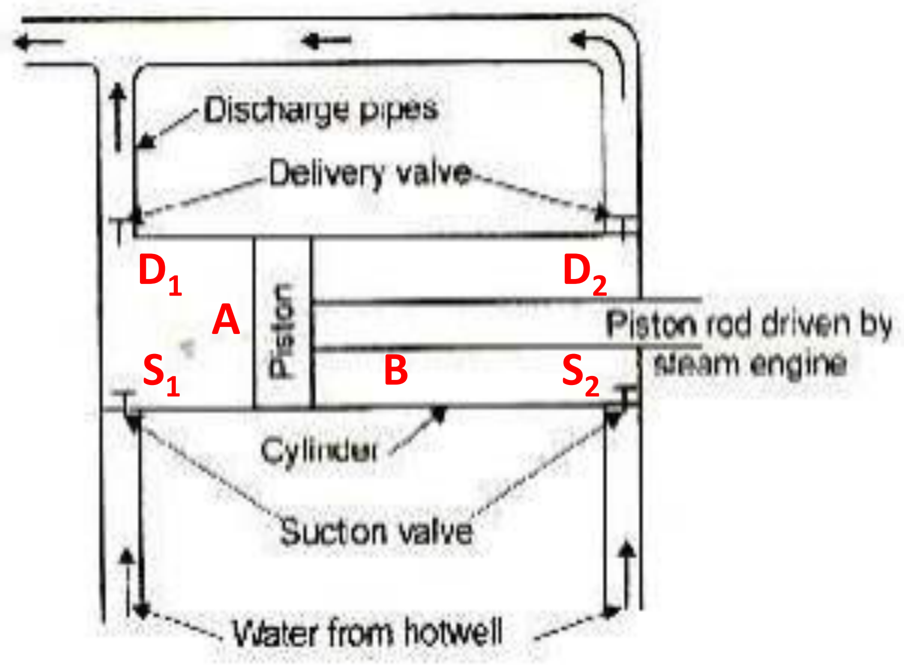


Figure: Feed pump (reciprocating type).

- **Steam trap:** Collect and discharge water resulting from partial condensation without allowing steam to escape. It is connected to steam pipe line
- **Steam separator(Steam drier):**Separate water particles from steam before it is supplied to steam engine or turbine
- **Steam injector:** It is used to feed water under pressure to boiler by using a convergent nozzle

Energy conservation for steam systems

1. For furnaces

- Preheating air for combustion
- Automatic combustion control
- Waste heat recovery from furnace flue gases
- Complete combustion with minimum excess air
- Control of furnace draft
- Minimising wall loss
- Proper maintenance

2. For boilers

- Automatic blow down Control
- Reduction of scaling and soot losses
- Reduction of boiler steam pressure
- Use energy efficient burners
- Feed water preheating using economiser
- Proper feed water treatment

3.Steam system

- Monitoring steam traps
- Avoiding steam leakages
- Providing dry steam for process
- Condensate recovery
- Insulation of Steam Pipelines

Steam Engine

- Heat energy in steam is converted into mechanical work by reciprocating motion of piston
- Combustion of fuel takes place out side the engine. Also called external combustion engine

Classification of steam engine

1. Position of cylinder

- Horizontal steam engine – axis of cylinder horizontal
- Vertical steam engine – axis of engine vertical

2. Based on speed of engine:

- High speed engine- 250rpm and above
- Medium speed engine- 100 to 250 rpm
- Slow speed engine- below 100 rpm

3.No. of working stroke

- Single acting steam engine – Steam admitted on one side of piston. One working stroke produced in each revolution of crank shaft
- Double acting steam engine – Steam admitted on both sides of piston alternately. Two working stroke produced in each revolution of crank shaft

4. Expansion of steam

- Simple steam engine: Expansion of steam in single cylinder and exhausted to atmosphere or condenser
- Compound steam engine: Expansion of steam in two or more cylinders.

Classification of steam engine

5. Type of exhaust

- Condensing engine – Exhaust steam passes to condenser where pressures is less than atmosphere
- Non-condensing engine – Exhaust steam directly pass to atmosphere.

6 Method of governing

- Throttle governed steam engine - Speed controlled by throttle valve which *regulates the pressure of steam*
- Automatic cut-off governed engine – Speed controlled by automatic cut of governor which controls the *amount of steam admitted* keeping steam pressure constant

7. Field of application

- Stationary engine
- Marine engine
- Locomotive engine

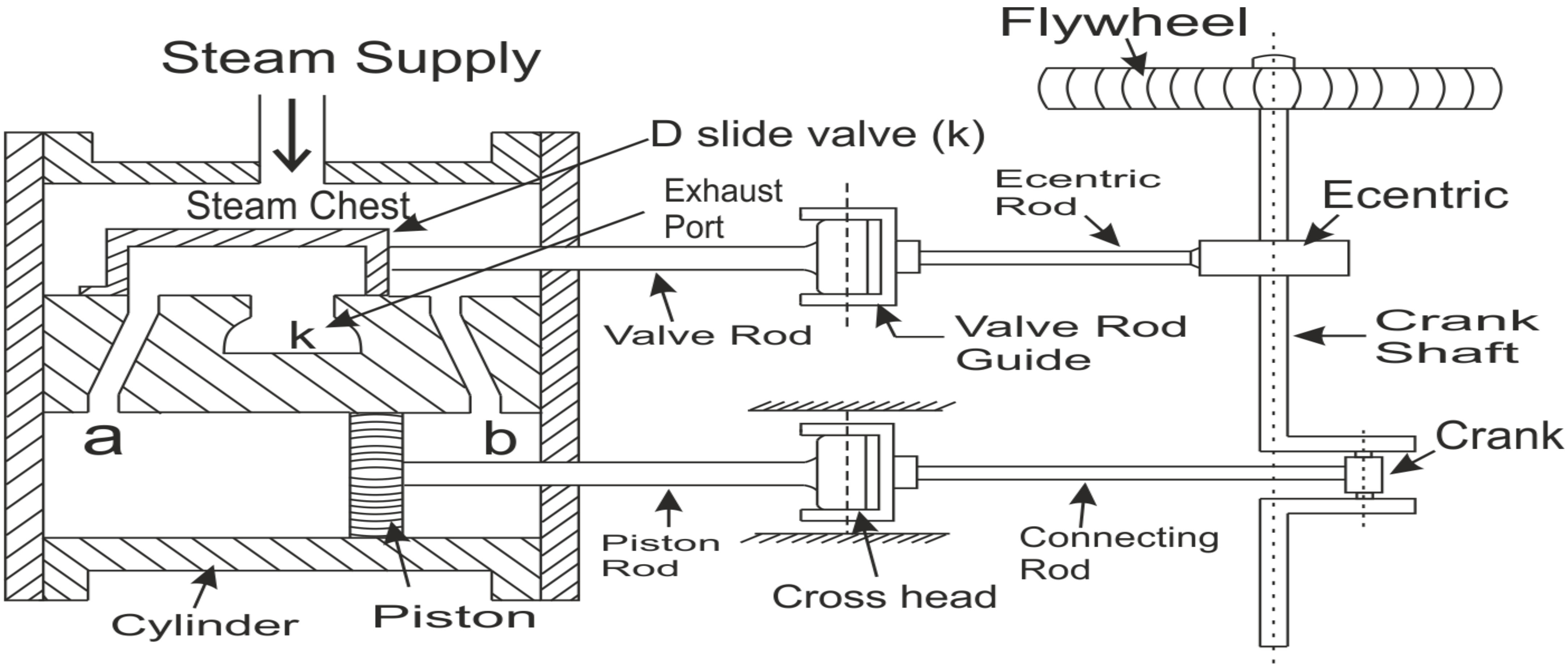
Single cylinder double acting steam engine - parts

- **Frame***:* Made of cast iron. It supports stationary and moving parts of the engine. It rests on foundation.
- **Cylinder***:* Steam tight cylindrical vessel in which piston reciprocates.
- **Piston:** Part that converts heat energy of steam to mechanical work. Piston rings are fitted in the grooves of piston to prevent leakage of steam
- **Piston rod**: Connects piston to cross head and transfer motion
- **Cross head:** It is a link between piston rod and connecting rod. It guides motion of piston rod and prevent it from bending

Single cylinder double acting steam engine - parts

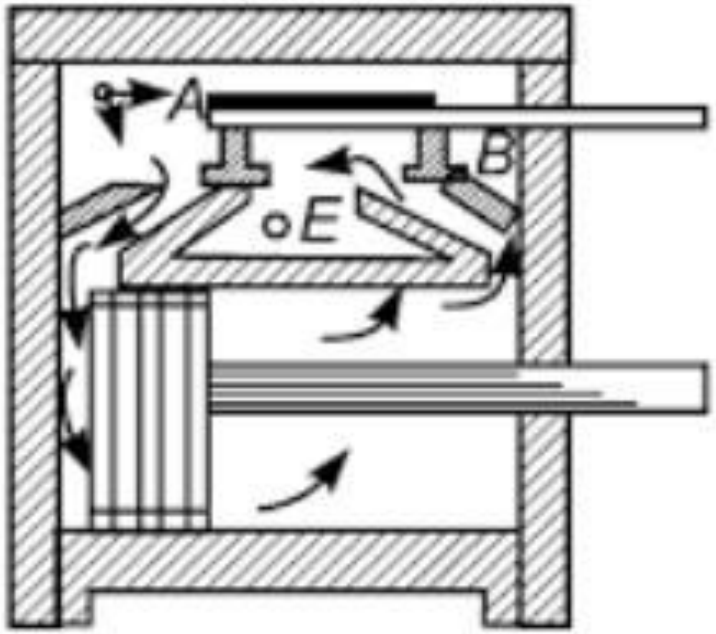
- **Connecting rod**: It converts reciprocating motion of piston to rotary motion of crank
- **Crank shaft**: Main shaft of the engine having a crank. It is supported on main bearing
- **Eccentric**: It is fitted to crank shaft. It converts rotary motion of crank shaft into reciprocating motion of D slide valves. An eccentric rod connects valve rod and eccentric
- **D slide valve**: It is situated in steam chest. It controls the steam entry into the cylinder and its exhaust
- **Fly wheel**: Heavy cast iron wheel mounted on crank shaft to prevent fluctuation of engine speed. It stores energy in the form of inertia when energy is excess and gives energy back when it is deficit.
- **Governer**:Maintain engine speed constant at all load condition

Single cylinder double acting steam engine

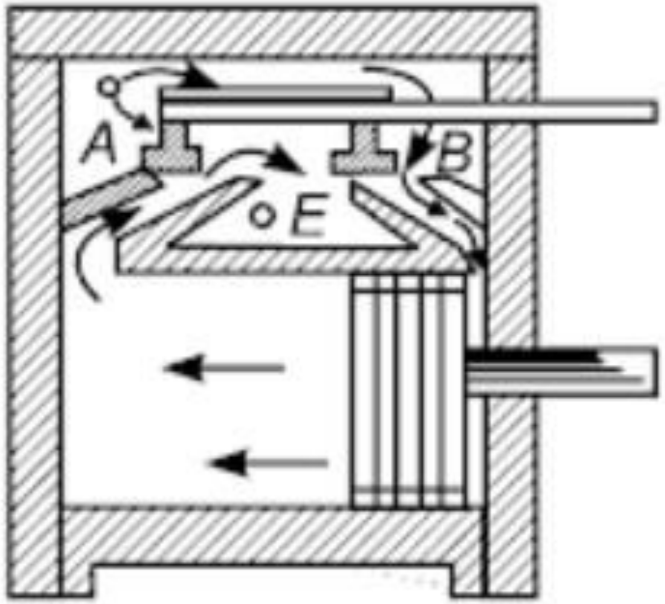


Single cylinder double acting steam engine- Working

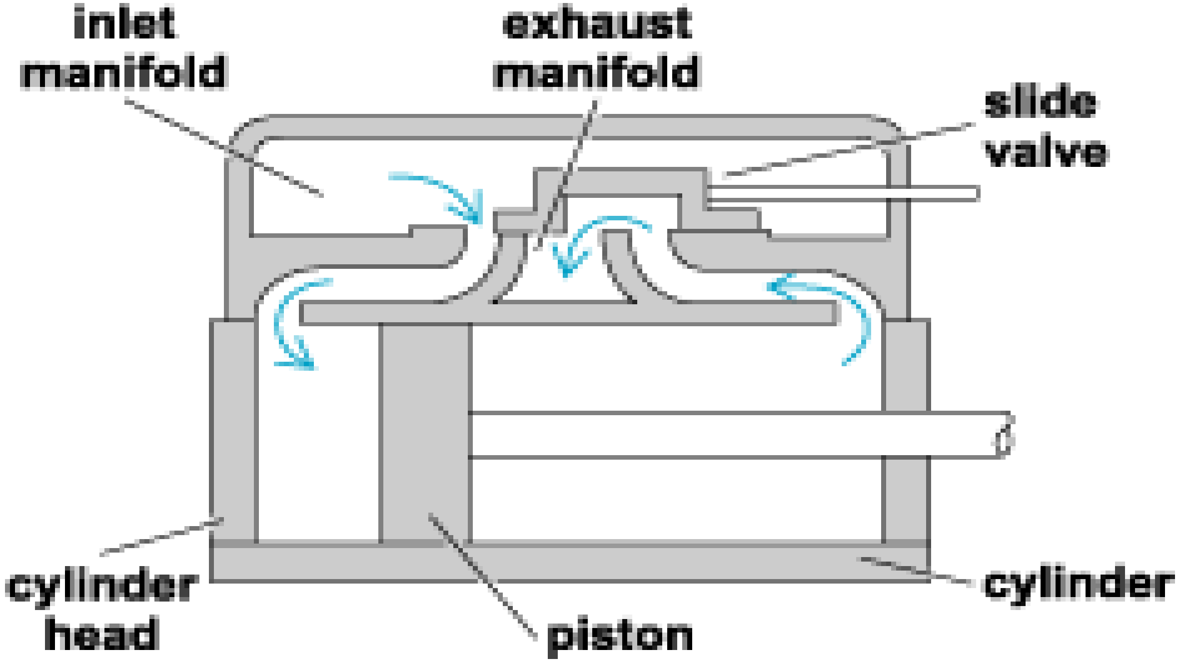
- Super heated steam from the boiler is supplied to steam chest
- Steam enters steam port A or B depending on the position of D slide valve
- When D slide valve opens steam port A for steam entry (cover end) and steam port B for steam exhaust (cylinder end): -
- *Steam rushes to left side of piston and forces it to right*
- *Steam from right side of piston is exhausted through steam port B and exhaust port E*
- At the end this stroke position of D slide valve changes
- Steam enters steam port B while used steam escape from steam port A and exhaust port E
- Steam rushes to right side of piston and forces it to left. Operations are repeated



Steam port A opens for steam entry and steam port B for exhaust



Port B opens for steam entry and port A opens for steam exhaust


inlet
manifold
exhaust
manifold
slide
valve
cylinder
head
piston
cylinder

MODULE 3

Classification of IC Engines, and working of IC Engines

INTERNAL COMBUSTION ENGINES

- Heat engines are devices which convert heat energy developed by combustion of fuel into mechanical energy
- These devices derive the heat energy from the combustion of a fuel
- Based on the location of the combustion process, heat engines are classified into

a. Internal combustion engines: Combustion of fuel takes place inside the engine cylinder and movement of piston produces power – eg. automobile engines(Petrol and diesel engines)

b. External combustion engines: Combustion of fuel takes place outside the engines .Heat energy produced during external combustion is used for producing useful work– eg. steam engine, steam turbine, gas turbine

- **Advantages of IC engines over EC engine**

1.Simple design

2.Compact,require less space

3.Low initial cost

4.Overall efficiency is high

5.Power to weight ratio is higher

6.Quick starting

- **Disadvantages of IC engines over EC engine**

1.Very high temperatures (combustion occurs inside the engine cylinder) necessitates engine cooling arrangements.

2.High temperatures restrict IC engines to be single-acting (where as EC engines are usually double-acting making every stroke a power stroke)

3.Fuels are relatively expensive.

5.Variety of fuels cannot be used. Only liquid and gaseous fuels with given specification can be used

4.Vibration produced by reciprocating components are high

- **Classification of IC engines**

1.According to fuel used:

Petrol engine, Diesel engine, Compressed natural gas(CNG) engine

2.According to number of strokes per cycle:

Four-stroke engine – One power stroke is obtained in two complete revolution of crankshaft

Two-stroke engine: One power stroke is obtained in one complete revolution of crankshaft

3.According to working cycle:

Otto cycle engine(Combustion at constant volume),Diesel cycle engine(Combustion at constant pressure), Dual cycle engine(Combustion partly at constant volume and partly at constant pressure)

4.According to speed of engine:

Low speed engine: up to 500 rpm

Medium speed engine: 500-1000 rpm

High speed engine: above 1000 rpm

5.According to method of ignition:

Spark ignition engine

Compression ignition engine

6.According to method of cooling:

Air cooled engine, Water cooled engine

7.According to method of governing: Hit and miss governing, Quality governing ,Quantity governing

8.According to arrangement of engine cylinders:

Horizontal engine, Vertical engine, V-engine, In-line engine

Opposed piston engine, Opposed cylinder engine, Radial engine

9.According to number of cylinders:

Single cylinder engine, Multi-cylinder engine

10.According to the application:

Stationary engine, Automobile engine, Marine engine, Aero engine

various parts and functions of I C engines:

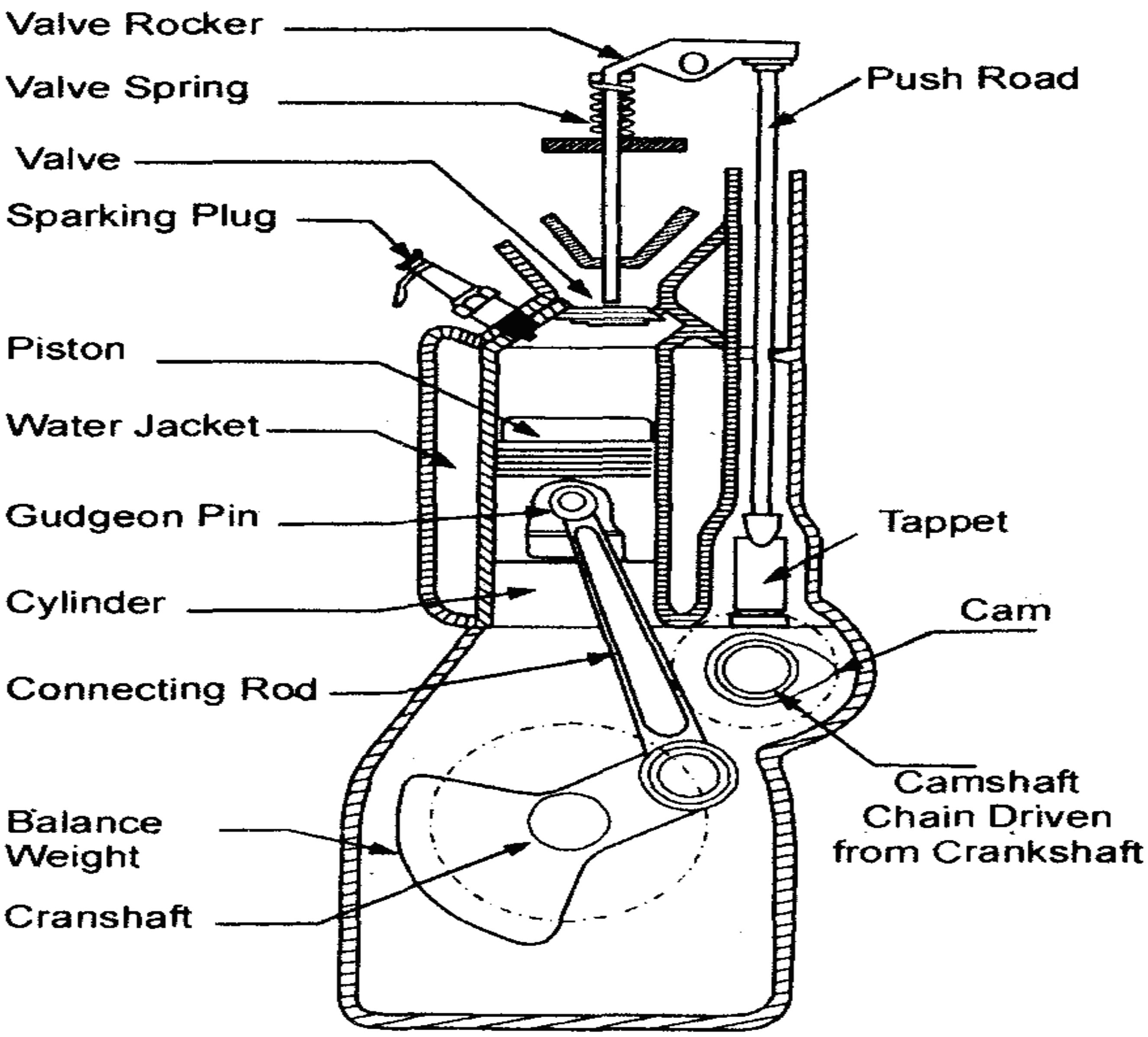
- **Cylinder :** Cylindrically shaped containers in which the piston reciprocates. It is made of cast iron or aluminum alloys. It is closed by cylinder head at one end and other end by moving piston. Combustion of fuel takes place inside the cylinder.Inorder to withstand high temperature water cooled jackets are provided outside the surface of cylinder.
- **Cylinder head:** It is a cast iron piece bolted to one end of the cylinder. It act as cover to close the cylinder. It holds the inlet and exhaust valves, their operating mechanisms, and the spark plug or fuel injector, as the case may be.

Piston: It is a close fitting member which reciprocates inside the engine cylinder. It is made of cast iron or aluminum alloys. It transmit the force excreted by high pressure gas to connecting rod.

Piston rings:They are housed in circumferential grooves provided on the outer surface of the piston. Generally, there are two sets of rings mounted for the piston. Function of the upper rings(**Compression rings**) is to provide air tight seal to prevent leakage of the burnt gases into the lower portion. Function of the lower rings(**Oil rings**) is to provide effective seal to prevent leakage of the oil into the engine cylinder

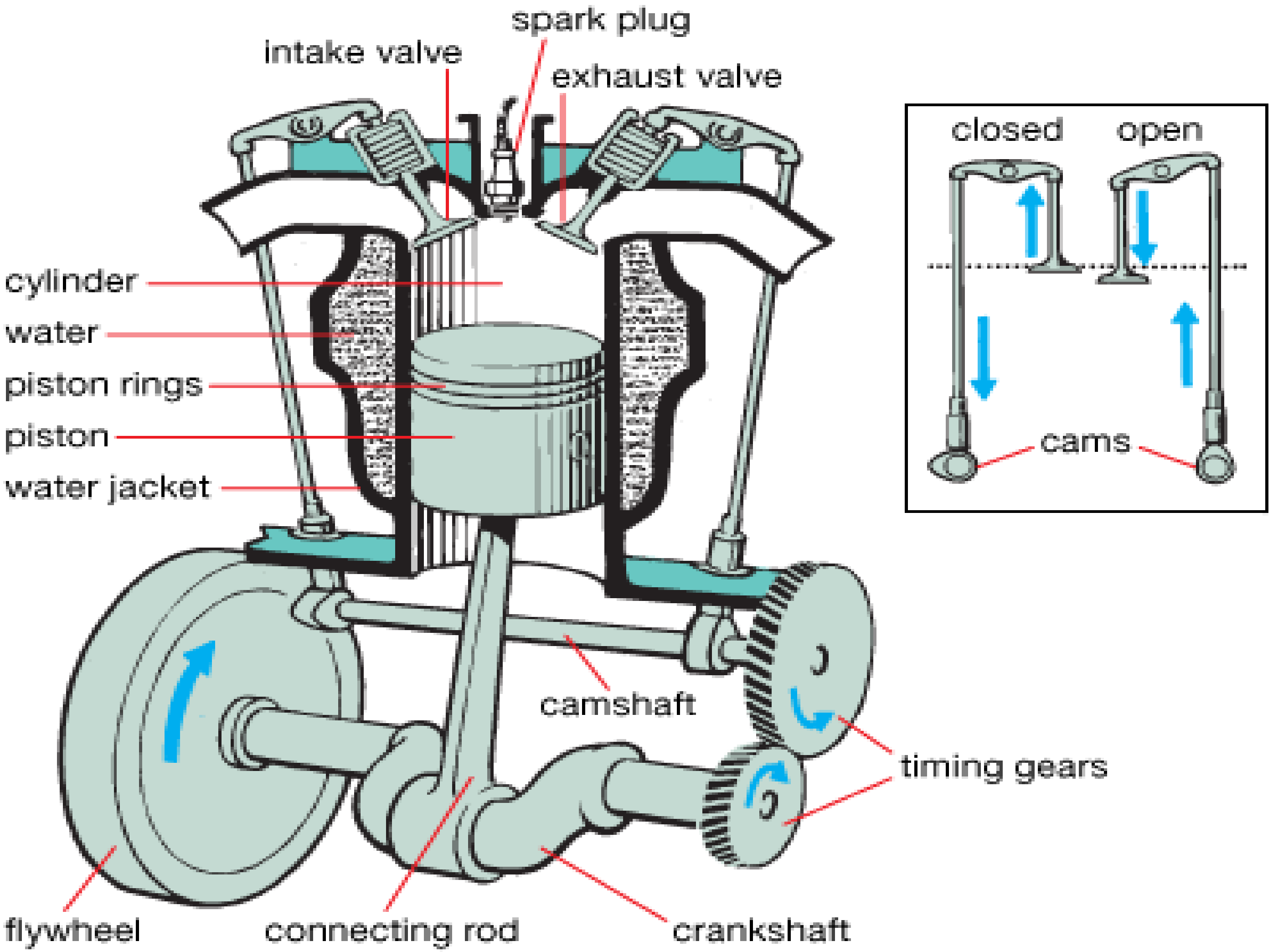
- **Connecting rod:**. It is a link between the piston and crankshaft. Its main function is to transmit force from the piston to the crankshaft .The upper (i.e. smaller) end of the connecting rod is fitted to the piston and the lower (i.e. bigger) end to the crank. The pin connecting it to the piston is called the **gudgeon pin** and that to the crankshaft is called **crank pin**
- **Crankshaft.** It converts the reciprocating motion of the piston into rotary motion with the help of connecting rod.
- **Crank case and sump.** Crank case is the engine casing having the main bearings in which the crank shaft rotates. The bottom cover of the engine is the sump which usually acts as a lubricating oil reservoir.

- **Flywheel** : It is a heavy wheel mounted on the crankshaft, whose function is to maintain uniform speed of engine. It is done by storing excess energy during power stroke, which, is returned during other stroke
- **Valves and Cam mechanism:** Valves controls the intake of air and fuel mixture(in SI engine) and exhaust combustion gases. Operated by cam mechanism. Push rod and rocker arm are used for operating the valves which automatically closes with the help of valve spring



Internal combustion engine mechanism.

Working parts of an engine



NOMENCLATURE

Cylinder Bore: Inside diameter of cylinder

Top Dead Centre(TDC) or Inner Dead Centre(IDC): Extreme position of piston at the top of cylinder

Bottom Dead Centre(BDC) or Outer Dead Centre: The position of piston when it is farthest from the top of cylinder

Stroke: The travel of piston from one dead center to other

Swept Volume: The volume of cylinder in between two dead centers

Clearance Volume: The volume of cylinder between TDC and cylinder head

Compression ratio: Ratio of volume of cylinder between BDC and cylinder head to clearance volume

FOUR STROKE ENGINE

- One cycle of operation is completed in four strokes of the piston, giving one power stroke in four strokes of the piston i.e., in two revolution of the crank shaft

Working principle of four stroke diesel engine

- Also called compression ignition or CI engine
- Works on diesel cycle(Constant pressure cycle)
- The entire process is completed in four strokes

(i) suction stroke, (ii) compression stroke, (iii) expansion or power stroke and (iv) exhaust stroke.

a. Suction stroke

- Piston movement : from TDC to BDC.
- Valve position :inlet valve is open and exhaust valve is closed.
- Process :draws atmospheric air into the cylinder through inlet valve. This is represented by 5- 1 in pV diagram.

b. Compression Stroke

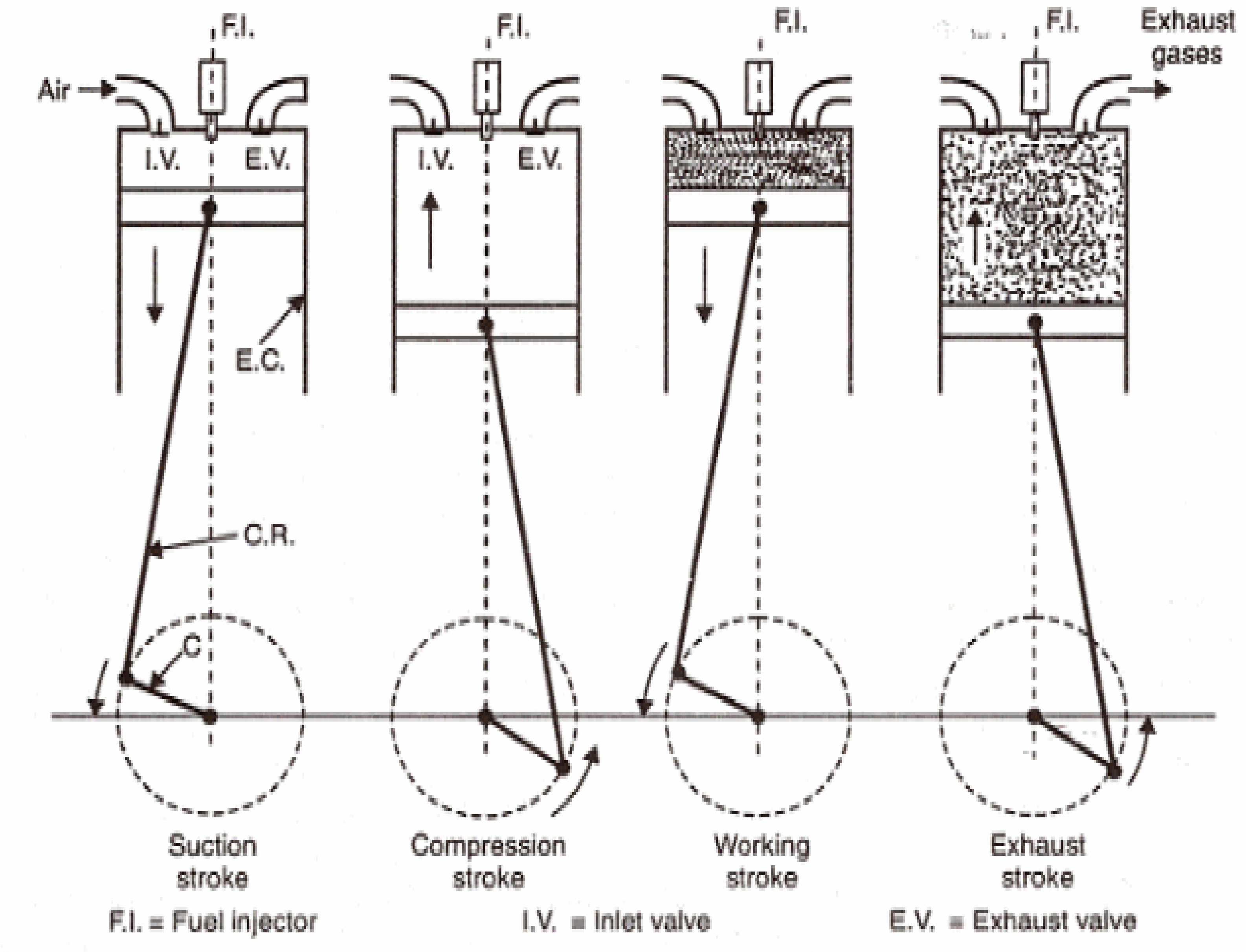
- Piston movement :from BDC to TDC.
- Valve position :both valves are closed.
- Process :the air inside the cylinder is compressed to high temperature and pressure. This operation is represented by line 1-2 in pV diagram

c. Power (Expansion) Stroke

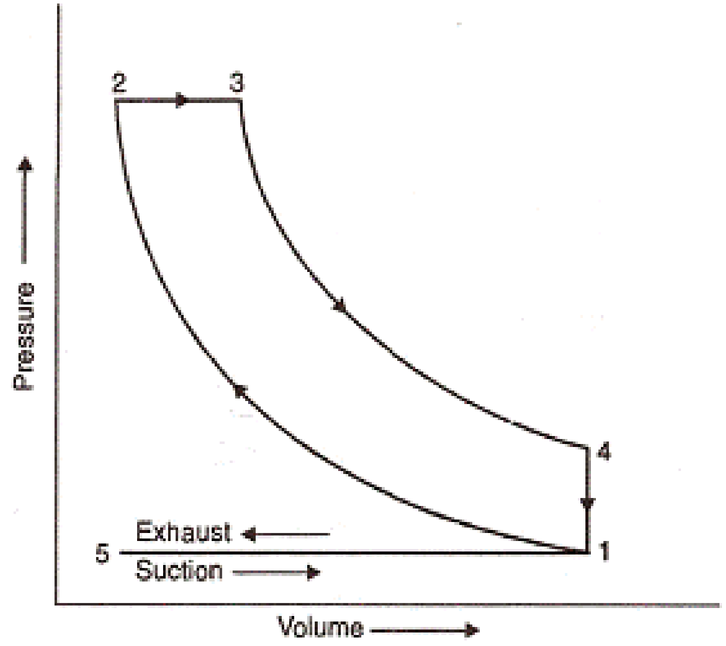
- Piston movement : from TDC to BDC.
- Valve position : both valves are closed
- Process : At the end of compression stroke a metered quantity of fuel is injected into the hot compressed air in the form of fine spray by means of a fuel injector. The fuel starts burning at constant pressure and pushes the piston from TDC.This is shown by line 2-3 in pV diagram. At point 3 fuel supply is cut off. The high pressure gas in the cylinder expands up to point 4 doing work on the piston. Power is obtained during this stroke.

d. Exhaust Stroke

- Piston movement :from BDC to TDC.
- Valve position :inlet valve is closed and exhaust valve is open.
- Process : the combustion products are pushed out of the cylinder through exhaust valve. It is represented by the line 1-5 in pV diagram. By this one cycle is completed



Working of 4 stroke diesel engine



Ideal pV diagram(indicator diagram) for four stroke diesel engine

Working principle of four stroke petrol engine

- Also called spark ignition or SI engine
- Works on Otto cycle(Constant volume cycle)
- Carburetor provides a mixture of petrol and air in the required proportion
- The entire process is completed in four strokes

(i) suction stroke, (ii) compression stroke, (iii) expansion or power stroke and (iv) exhaust stroke.

a.Suction stroke

- Piston movement :from TDC to BDC.
- Valve position :inlet valve is open and exhaust valve is closed.
- Process :vacuum created inside the cylinder draws air fuel mixture into the cylinder through inlet valve. This is represented by line 5-1 in pV diagram.

b**. Compression stroke**

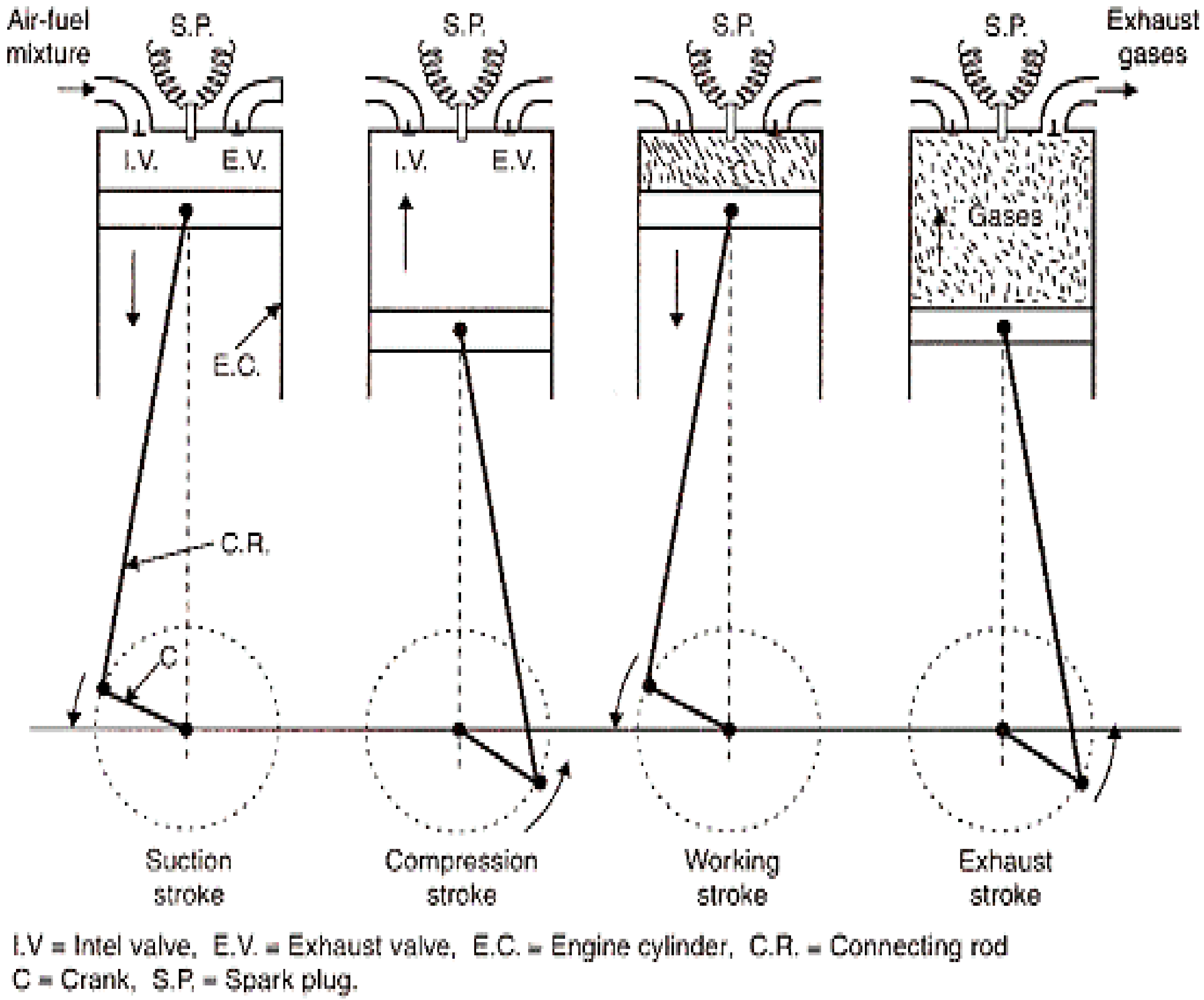
- Piston movement :from BDC to TDC.
- Valve position :both valves are closed.
- Process :the air fuel mixture inside the cylinder is compressed to high temperature and pressure. This operation is represented by line 1-2 in pV diagram

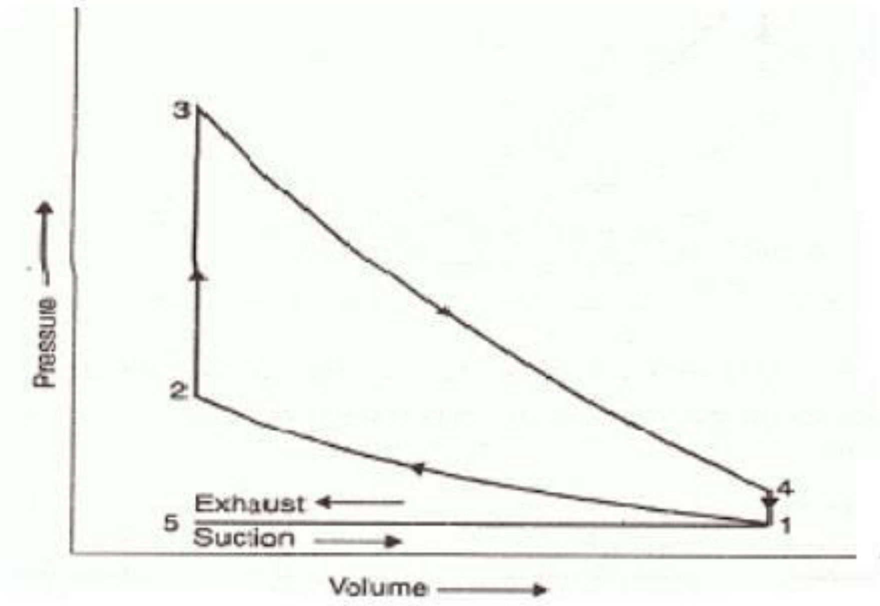
c. Power (Expansion) Stroke

- Piston movement :from TDC to BDC.
- Valve position :both valves are closed.
- Process :At the end of compression stroke spark plug initiates a spark which ignite the air fuel mixture. The air fuel mixture burns, hot gases are produced which drives the piston towards BDC and thus work is done on the piston. This is shown by line 2-3 in pV diagram. Power is obtained during this stroke.

d. Exhaust Stroke

- Piston movement :from BDC to TDC.
- Valve position :inlet valve is closed and exhaust valve is open.
- Process :the combustion products are pushed out of the cylinder through exhaust valve. It is represented by the line 1-5 in pV diagram. By this one cycle is completed





Ideal pV diagram for four stroke petrol engine

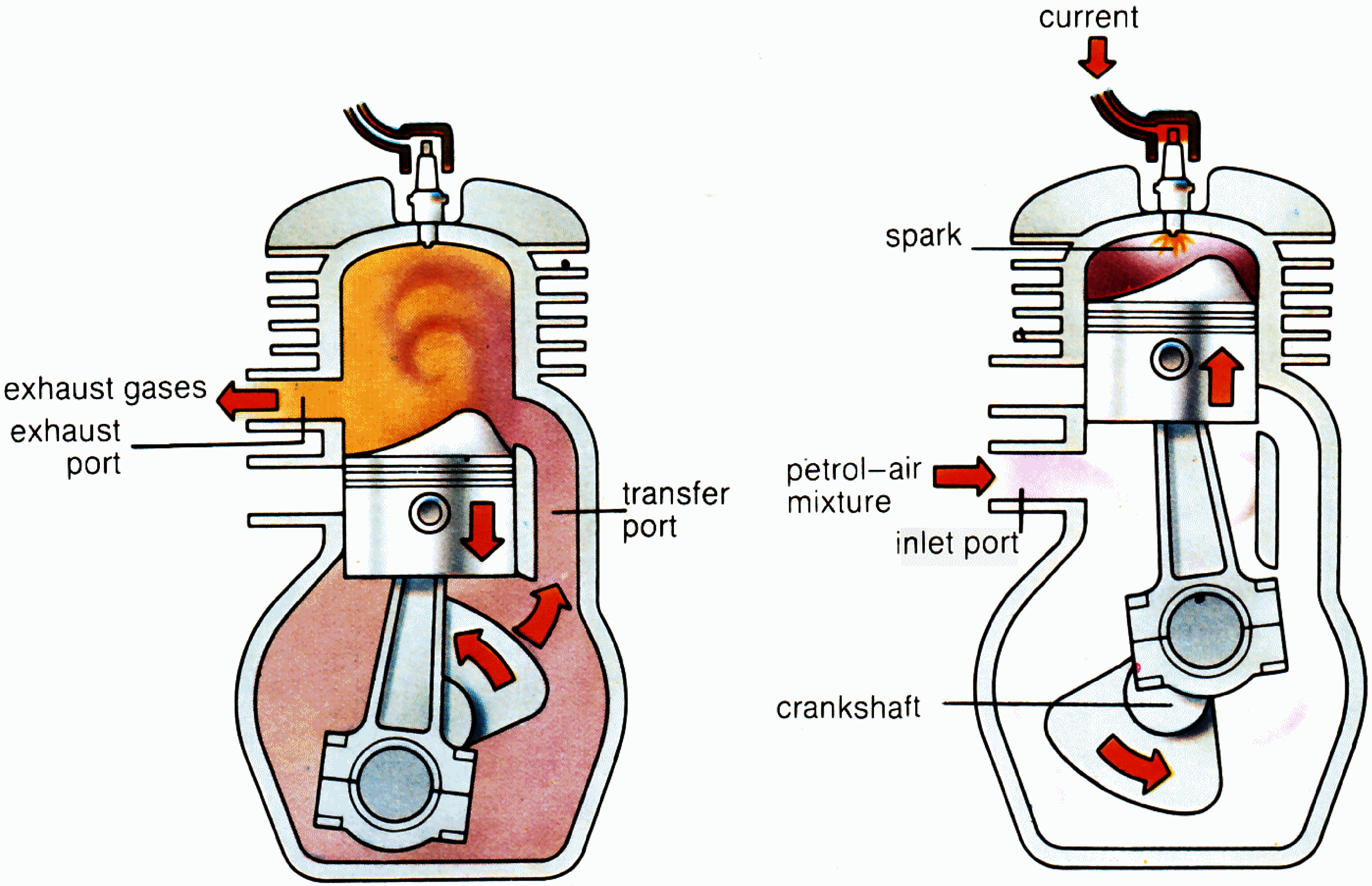
Working of 4 stroke petrol engine

Two-stroke internal combustion engine

- One cycle of operation is completed in two strokes of the piston giving one power stroke per two strokes of the piston,i.e in one revolution of the crankshaft.
- Here ports are provided instead of valves
- Cylinder is connected to a closed crankcase
- The three ports are:
- Crank case inlet port :admits the charge into the crank case.
- Transfer port :admits the charge from the crank case into the cylinder.
- Exhaust port :exhausts the burnt gases from the cylinder.

Working of 2 stroke Diesel Engine

- During upward stroke of piston, the air in the cylinder is compressed. At the same time fresh air enters the crankcase through the inlet port.
- Towards the end of this stroke fuel is introduced in the form of fine spray by fuel injector and due to high pressure and temperature of air, fuel starts burning. The piston, then travels downward due to the expansion of the gases and near the end of this stroke the piston uncovers the exhaust port and the burnt gases escape through this port.
- The transfer port is then uncovered and compressed air from the crankcase flows into the cylinder. The incoming fresh air help to remove the burnt gases from the engine cylinder


exhaust gases
exhaust port
transfer port
current
spark
petrol–air mixture
inlet port
crankshaft

Working of 2 stroke Petrol Engine

- During upward stroke of piston, the air fuel mixture in the cylinder is compressed. At the same time fresh air fuel mixture enters the crankcase through the inlet port.
- Towards the end of this stroke fuel air mixture is ignited using an electric arc from the spark plug. The piston, then travels downward due to the expansion of the gases and near the end of this stroke the piston uncovers the exhaust port and the burnt gases escape through this port.
- The transfer port is then uncovered and compressed air fuel mixture from the crankcase flows into the cylinder. The incoming fresh air fuel mixture help to remove the burnt gases from the engine cylinder. Thus one complete cycle is finished and process repeats

PETROL ENGINE(SI Engine)	DIESEL ENGINE(CI Engine)
1. Working based on Otto cycle.	Working based on Diesel cycle.
2. Air fuel mixture is taken in during suction stroke	Only fresh air is taken in during suction stroke
3.Fuel used is petrol or gasoline(High volatile)	Fuel used is diesel(non volatile)
4. Spark plug is used.	Fuel injector is used
5. Lower engine efficiency.	Higher engine efficiency.
6. Higher fuel consumption.	Lower fuel consumption.
7. Lower vibration and engine noise.	Higher vibration and engine noise.
8. Low initial cost.	High initial cost.
9. High running cost.	Low running cost.
10.Light duty application.	Heavy duty application.
11.Light weight	11.Heavy weight
12.High speed engine	12.Low speed engine
13.Quantity governing(Throttle controls the quantity of air fuel mixture to regulate the load)	13.Quality governing(Quantity of fuel is regulated to control the load)

Four Stroke Cycle Engine	Two stroke cycle Engine
1. One power stroke is obtained in every two revolution of the crankshaft	One power stroke is obtained in every one revolution of the crankshaft
2. Heavy flywheel is required due to non uniform torque	Lighter flywheel is required
3.Valves are present	Ports are used instead of valves
4. More efficient, because burnt gases are completely removed during exhaust stroke	4.Less efficient because some amount of burnt gases always present in the cylinder and mixes with fresh charge
5.For the same size, four stroke engine develops one half of power developed by two stroke engine	5.For the same size, two stroke engine develops twice power developed by four stroke engine
6. Thermal efficiency is higher	6.Thermal efficiency is lower
7. Heavy weight and complicated design(High initial cost).	7.Light weight , simple design(Low initial cost.)
8.Separate intake and exhaust stroke provides greater opportunity for heat dissipation.	8.Absence of separate intake and exhaust stroke. So greater cooling and lubrication requirement.
9.Less rate of wear and tear	9.High rate of wear and tear
10.Used in cars,buses,trucks,aeroplane,tractors,power generators etc. where efficiency is important	10.Used in scooters,motorcycles,hand sprayers,mopeds,lawn movers where low cost,compactness and light weight is

MODULE 4

Basic power plant and its working

POWER PLANTS – Definition

- Industrial locations that are utilised for the production and distribution of electrical energy from available source of energy

Classification of Power Plants

1.On the basis of source of energy

a)Conventional energy power plants

- Hydro-electric Power Plant
- Thermal (Steam) Power Plant
- Diesel Engine Power Plant
- Nuclear Power Plant
- Gas Turbine Power Plant

b)Non Conventional energy power plants

- Solar Power Plants
- Geothermal Power Plants
- Wind Power Plants
- Tidal Power Plants
- Thermo electric power plant

2)On the basis of nature of load

a)Base load power plants: Large capacity plants for continuous operation

Eg:Hydro-electric Power Plant, Nuclear power plant, Coal fuel steam power plant etc.

b)Peak load power plants: Operated to meet power demand at peak time

Eg:Diesel power plant, Gas turbine power plant, pumped storage hydro electric power plants etc.

3.On the basis of service conditions

a)Stationery Eg:Steam power plants

b)Locomotive Eg:Diesel power plant

4.One basis of location

a.Central power plants: Large capacity power plants, located near natural source of energy.Eg:Coal fuel steam power plants

b.Isolated power plants: Plants located away from the energy source and load centres

Hydraulic Power Plants

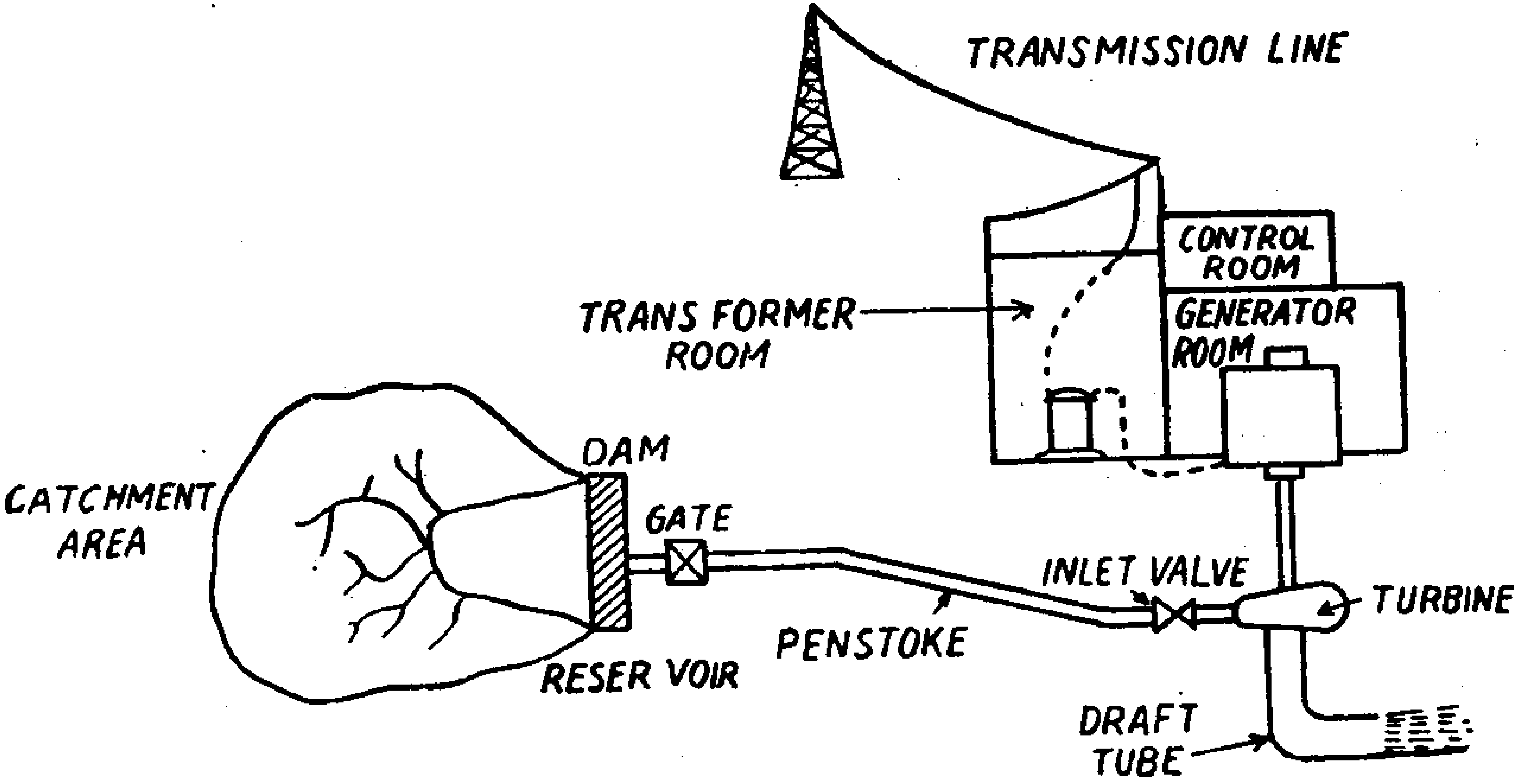
- Produce electric power from water
- Water collected in earth surface possess PE
- PE is converted to KE when water falls through certain height
- KE converted into mechanical energy by prime movers (Hydraulic Turbines)
- Mechanical energy is used to run an electric generator which is directly coupled to turbine shaft.

Main Elements

- Catchment area : Whole area behind the dam draining into a river across which dam has been built
- Reservoir : To store water, Natural(lake in a high mountain) or artificial(dam across a river).
- Dam : construction across a river to store water and to create head for power generation.
- Penstock : Conduit to supply water under pressure to turbine
- Surge Tank : Additional storage space between main reservoir and power house. Also controls pressure variations from rapid changes in rate of flow of water through penstock (Reduce water hammer)
- Draft tube: Diverging passage connecting the turbine outlet with the tail raise. It allows turbine to be set above tail raise without loss in head ,to facilitate for inspection and maintenance
- Tail raise: It is a passage for discharging the water leaving the turbine, into river or canal
- Power House :Building where turbine, generators and controlling equipments are housed and power generated
- Power transmission system: It consists of step up transformers, switch gear mechanisms, outgoing connections etc.
- Spill way: It is used to discharge the water during flood without passing through power house

WORKING OF HYDROELECTRIC POWER PLANTS

- Water available from catchment area is collected in the reservoir behind the dam
- Power house is located at a lower level to obtain maximum head from water
- PH is provided with turbine which is coupled to electric generator for producing power
- Water from reservoir is supplied to turbine through pen stock
- Turbine convert kinetic energy of water into mechanical energy.
- The mechanical energy developed by the turbine is used for running electric generator
- Water after doing work on the turbine passes through draft tube to the tail race

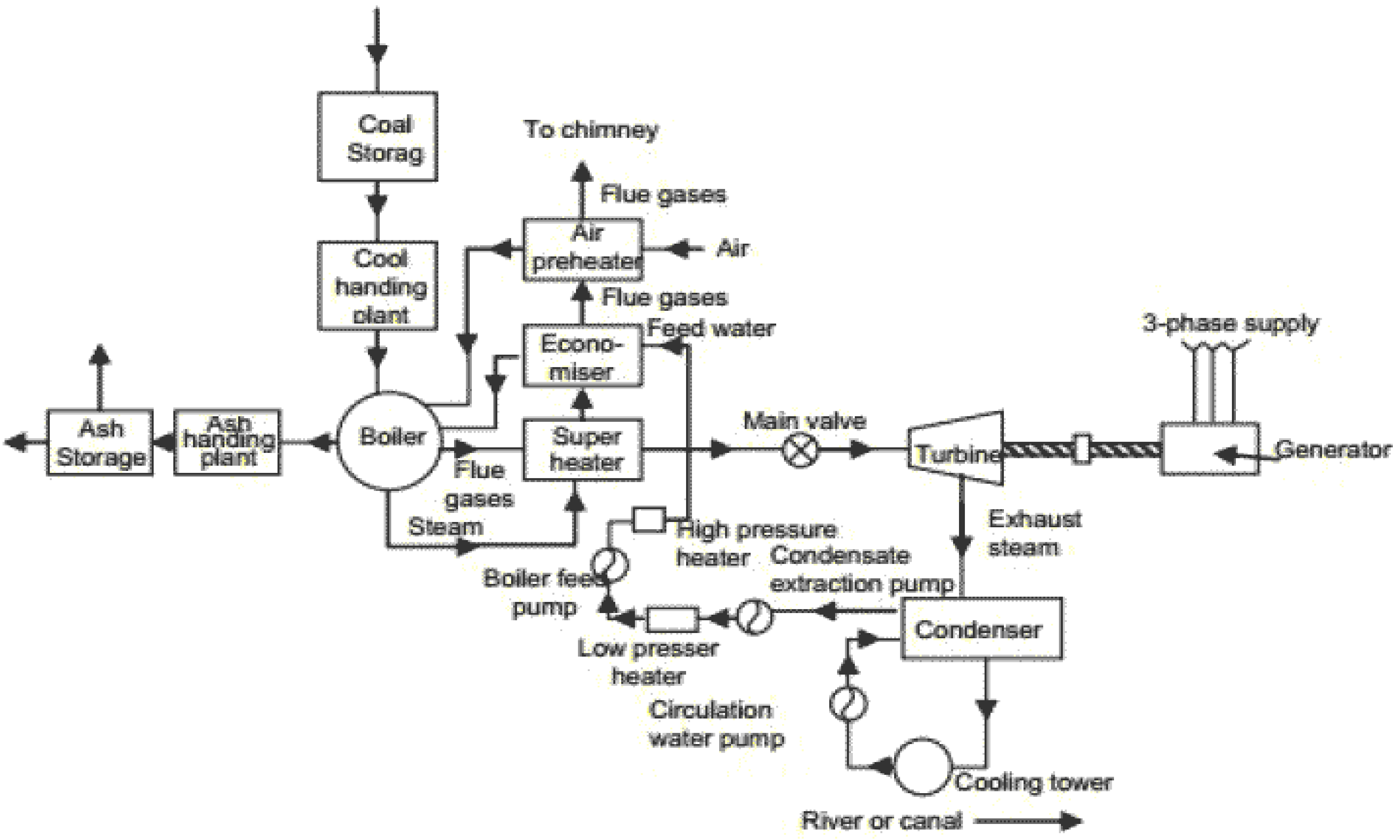

TRANSMISSION LINE
CONTROL ROOM
TRANS FORMER ROOM
GENERATOR ROOM
DAM
CATCHMENT AREA
GATE
INLET VALVE
TURBINE
PENSTOKE
RESER VOIR
DRAFT TUBE

Advantages

- Low operating and maintenance cost
- No fuel charges
- Less supervising staff required
- Can be switched on and off in very short time
- No air or water pollution
- Load can be varied according to changing load demand
- Can be used for irrigation and flood control
- Long life(100 – 125 years)

Disadvantage

- Initial cost of plant very high
- Takes longer time for erection and commissioning
- Usually located far away from load centers.Transmission cost are high
- Power generation depend on availability of water which depends on rain


Coal
Storag
Cool
handing
plant
To chimney
Flue gases
Air
preheater
Air
Flue gases
Econo-
miser
Feed water
3-phase supply
Ash
Storage
Ash
handing
plant
Boiler
Super
heater
Main valve
Turbine
Generator
Flue
gases
Steam
High pressure
heater
Exhaust
steam
Condensate
extraction pump
Boiler feed
pump
Condenser
Low presser
heater
Circulation
water pump
Cooling tower
River or canal

Steam Power Plant

- Converts chemical energy of the fossil fuels (coal,oil,gas) into mechanical/electrical energy through expansion of steam in a suitable prime mover such as steam engine or steam turbine

A thermal power plant consists of the following four main circuits

1. Coal and ash circuit.

- Coal from storage yard is transferred to coal preparation center where it is pulverized
- This coal is fed into furnace along with preheated air and ignited
- Ash resulting from combustion of fuel is collected in ash pit and is removed to ash storage yard

2. Air and gas circuit

- Air is taken from atmosphere is preheated in an air preheater by heat of flue gases leaving the furnace
- Preheated air then passes on to furnace

3.Feed water and steam flow circuit.

- Water is converted into steam in boiler
- Steam gets super heated in super heater

- Super heated steam is then fed to steam turbine where it gets expanded
- Thermal(Heat) energy of steam is converted into mechanical energy
- The expanded steam is cooled and condensed to water in a condenser by the circulation of cooling water .
- The condensed steam (condensate) is extracted by a condensate extraction pump
- The condensate is heated in feed water heater using steam trapped(bled steam) from steam turbine
- The feed water pump forces the feed water under pressure to economiser where the feed water is heated by flue gas leaving the furnace
- Hot feed water from economiser enters the boiler and the process is repeated

4. Cooling water circuit.

- Cooling water circulated through condenser extracts heat from exhaust steam and gets heated up
- The resulting hot water is further cooled in a cooling pond or tower

Working

- Air taken from the atmosphere is first passed through the air pre-heater, where it is heated by flue gases
- Heat produced due to burning of coal is utilized in converting water contained in boiler drum into steam
- The steam generated is passed through the super-heater.
- Superheated steam then flows through the turbine, where the steam is expanded and the thermal energy of steam is converted in to mechanical energy
- Mechanical energy is used to run an electric generator which is directly coupled to turbine shaft.
- After doing work in the turbine the exhaust steam passes into a condenser where it is condensed to water
- The condensate is heated in feed water heater with the help of steam trapped from steam turbine
- Feed pump forces the feed water under pressure to economiser
- In economiser ,the feed water is further heated up by the hot flue gases leaving the furnace .The hot feed water from the economiser enters the boiler and cycle is repeated

- Advantages
- Less capital cost • Construction time is low • Power generation not dependent on nature’s mercy • Power plant can be located near industrial areas, so transmission cost will be less
- Disadvantages
- Power generation cost is high • Part load efficiency is less • Fuel transportation and handling is difficult. • Pollution • Ash handling is difficult • Life time of 20-25 years.

Diesel Power Plant

- Produce power in the range of 2 to 50 MW.
- They are used where standby sets are required for continuity of supply such as hospitals, telephone exchanges, radio stations, cinema theatres and industries.
- They are suitable for mobile power generation and widely used in railways and ships.

Essential component of Diesel Power Plant

- Diesel Engine
- Air intake system
- Fuel supply system
- Exhaust system
- Cooling system
- Lubricating system
- Starting system

1. Diesel engine :

- Act as prime mover which is directly coupled to generator

2. Air intake system :

- The air required for the combustion of fuel is drawn through the air filter.
- The purpose of the filter is to remove dust from the incoming air

3. Exhaust system:

- Discharges exhaust gas to atmosphere
- The exhaust gases coming out of the engine is very noisy. In order to reduce the noise a silencer(muffler) is used

4. Fuel supply system:

- Fuel from the storage tank is pumped through a filter into a smaller tank called all day tank.
- This tank supplies the daily requirements of the diesel engine.

5. Starting system:

- Diesel engine used in diesel power plants is not self starting.
- The engine is started from cold condition with the help of an air compressor.

6. Lubricating System:

- This circuit includes lubricating oil tank, oil pump and oil cooler.
- The purpose of the lubrication system is to reduce the wear of the engine moving parts.
- Lubrication also helps to cool the engine.
- In the lubrication system the oil is pumped from the lubricating oil tank through the oil cooler where the oil is cooled by the cold water entering the engine.
- The hot oil after cooling the moving parts return to the lubricating oil tank.

7. Cooling system:

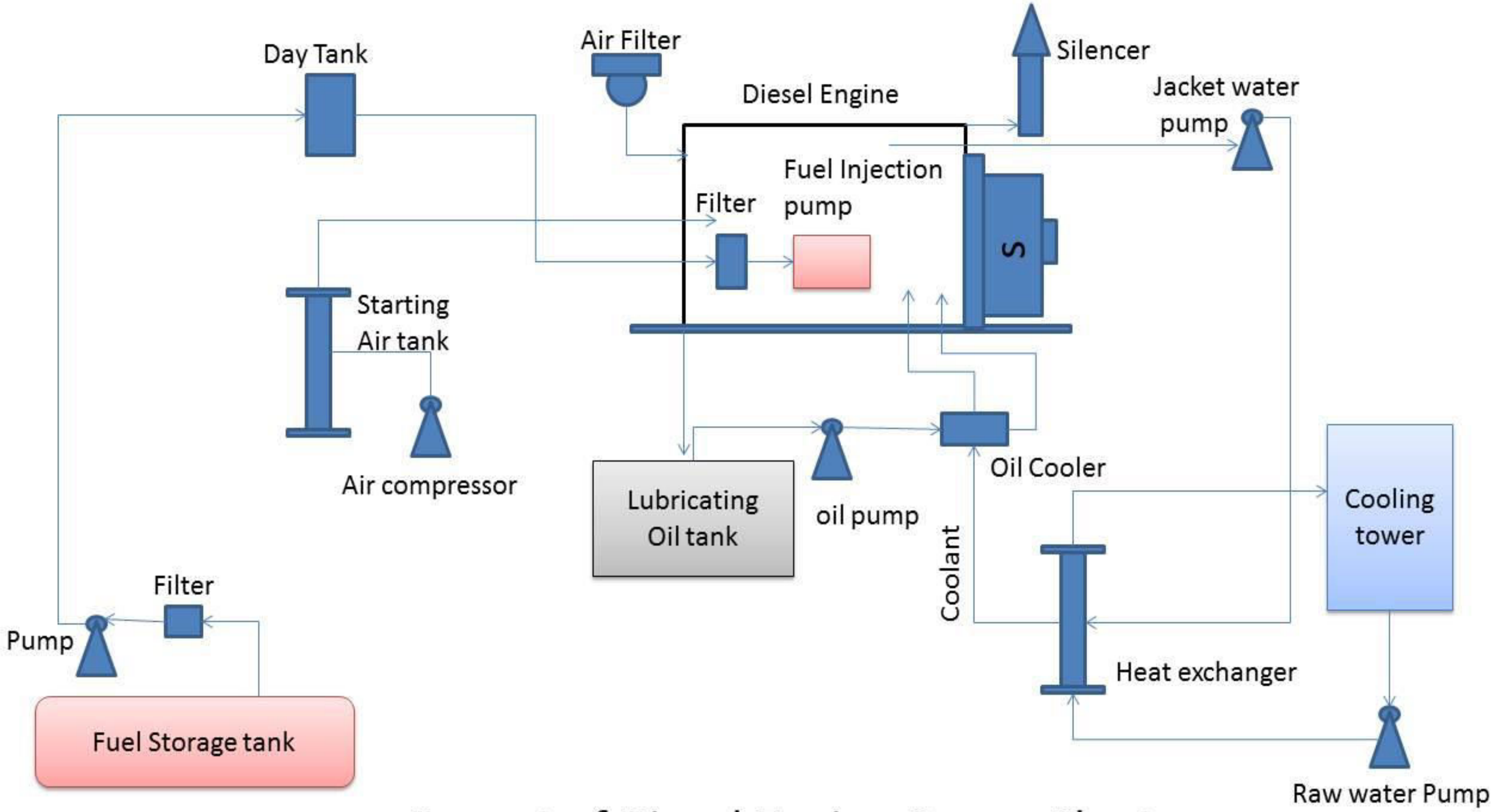
- The temperature inside the engine cylinder is in the order of 15000 °C to 20000 °C. In order to lower this temperature water is circulated around the engine.
- The hot water leaving the jacket is passed through the heat exchanger
- The heat from the heat exchanger is carried away by the raw water circulated through the heat exchanger and is cooled in the cooling tower.

Advantages of Diesel power plant :

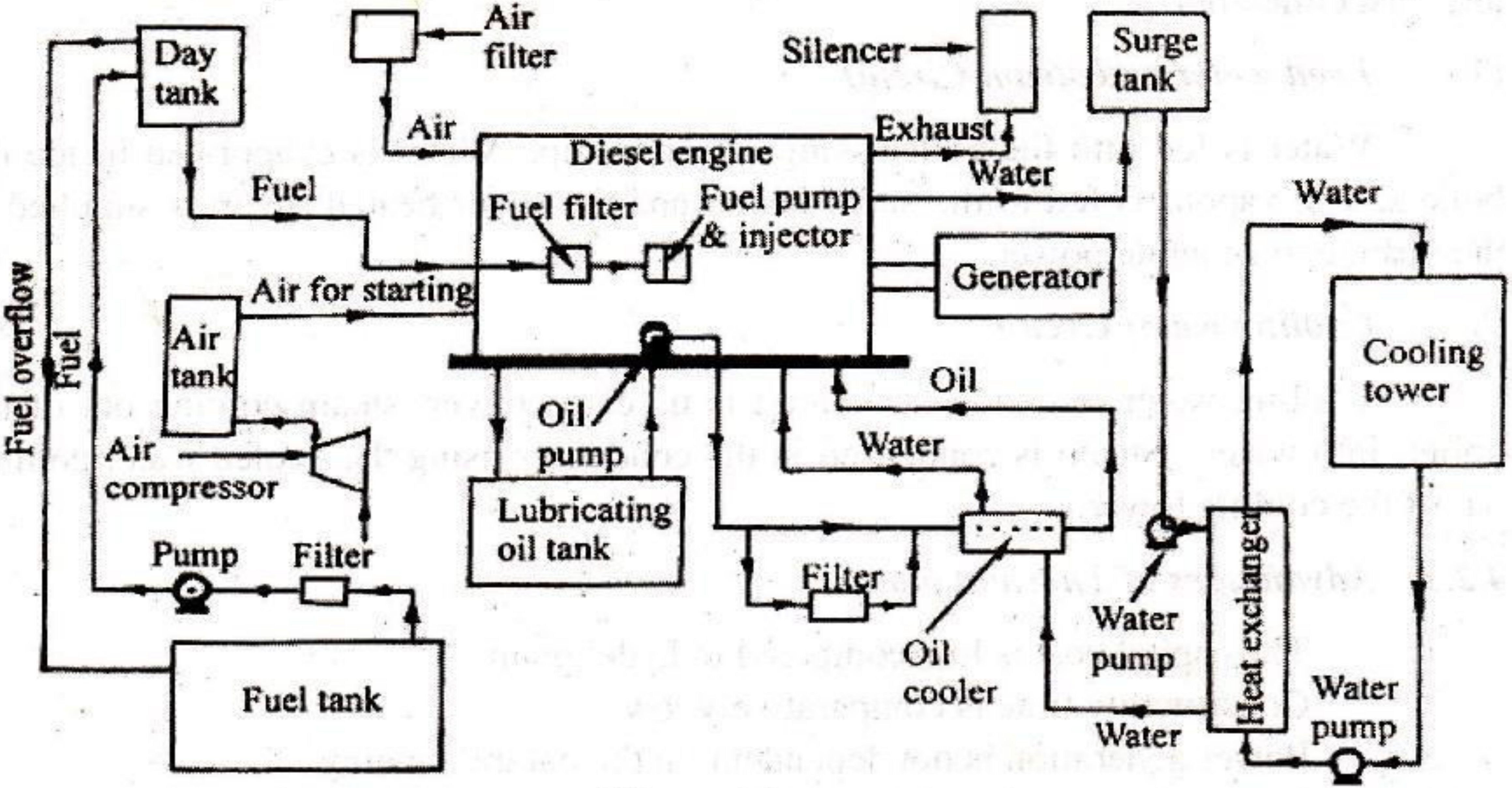
- Simple design and installation
- Occupies less space.
- Can be started and put on load quickly
- Less cooling water requirement.
- No problem of ash handling
- Less supervision required
- Less area needed for fuel storage.
- Can be located near load centers
- It can respond to varying loads without any difficulty.

Disadvantages of Diesel power plant :

- High Maintenance ,lubrication cost and operating cost
- The capacity of a diesel plant is limited. They cannot be constructed in large sizes.
- In a diesel plant noise is a serious problem.
- The life of diesel power plant is small (2 to 5 years)



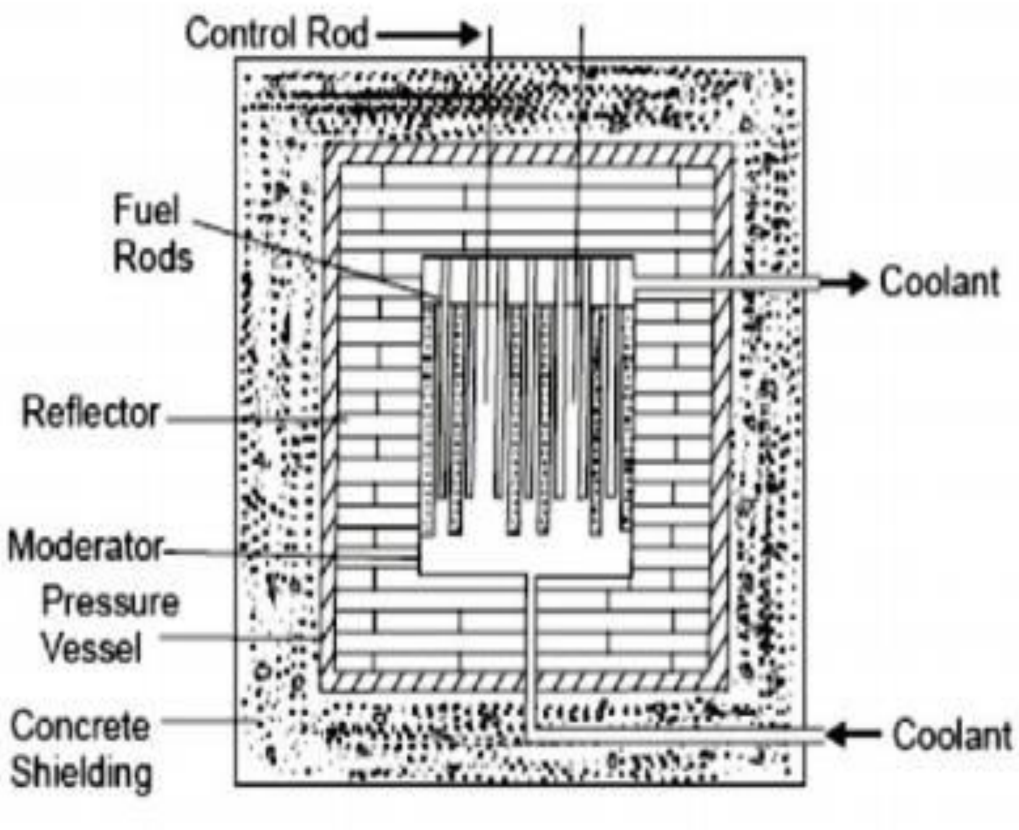
Layout of Diesel Engine Power Plant



Day tank
Air filter
Silencer
Surge tank
Air
Exhaust
Diesel engine
Water
Fuel
Fuel filter
Fuel pump & injector
Water
Generator
Air for starting
Air tank
Fuel overflow
Fuel
Cooling tower
Oil
Oil pump
Water
Air
Air compressor
Lubricating oil tank
Pump
Filter
Filter
Heat exchanger
Water pump
Oil cooler
Fuel tank
Water
Water pump

Figure 5.3

Parts of Nuclear Reactor



Nuclear reactor

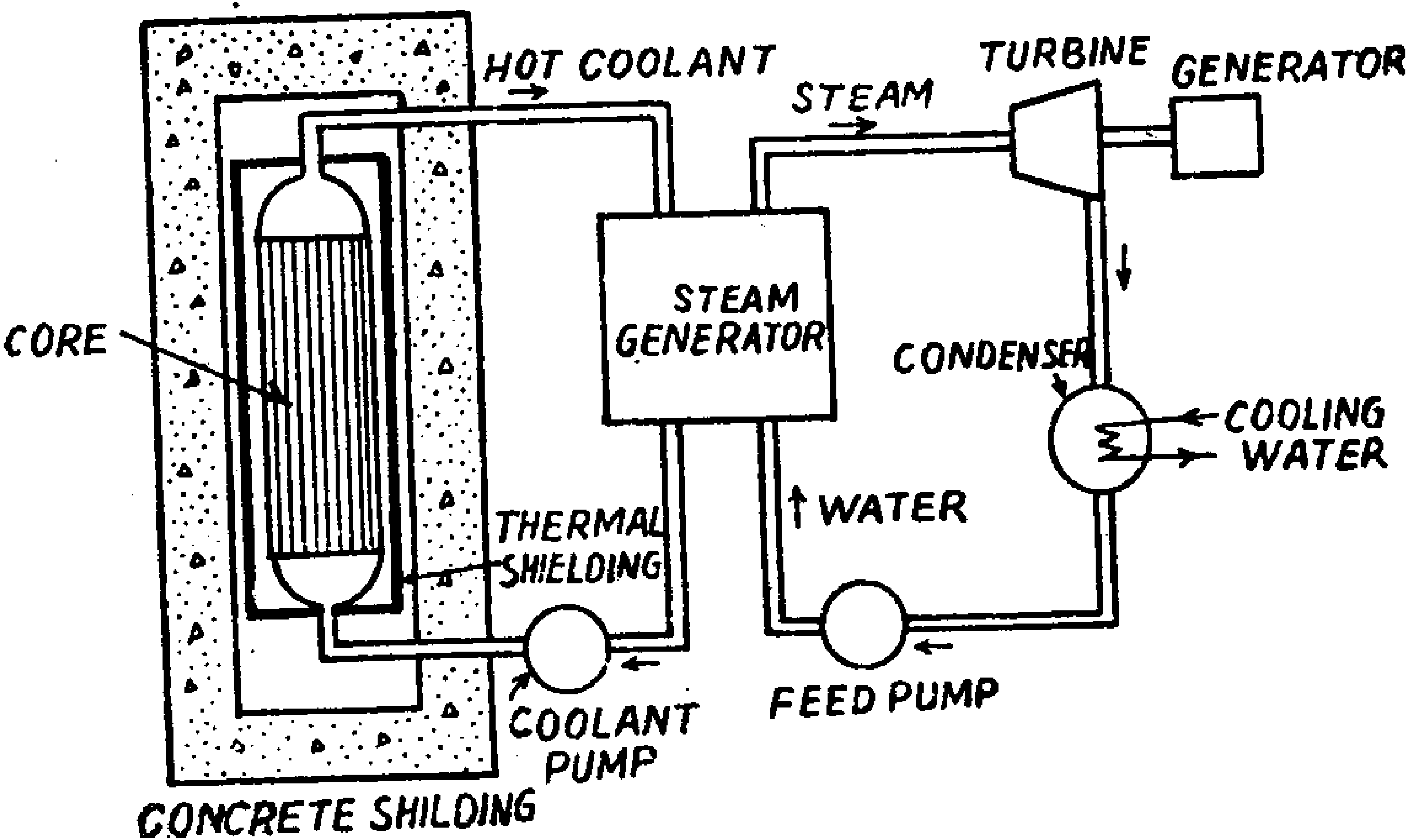
- Fuel rod: Fissionable materials like U^{235}, U^{238} , Pu^{239}
- Control rod: Energy produced due to fission of nuclear fuel is so much that if it is not controlled the entire core and surrounding structure may melt and radioactive fission products may come out of the reactor. Boron or cadmium strips
- Moderator:Fast moving neutrons are far less effective in causing the fission. So their speed must be reduced. Graphite, heavy water and beryllium
- Coolent:Used to transfer large amount of heat produced in the reactor for being utilized.
- Reflector: Reflect back the neutron that leak out from core surface. Made of same material as the moderator

NUCLEAR POWER PLANT

- Working is similar to thermal power plant except that there is a nuclear reactor and heat exchanger instead of furnace and boiler
- Other difference between the two is in the fuel they use to heat the water in the boiler(steam generator).
- The main components of a nuclear power plant are
- Nuclear reactor
- Heat exchanger (steam generator)
- Steam turbine
- Electric generator
- Condenser.

Working of Nuclear Power Plant

- Heat is liberated in the reactor as a result of nuclear fission of fuel (U^{235}, U^{238} , Pu^{239})
- This heat is taken up by the primary coolant circulating through the reactor core.
- The primary coolant transfers this heat to secondary coolant (water) circulating through heat exchanger(steam generator) and gets converted to steam.
- This steam is expanded in the turbine which turns the turbine shaft.
- Mechanical energy is used to run an electric generator which is directly coupled to turbine shaft.
- The expanded steam coming out of the turbine is condensed and is pumped back as feed water by the feed water pump into the reactor core.


HOT COOLANT
STEAM
TURBINE
GENERATOR
STEAM GENERATOR
CORE
CONDENSER
COOLING WATER
WATER
THERMAL SHIELDING
COOLANT PUMP
FEED PUMP
CONCRETE SHILDING

Advantages of Nuclear power plant:

- A nuclear power plant uses much less fuel than a fossil-fuel plant(Heat produced by 1 kg of uranium = Heat produced by 4500 tones of coal)
- Space required is less when compared with other power plants.
- No problem of fuel transportation, storage and handling , ash handling
- Low man power required
- No green house gases

Disadvantages of Nuclear power plant:

- Maintenance cost of the plant is high
- Danger of nuclear radiation.
- Disposal of radio active wastes
- Part load operation is inefficient.
- Risk of disaster

Solar Energy

Solar energy can be exploited in various ways as follows:

(i) By direct conversion to electricity by photo voltaic cell

(ii) By conversion to electricity via thermo-electric power system.

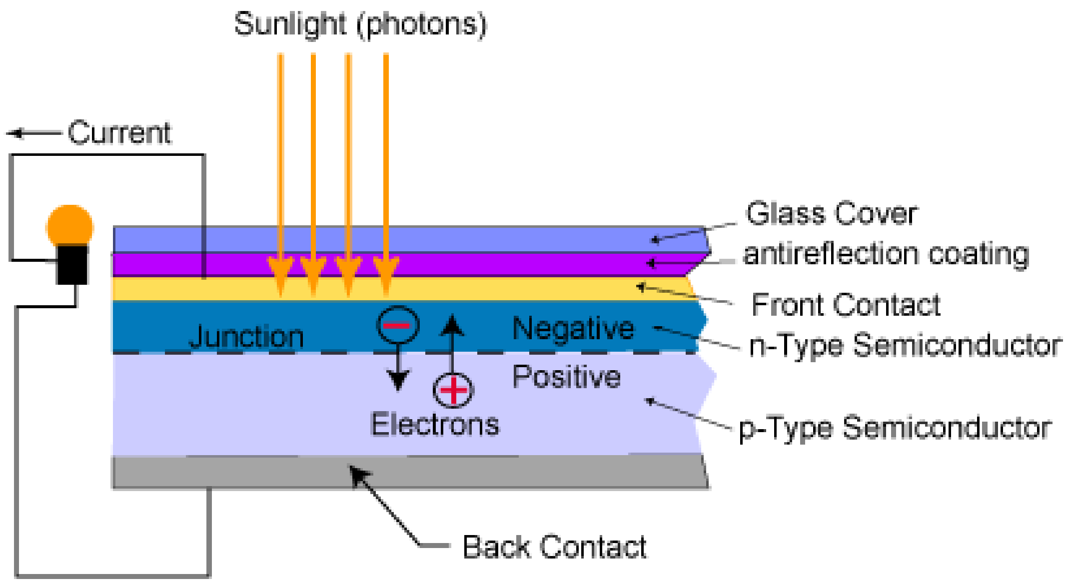
Following thermo-electric systems are presently used for power generation .

(a) Low temperatures cycles using flat plate collectors.

(b) Concentrating collectors for medium and high temperature cycles.

Photo voltaic cell

- Consists of n and p type semiconductors stacked together
- When exposed to sunlight, electron flow takes place across the circuit and DC current is produced



Solar collectors

I. Non concentrating collectors –

Flat collectors

- Made in the form of rectangular panels
- Absorbing surface made of copper, aluminum, or steel to which (carbon) black coating is applied
- Solar energy is converted to heat energy and water flowing through the tubes get heated
- Tubes are coated with insulating material(fiber glass) to prevent heat loss
- Operating temperature up to 90˚C

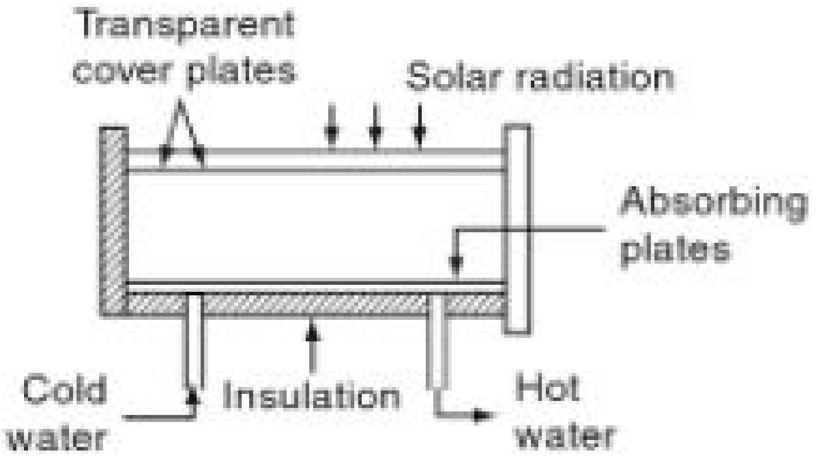
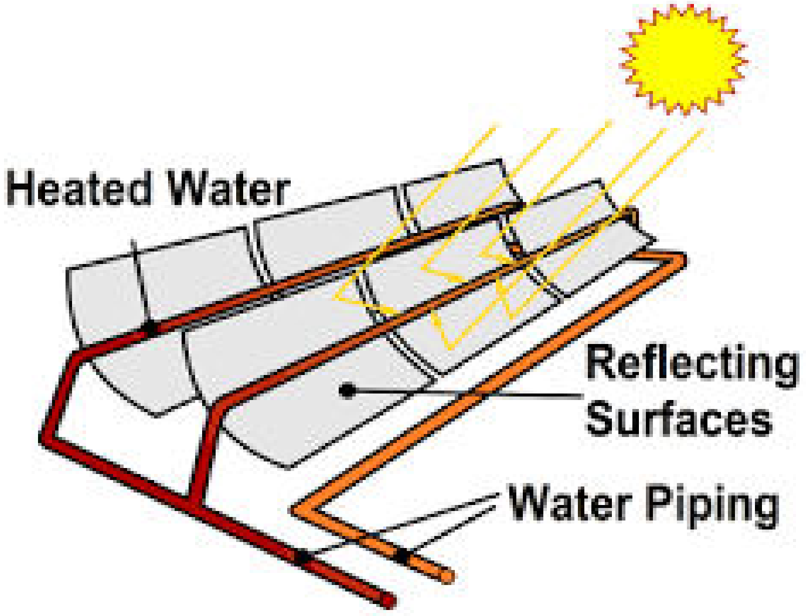


FIG. 2.2 *Flat plate collector*

II.Concentrating(focusing) collectors

a. Line focusing collector

- Solar radiation reflected from parabolic trough is concentrated on a absorber tube placed on its focus point
- Heat energy is absorbed by water flowing through the tube



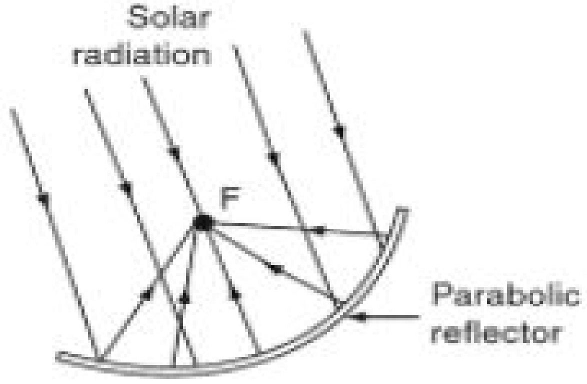


FIG. 2.3 *Parabolic trough collector*

b.Point focussing collector

- Solar radiation reflected from parabolic dish surface is concentrated on a single focus.
- Water flows through this focus and is heated

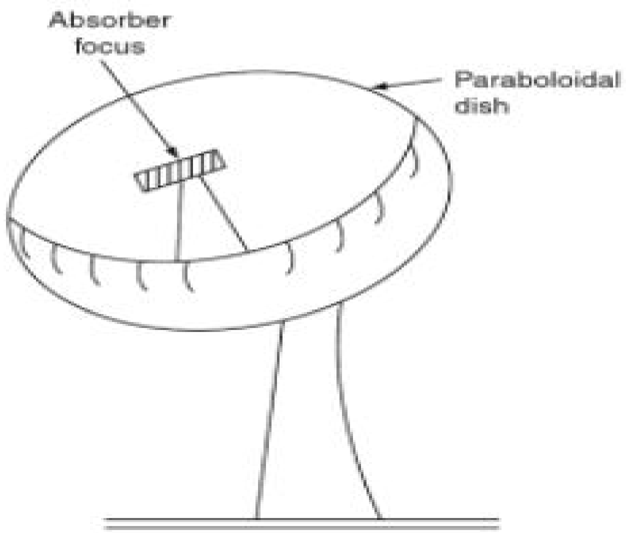
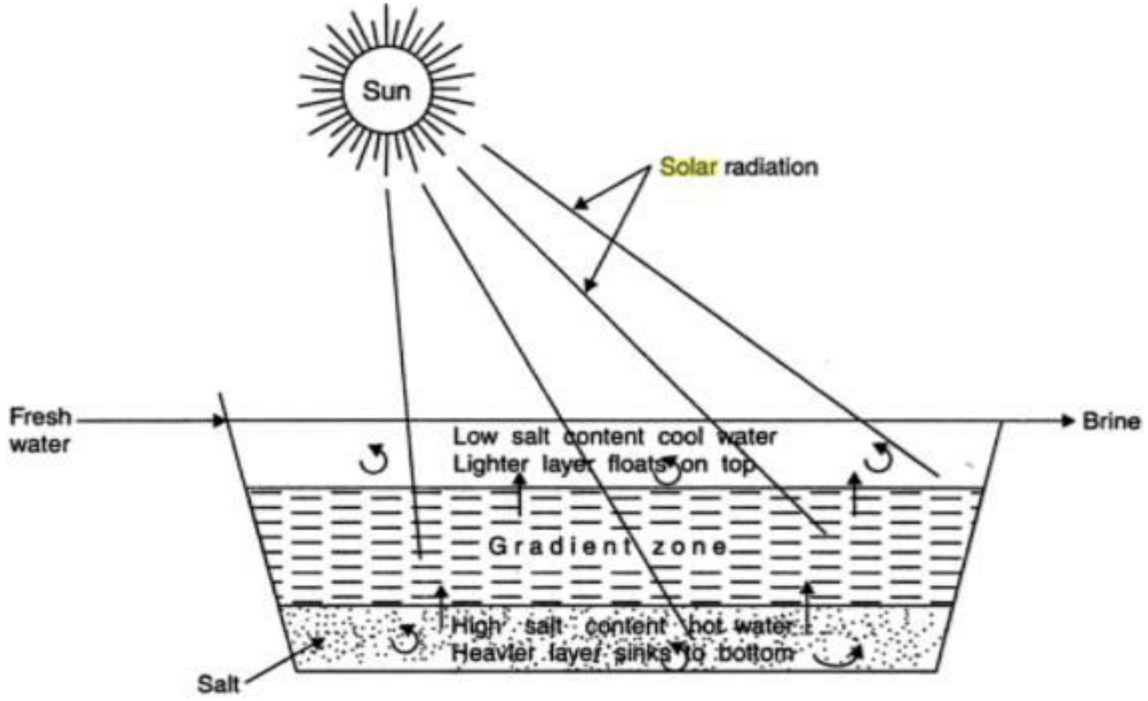


FIG. 2.5 *Point focusing collector*

Solar Pond Electric Power Plant

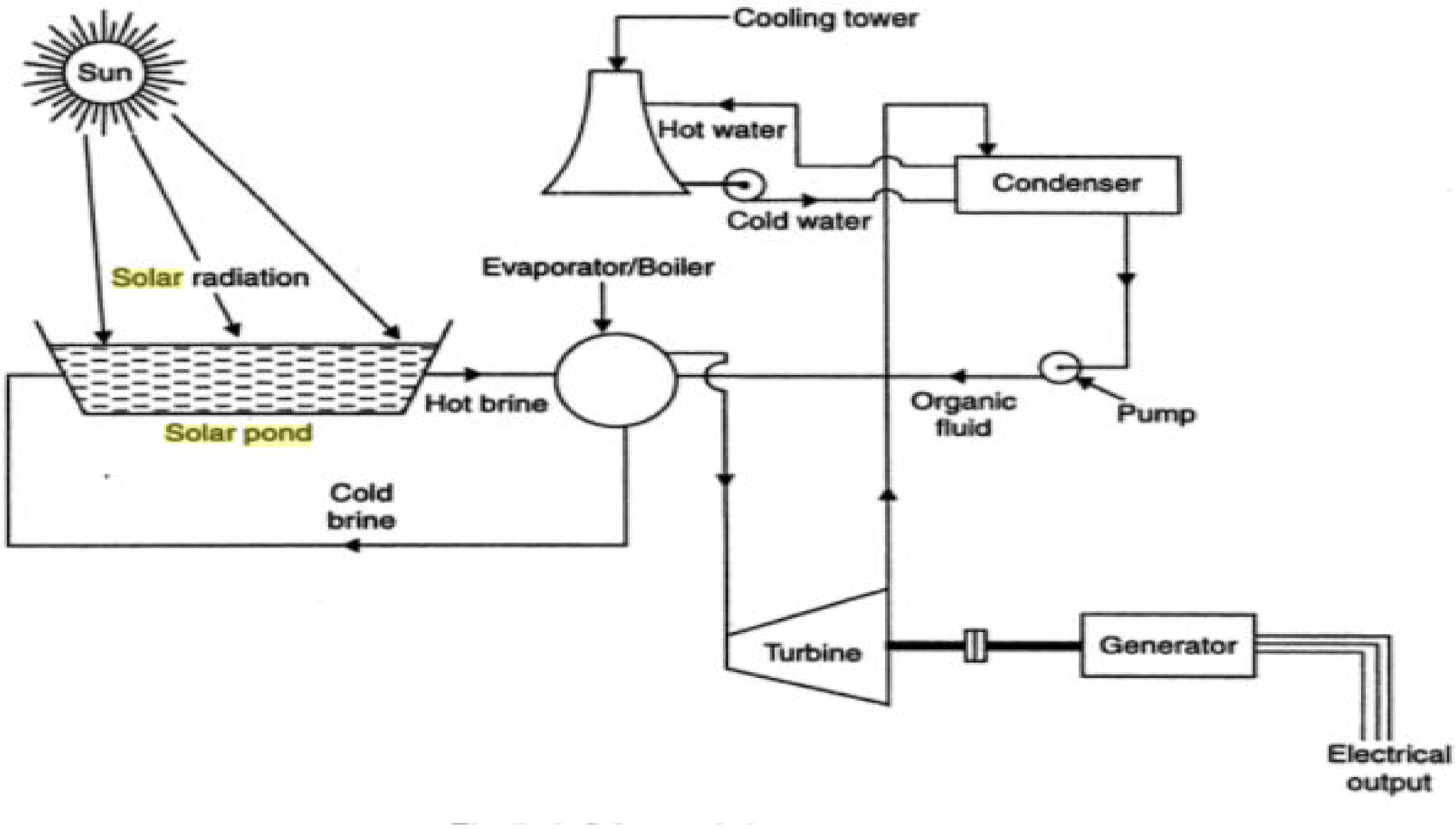
- When water at the bottom of an ordinary pond is heated by sun's rays they become less dense than cooler water above it and convection begins
- The water losses heat to the atmosphere and net temperature in the pond remains nearly atmospheric
- A solar pond is a pool of salt water that collects and store solar energy
- It heats water by impeding the convection
- It has three distinct zones
- A top convective zone with least salt content where the temperature is atmospheric
- An intermediate non convective zone (or the gradient zone) where no convection occurs. Temperature and salinity decrease from bottom to the top in this layer.
- A bottom zone with maximum salt content and it has high temperature(70-85 ˚C)
- This zone collects and store solar energy. The heat loss from this zone is prevented due to non convective gradient zone in between.
- Hot water from bottom level of pond is passed to the evaporator where heat of brine is absorbed by an organic working fluid and get vaporised

- This vapour runs a turbine which is coupled to a generator and electricity is produced
- The exhaust vapour is then condensed in a condenser and the liquid is pumped back to the evaporator and the cycle is repeated



Principle of Solar Pond

Solar Pond Electric Power Plant



Low temperature solar power plants

- Uses flat plate collectors to collect solar energy. Working temperature is limited to 100°C
- The solar energy absorbed by water is passed through a heat exchanger
- Heat of water is absorbed by a low working temperature fluid like butane(or refrigerant like ammonia,freon etc.) and get vaporised
- This vapour runs a turbine which is coupled to a generator and electricity is produced
- The exhaust vapour is then condensed in a condenser and the liquid is pumped back to the evaporator and the cycle is repeated

Low temperature solar power plant

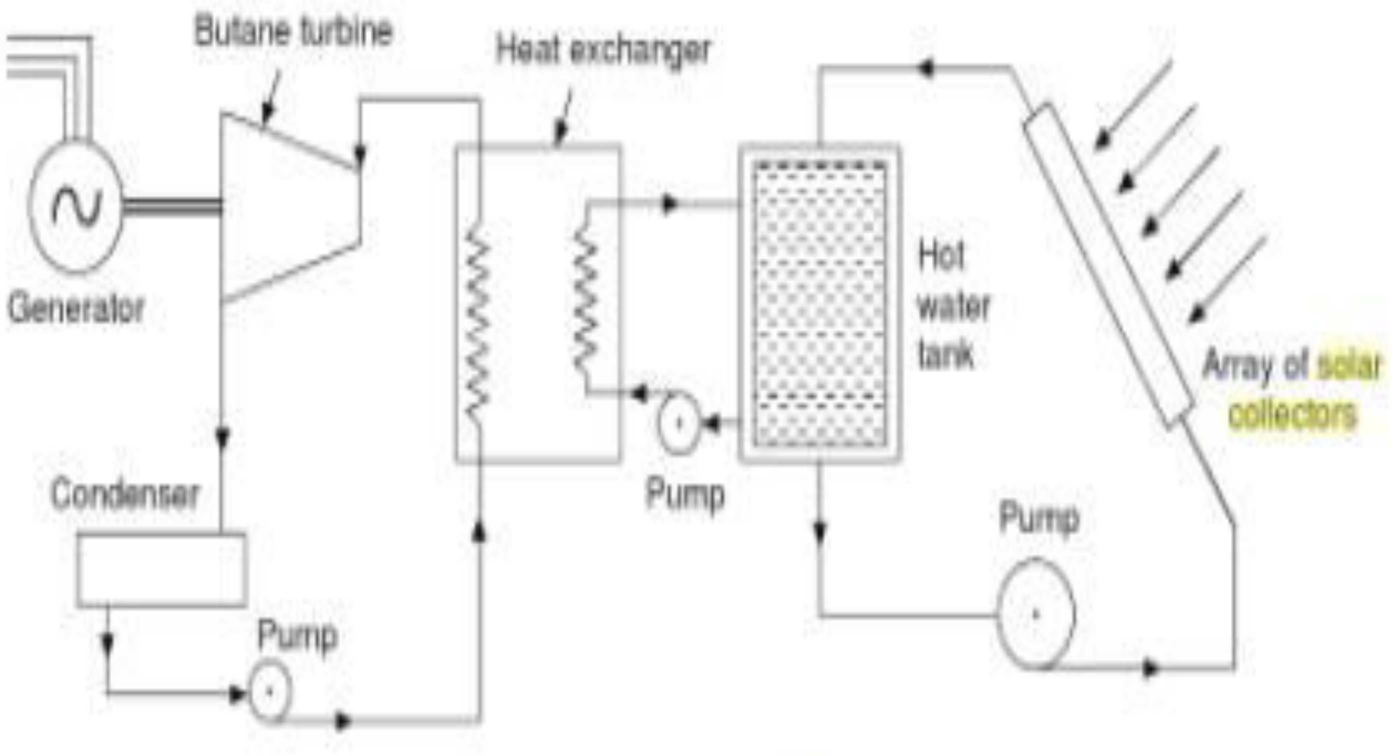


Figure 5.9 Low temperature solar power plant.

Advantages

- Renewable energy
- No moving parts
- Absence of pollution
- Low maintenance cost
- Noise free
- Excellent for remote areas not connected to electric grid
- No fuel cost
- Long life

Disadvantages

High initial investments

Generate electricity only during day light

Weather and climate dependant

Solar panels and collectors requires large area

They can be used to generate small amount of electric power.

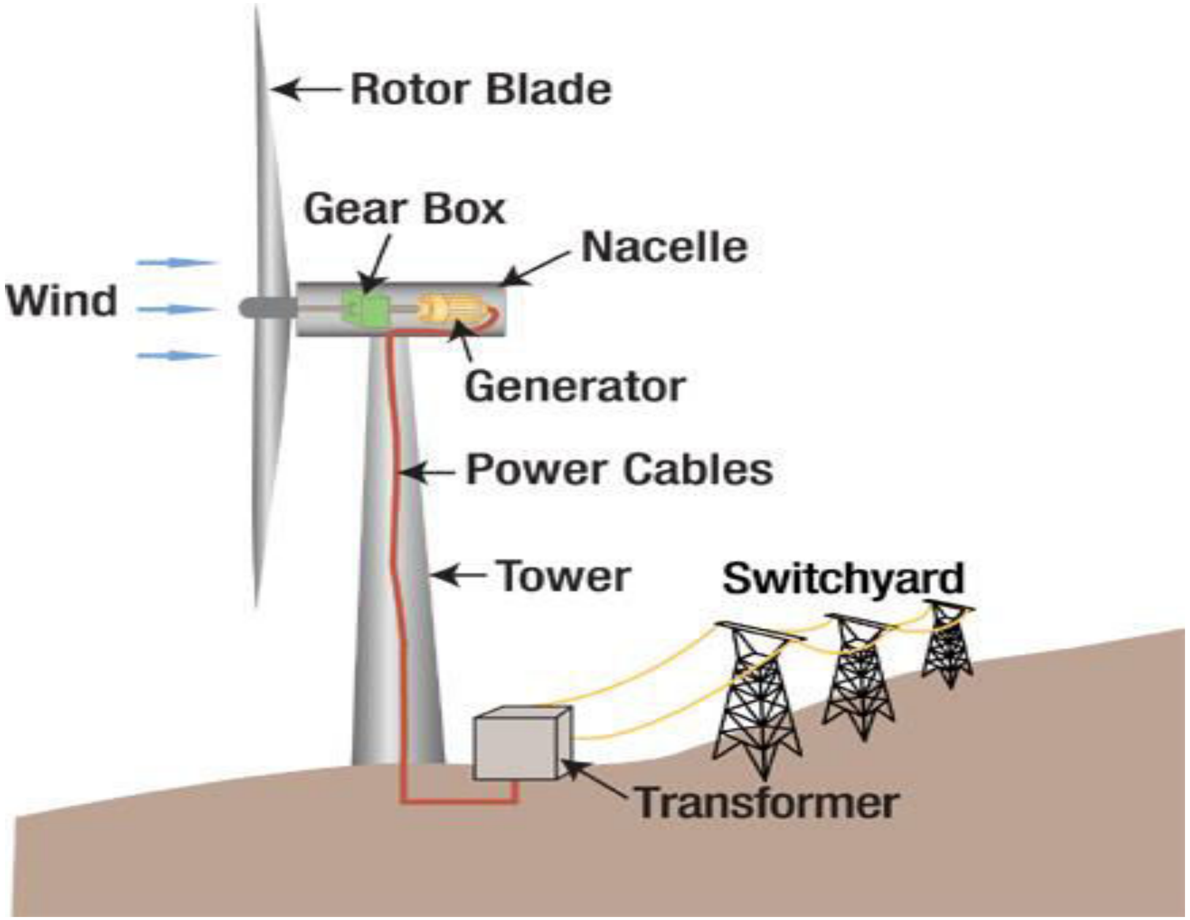
Wind Power plants

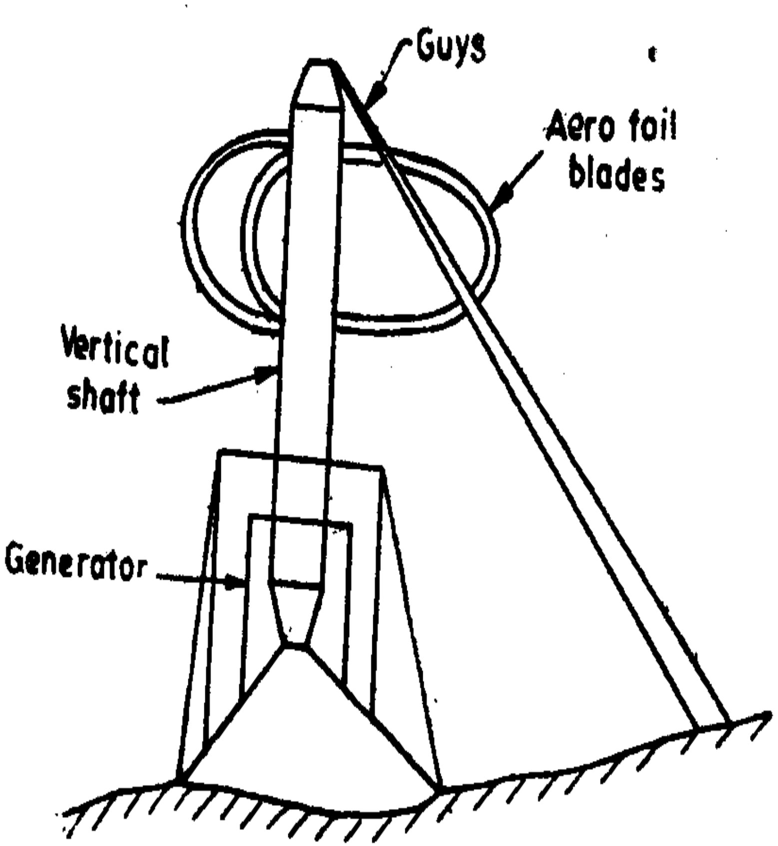
- System components

a. Tower
b. Rotor
c. Nacelle(Wind mill head)
d. Gear box
e. Generators
f. Yaw mechanism, such as the tail vane

- Wind turbines(wind mills) are mounted on towers to capture the most energy
- Rotor consists of 2 or 3 blades attached to the hub. The blade are of aerofoil cross section
- Kinetic energy of wind causes rotor blade to rotate
- Rotor turns a low-speed shaft at 30 to 60 rpm
- A step up gear box connect the low-speed shaft to the high-speed shaft and increase the turbine speed to from 30 to 60 rpm to 1200 to 1800 rpm
- The high speed shaft runs a generator coupled to it and produce electricity
- Casing that protect generator and gear assembly is called nacelle(wind mill head)
- Yaw mechanism keeps the turbine facing into the wind as the wind direction changes.

Horizontal axis wind power plant





Advantages

- Free from pollution. Does not create green house gases
- Clean, renewable source of energy.
- No fuel cost, no transportation
- Construction of plants require less time and simpler

Disadvantages

- Availability of wind is variable
- Noise pollution
- Threat to birds
- Require large open area
- High initial cost
- Requires back up storage when there is no wind

Tidal power plant

- Tide is periodic rise and fall of water level of the sea
- Tides are produced by the gravitational attraction of the moon(70 %) and the Sun(30%).
- When the water is above the mean sea level, it is called high tide. When the water level is below the mean level it is called low tide
- This difference in head can be utilised in running a hydraulic turbine coupled with generator producing electricity

Factors to be considered in the selection of tidal power plant

The site selected

a. Should have adequate tidal range throughout the year
b. Should be free from the wave attack of sea
c. Should not have appreciable change in tidal pattern
d. Should not have excessive sediment deposit

Components of a tidal power plant

Dam or barrage: It forms a barrier between the sea and the basin

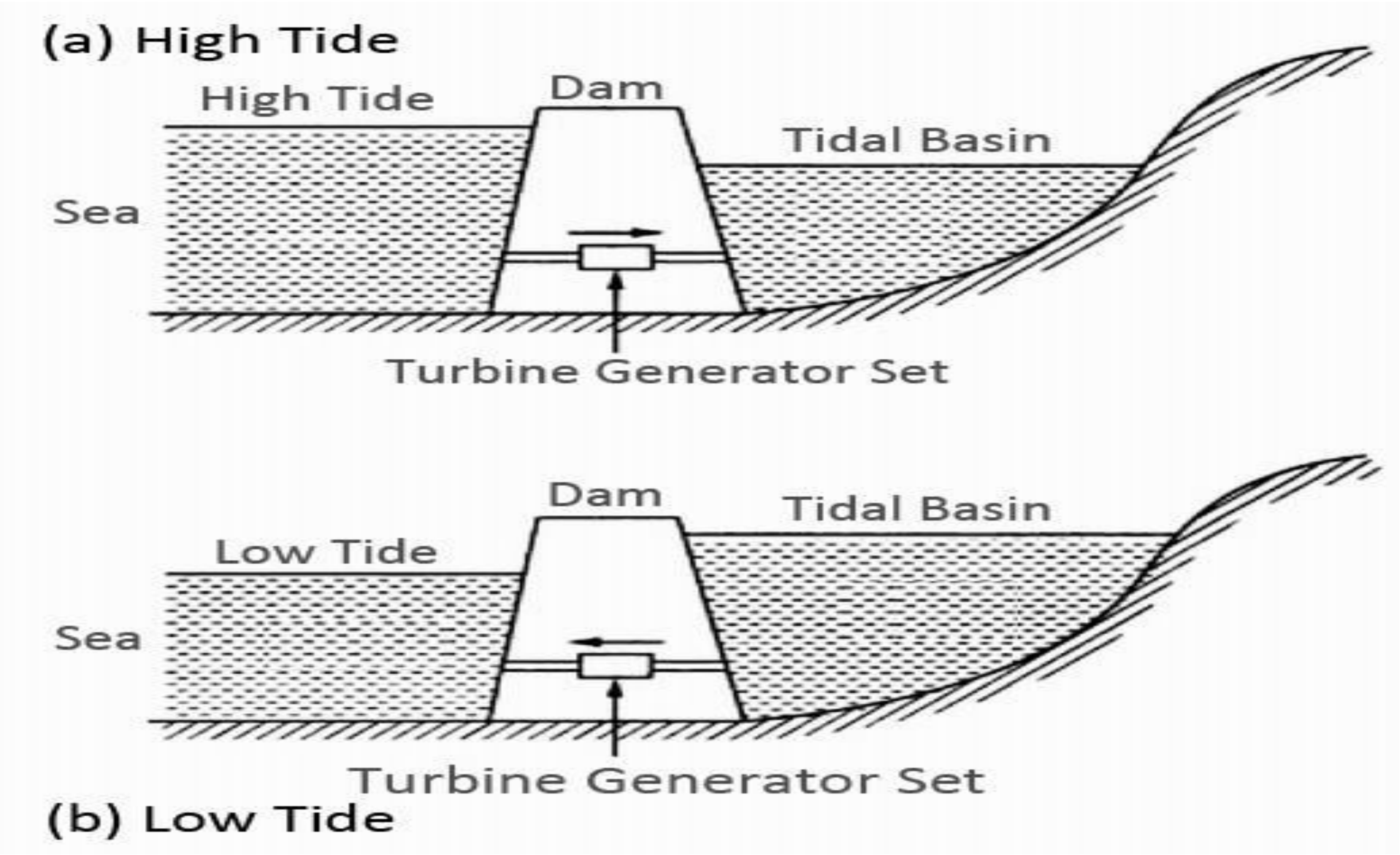
Sluice ways: It is a gate controlled valve used either to fill the basin during the high tide or empty the basin during the low tide

Power house: It includes generator, turbines and control devices

Working of tidal power plant

- During high tide, water flows from sea to basin through the sluice way and operate the turbine.
- Turbine is directly coupled to a generator and produce electricity.
- During low tide, water flows back from basin to sea through the sluice valve and operate the turbine
- Electricity is produced while filling and emptying the basin
- A reversible hydraulic turbine is used for this purpose

Power generation during low & high tide



Classification of tidal power plant

- Tidal power plants are classified on the basis of number of basin used for the power generation.
- They are further subdivided as one way or two way system as per the cycle of operation for power generation.
- Various types of tidal power plants are as follows:

(i) Single basin system

(a) One way system

(b) Two way system

(c) Two way with pump storage

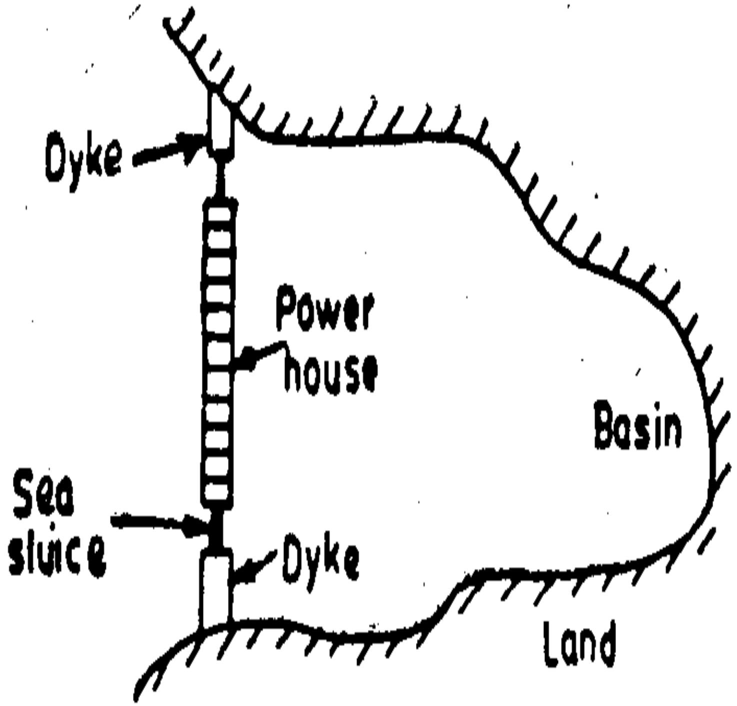
(ii) **Double basin system**

(a) Simple double basin system

(b) Double basin with pumping

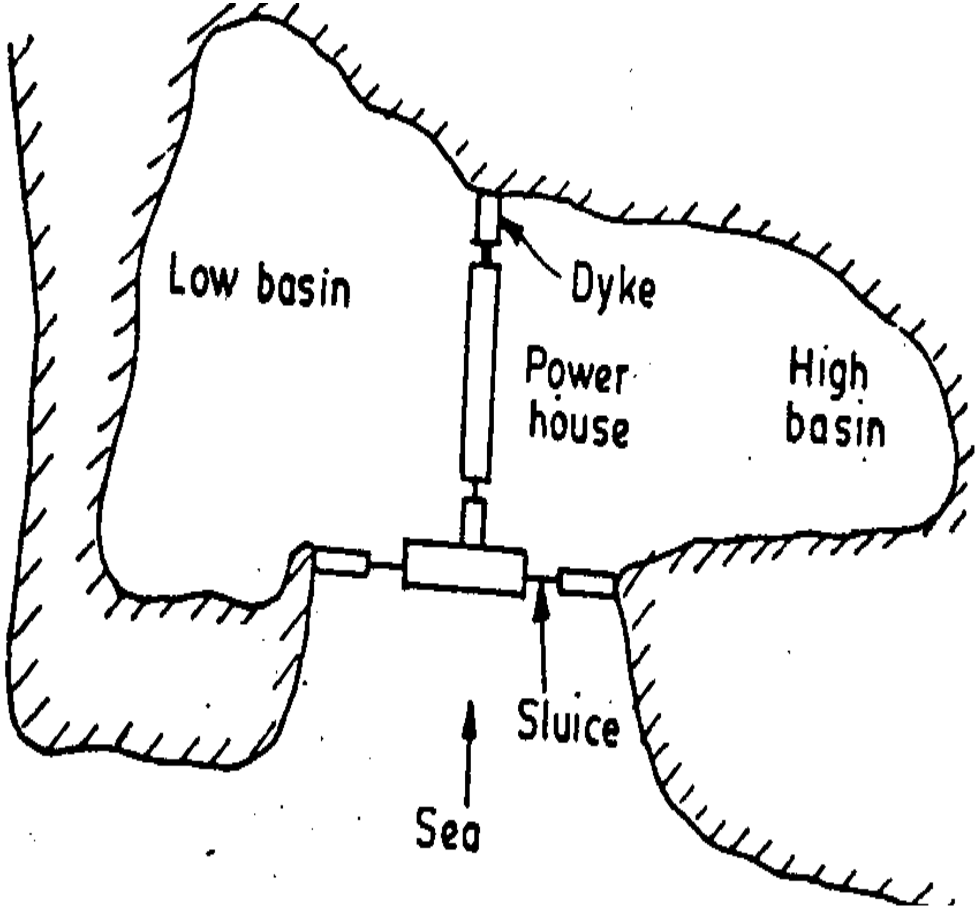
Single basin one way tidal power plant

- Basin is allowed to fill during flood tide(high tide)
- During ebb tide(low tide), water flow from basin to sea through the turbine and generates power.
- The power is available for a short duration during ebb tide.



Double basin one way tidal power plant

- The turbine is set up between the basins
- One basin is intermittently filled by flood tide and other is intermittently drained by ebb tide



TIDAL POWER PLANT

Advantages

- Free from pollution. Does not create green house gases.
- Eco friendly
- Inexhaustible source of energy
- No fuel cost, no transportation
- It is superior to hydro-power plant as it is totally independent of rain
- It improves the possibility of fish farming in the tidal basins and it can provide recreation to visitors
- Do not demand large area of land because they are on the sea shore.
- Low operation and maintenance cost

Disadvantages

- Cost of construction is high.
- There are very few ideal locations for construction of plant
- Influences aquatic life adversely.
- The actual generation is for a short period of time.
- Transmission is difficult and expensive
- The variability in output caused by the variations in the tidal range