Unit- I

Classification of Engineering Materials

1. Metals and alloys;
2. Ceramics
3. glasses
4. Polymers(plastics);
5. Semiconductors
6. Composite materials

1- Metals and Alloys:

Metals include aluminum, magnesium, zinc, cast iron. An alloy is a metal that contains additions of one or moremetalslikesteel,titanium alloy…etc. In general,metalshave goodelectrical andthermalconductivity. Metals and alloys have relatively high strength, high stiffness, ductility or formability, and shock resistance. Theyareparticularlyusefulforstructuralorload-bearingapplications.Althoughpuremetalsareoccasionally used, alloys provide improvement in a particular desirable property or permit better combinations of properties.

2- Ceramics:

Ceramics can be defined as inorganic crystalline materials. Sand and rocks are examples of naturally occurring ceramics. Advanced ceramics are materials made by refining naturally occurring ceramics and other special processes. Advanced ceramics are used in sensors and capacitors, wirelesscommunications, inductors, and electrical insulation. Ceramics are also used in such consumer products aspaints, and tires, and for industrial applications such as the tiles for the space shuttle.

Traditional ceramics are used to make bricks, tableware, toilets, bathroom sinks. In general, due to the presence of porosity (small holes), ceramics do not conduct heat well; they must be heated to very high temperatures before melting. Ceramics are strong and hard, but also very brittle. We normally prepare fine powders of ceramics and convert these into different shapes.

3- Glasses:

Glass is an amorphous material, (often, but not always), derived from a molten liquid. The term "amorphous" refers to materials that do not have a regular, periodic arrangement of atoms. The fiber optics industry is founded on optical fibers based on high purity silica glass. Glasses are also used in houses, cars, computer and television screens, and hundreds of other applications. Glasses can be thermally treated (tempered) to make them stronger.

4- Polymers:

Polymers are typically organic materials. They are produced using a process known as polymerization. Polymersincluderubber(elastomers)andmanytypesofadhesives.Polymerstypicallyaregoodelectricalandthermal insulators. Although they have lower strength, polymers have a very good strength-to-weight ratio. They are typically not suitable for use at high temperatures. Manypolymers have very good resistance tocorrosive chemicals. Polymers havethousands of applications ranging from bulletproofvests, compact disks (CDs), ropes, and liquid crystal displays (LCDs) to clothes and coffee cups. Thermoplastic polymers, in which the long molecular chains are not rigidly connected, have good ductility and formability.

5- Semiconductors:

Silicon, germanium, are semiconductors such as those used in computers and electronics are part of abroader class of materials known as electronic materials. The electrical conductivityof semiconducting materials is between that of ceramic insulators andmetallic conductors. In some semiconductors, the level of conductivity can be controlled to enable electronic devices such as transistors, diodes,etc.,that are used to build integrated circuits.

6- Composite Materials:

The main idea in developing composites is to blend the properties of different materials. These are formed from two or more materials, producing properties not found in any single material. Concrete, plywood, and fiberglass are examples of composite materials. Advanced aircraft and aerospace vehicles rely heavily on composites such as carbon fiber-reinforced polymers. Sports equipment such as bicycles, golf clubs, tennis rackets, and the like also make use of different kinds of composite materials that are light and stiff.

Characteristics of ferrous materials:

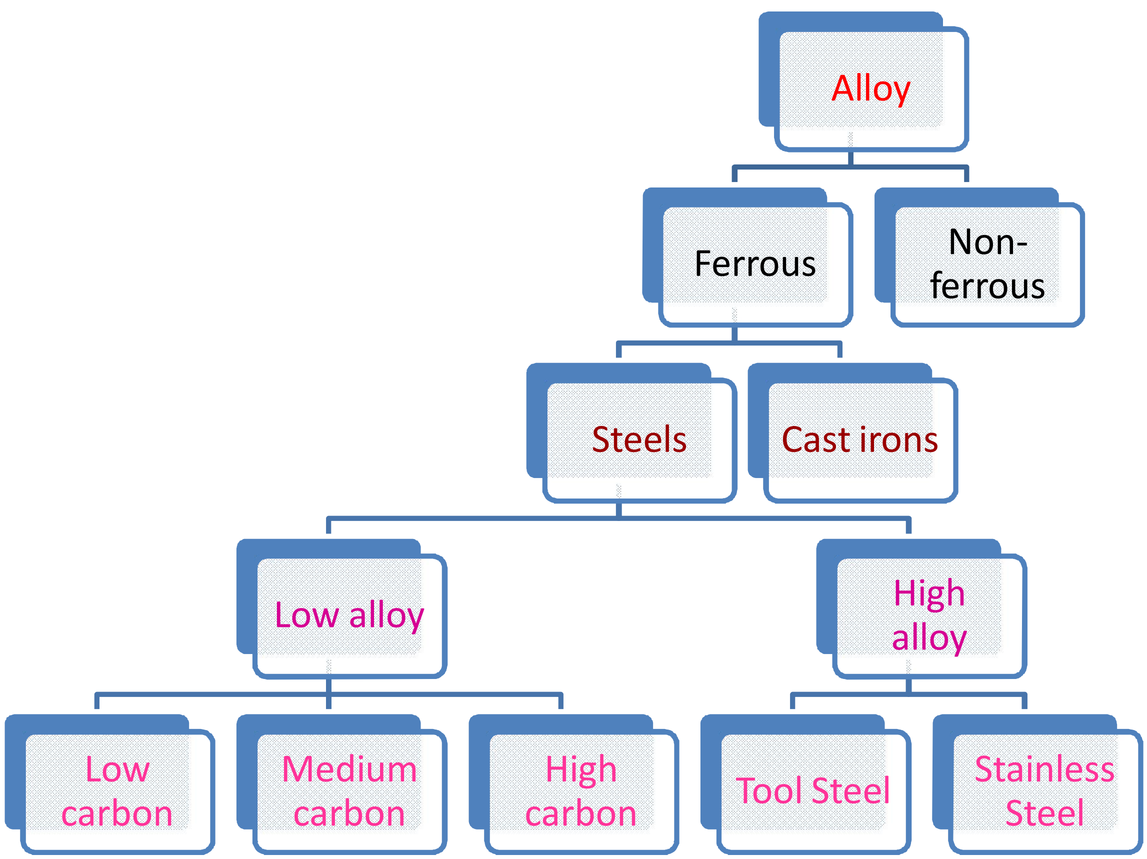
- Ferrous materials are metals or metal alloys that contain the iron as a base material.
- Steel is a ferrous alloy, and there are a number of other alloys that contain iron.
- Ferrous metals are good conductors of heat and electricity.
- Metal alloys have high resistance to shear, torque and deformation.
- The thermal conductivity of metal is useful for containers to heat materials over a flame.

The principal disadvantages of many ferrous alloys is their susceptibility to corrosion.

Application:

- Due to the strength and resilience of metals they are frequently used in high-rise building and bridge construction, most vehicles, many appliances, tools, pipes, non-illuminated signs and railroad tracks.
- Corrosion resistance property makes them useful in food processing plants, e.g., steel.
- Cast iron is strong but brittle, and its compressive strength is very high. So used in castings, manhole covers, engine body, machine base etc.
- Mild steel is soft, ductile and has high tensile strength. It is used in general metal products like structural, workshop, household furniture etc.
- Carbon steels are used for cutting tools due to their hardness, strength and corrosion resistance properties.

Classification:



Steel-It is an alloy of iron and carbon in which carbon content is upto 2%.

It may contain other alloying elements.

Cast iron-In cast iron carbon content is 2% to 6.67%

Lower melting point (about 300 °C lower than pure iron) due to presence of eutectic point at 1153 °C and more carbon content.

Types of cast iron: grey, white, nodular, malleable and compacted graphite.

Low carbon steel-Carbon content in the range of 0 – 0.3%.

Most abundant grade of steel is low carbon steel (greatest quantity produced; and least expensive).

Not responsive to heat treatment; cold working needed to improve the strength.

It has good weldability and machinability

Medium carbon steel-Carbon content in the range of 0.3 – 0.8%.

It can be heat treated - austenitizing, quenching and then tempering.

Most often used in tempered condition – tempered martensite

Medium carbon steels have low hardenability

Addition of Cr, Ni, Mo improves the heat treating capacity

Heat treated alloys are stronger but have lower ductility

Typical applications – Railway wheels and tracks, gears,crankshafts.

High carbon steel-High carbon steels – Carbon content 0.8 – 2%

High C content provides high hardness and strength.

Hardest and least ductile.

Used in hardened and tempered condition

Strong carbide formers like Cr, V, W are added as alloying elements to from carbides of these metals.

Used as tool and die steels owing to the high hardness and wear resistance property

Tool steel- Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures. Tool steel is generally used in a heat-treated state. Many high carbon tool steels are also more resistant to corrosion due to their higher ratios of elements such as vanadium. With a carbon content between 0.7% and 1.5%, tool steels are manufactured under carefully controlled conditions to produce the required quality.

Stainless steel-Stainless steel does not readily corrode, rust or stain with water as ordinary steel does, but despite the name it is not fully stain-proof, most notably under low-oxygen, high-salinity, or poor-circulation environments. There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and corrosion resistance are required.

Stainless steel differs from carbon steel by the amount of chromium present.

Plain Carbon Steel

Plain Carbon Steel is an alloy of iron and carbon with carbon content up to 1.5% although other elements such as Silicon, Manganese may be present. The properties of carbon steel are mainly due to its carbon content.

Carbon Steel is classified into

- i) Low carbon steel or Mild steel
- ii) Medium carbon steel
- iii) High carbon steel

Low carbon steel or Mild steel:

Low carbon steel or mild steel is further classified in to three types basing on their composition i-e percentage of carbon.

- a) Dead mild steel or mild steel containing 0.05 to 0.15% of carbon.
- b) Mild steel containing 0.15 to 0.2% of carbon.
- c) Mild steel containing 0.2 to 0.3% of carbon.

Application of Mild Steel:

- i) Dead mild steel is used for making steel wire, sheet, rivets, screws, pipe, nail, chain, etc.
- ii) Mild steel containing 0.15 to 0.2% carbon is used for making camshafts, sheets, strips for blades, welded tubing, forgings, drag lines, etc.
- iii) Mild steel containing 0.2 to 0.3% carbon is used for making valves, gears, crank shafts, connecting rods, railways axles, fish plates and small forgings, etc.

Medium Carbon Steel

Steel containing 0.3 to 0.7% carbon is known as Medium carbon steel.

Medium carbon steel are of three categories.

i) Steel containing 0.35 to 0.45% carbon is used for connecting rod, wires & rod, spring clips, gear shaft, key stock, shafts & brakes lever, axle, small & medium forgings, etc.
ii) Steel containing 0.45 to 0.55% carbon is used for railways coach axles, axles & crank pins on heavy machines, splines shafts, crank shafts, etc.
iii) Steel containing 0.6 to 0.7% carbon is used for drop forging die & die blocks, clutch discs, plate punches, set screws, valve springs, cushion ring, thrust washers, etc.

High carbon steel

Steel containing 0.7 to 0.1.5% carbon is known as high carbon steel.

Uses

i) Steel containing 0.7 to 0.8% carbon is used for making cold chisels, wrenches, jaws for vice, pneumatic drill bits, wheels for railway service, wire for structural work, shear blades, automatic clutch disc, hacksaws, etc.
ii) Steel containing 0.8 to 0.9% carbon is used for making rock drills, railway rail, circular saws, machine chisels, punches & dies, clutch discs, leaf springs, music wires, etc.
iii) Steel containing 0.9 to 1.0% carbon is used for making punches & dies, leaf & coil springs, keys, speed discs, pins, shear blades, etc.
iv) Steel containing 1.0 to 1.1% carbon is used for making railway springs, machine tools, mandrels, taps, etc.
v) Steel containing 1.1 to 1.2% carbon is used for making taps, thread metal dies, twist drills, knives, etc.
vi) Steel containing 1.2 to 1.3% carbon is used for making files, metal cutting tools, reamers, etc.
vii) Steel containing 1.3 to 1.5% carbon is used for making wire drawing dies, metal cutting saws, paper knives, tools for turning chilled iron, etc.

Alloy Steel:

Steel is considered to be alloy steel when the maximum of the range given for the content of alloying element exceeds one or more of the following limits.

Mn-1.65%, Si-0.6%, Cu-0.6%

or in which a definite maximum quantity of any of the following elements is specified.

Al, B, Cr up to 3.99%, Cu, Mo, Ni,Ti, W, V or any other alloying element added to obtain a desired alloying effect.

Low and medium alloy steel: In low and medium alloy steel alloying element is not exceeding 10%.

i) 1st symbol: 100 times the average percentage of carbon.

ii) 2nd, 4th, 6th ,etc symbol: Elements

iii) 3rd, 5th, 7th, etc. symbol: percentage of elements multiplied by factors as follows.

Element	Multiplying factor
Cr, Co, Ni, Mn, Si & W	4
Al, Be, V, Pb, Cu, Nb, Ti, Ta, Zr & Mo	10
P, S, N	100

iv) Last element: It indicates special characteristics.

High alloy steel: In high alloy steel, total alloying element is more than 10%.

For example: X10 Cr 18 Ni 9 S3

X- High alloy steel

10 %- 0.1 %C

Cr18 – 18 % Cr

Ni 9 – 9 % Ni

S 3 – Pickled condition

Tool Steel:

Tool steel may be defined as special steel which are used to form, cut or otherwise change the shape of a material in to finished 0r semi-finished product.

Properties of Tool steel:

i) Slight change of form during hardening.
ii) Little risk of cracking during hardening.
iii) Good toughness
iv) Good wear resistance
v) Very good machinability
vi) A definite cooling rate during hardening
vii) A definite hardening temperature
viii) Resistance to de-carburization
ix) Resistance to softening on heating

Classification of Tool steel:

The Joint Industry Conference, U.S.A. has classified tool steel as follows:

Symbol	Meaning
T	W-High speed steel
M	Mo-High speed steel
D	High C, high Cr steel
A	Air hardening steel
O	Oil hardening steel
W	Water hardening steel
H	Hot work steel
S	Shock resistance steel

Composition of Tool Steel:

1) W-High speed steel

T_1: C 0.7 Cr 4 V 1 W 18
T_4: C 0.75 Cr 4 V 1 W 18 Co 5
T_6: C 0.8 Cr 4.5 V 1.5 W 20 Co 12

2) Mo-High speed steel

M_1: C 0.8 Cr 4 V 1 W 1.5 Mo 8
M_6: C 0.8 Cr 4 V 1.5 W 4 Mo 5 Co 12

3) High C, high Cr steel

D_2: C 1.5 Cr 12 Mo 1
D_5: C 1.5 Cr 12 Mo 1 Co 3
D_7: C 2.35 Cr 12 V 4 Mo 1

4) Air hardening steel

A_2: C 1 Cr 5 Mo 1
A_7: C 2.25 Cr 5.25 V 4.75 W 11 Mo 1
A_9: C 0.5 Cr 5 Ni 1.5 V 1 Mo 1.4

5) Oil hardening steel

O_1: C 0.9 Mn 1 Cr 0.5 W 0.5
O_2: C 1.45 Si 1 Mo 0.25

6) Water hardening steel

W_2:	C 0.6/1.4	V 0.25
W_5:	C 1.1	Cr 0.5

7) Hot work steel

H_{10}:	C 0.4	Cr 3.25	V 0.4	Mo 2.5	
H_{12}:	C 0.35	Cr 5	V 0.4	W 1.5	Mo 1.5

8) Shock resistance steel

S_1:	C 0.5	Cr 1.5	W 2.5	
S_2:	C 0.5	Si 1	Mo 0.4	
S_5:	C 0.55	Mn 0.8	Si 2	Mo 0.4
S_7:	C 0.5	Cr 3.25	Mo 1.4	

Stainless Steel:

When 11.5% or more chromium is added to iron, a fine film of chromium oxide forms spontaneously on the surfaces. The film acts as a barrier to retard further oxidation, rust or corrosion. As this steel cannot be stained easily, it is called stainless steel. The stainless steel basing on their micro-structure can be grouped in to three metallurgical classes such as Austenitic stainless steel, Ferritic stainless steel & Martensite stainless steel.

Austenitic Stainless Steel:

Properties:

1) They possess austenitic structure at room temperature.
2) They possess the highest corrosion resistance of all the stainless steels.
3) They possess greatest strength and scale resistance at high temperature.
4) They retain ductility at temperature approaching absolute zero.
5) They are non-magnetic.

Composition:

C 0.03 to 0.25% Mn 2 to 10% Si 1 to 2%

Cr 16 to 26% Ni 3.5 to 22%

P & S Normal Mo & Ti in some cases

Uses:

1) Aircraft industry (Engine parts)
2) Chemical processing (heat exchangers)
3) Food processing (Kettles, tanks)
4) Household items (cooking utensils)
5) Dairy industries (milk cans)
6) Transportation industry (Trailers & railways cars)

Ferritic stainless steel:

Properties:

1) They posses a microstructure which is primarily ferritic.
2) They are magnetic & have good ductility
3) They do not work harden to any appreciable degree.
4) They are more corrosion resistant than martensitic steel.
5) They develop their maximum softness, ductility & corrosion resistance in the annealed condition.

Composition:

C 0.08 to 0.20% Si 1% Mn 1 to 1.5% Cr 11to 27%

Uses:

1) Lining for petrolium industry.
2) Heating elements for furnaces.
3) Interior decorative work.
4) Screws & fittings.
5) Oil burner parts.

Martensitic stainless steel:

Properties:

1) They posses martensitic microstructure.
2) They are magnetic in all condition & possess the best thermal conductivity of the stainless types.
3) Hardness, ductility & ability to hold an edge are characteristics of martensitic steels.
4) They can be cold worked without difficulty, especially with low carbon content, can be machined satisfactorily.
5) They have good toughness.
6) They have good corrosion resistance to weather and to some chemicals.
7) They are easily hot worked.

Composition:

C 0.15 to 1.2% Si 1% Mn 1% Cr 11.5 to 18%

Uses:

1) Pumps & valve parts
2) Rules & tapes
3) Turbine buckets
4) Surgical instruments, etc.

Effect of Alloying Elements:

Chromium: It joins with carbon to form chromium carbide, thus adds to depth hardenability with improved resistance to abrasion & wear.

Manganese:

1) It contributes markedly to strength and hardness.
2) It counteracts brittleness from sulphur.
3) Lowers both ductility & weldability if it is present in high percentage with high carbon content in steel.

Nickel: It

1) increases toughness & resistance to impact.
2) lessens distortion in quenching.
3) Lowers the critical temperatures of steel & widens the range of successful heat treatment.
4) strengthens steels.
5) Renders high-chromium iron alloys austenitic.
6) does not unite with carbon.

Vanadium: It

1) promotes fine grains in steel.
2) increases hardenability.
3) imparts strength & toughness to heat-treated steel
4) causes marked secondary hardening.

Molybdenum: It

1) promotes hardenability of steel.
2) makes steel fine grained.
3) makes steel unusually tough at various hardness levels.
4) counteracts tendency towards temper brittleness.
5) raises tensile & creep strength at high temperatures.
6) enhances corrosion resistance in stainless steels.
7) forms abrasion resisting particles.

Tungsten: It

1) increases hardness.
2) promotes fine grains.
3) resists heat.
4) promotes strength at elevated temperature.

Mechanical Properties of Materials:-

(1) Ductility :- It is the property of material by virtue of which it can be drawn into thin wires under the action of tensile force.

A Ductile material must have a high degree of plasticity and strength so that large deformation can takes place without failure or rupture of material. In ductile extension a material exhibits a certain amount of elasticity along with a high degree of plasticity.

(2) Brittleness:- It is opposite to ductility i.e. when a material can not be drawn out by tension to smaller sections. A brittle material fails instantly under the load without exhibiting and significant deformation.
Example : cast Iron, concrete, glass, stone etc.

(3) Malleability:- The property of material allows it to expand in all directions without rupture. A malleable material has to be highly plastic, though it may not possess high strength. This property is of great use in processes such as forging, hot rolling etc.

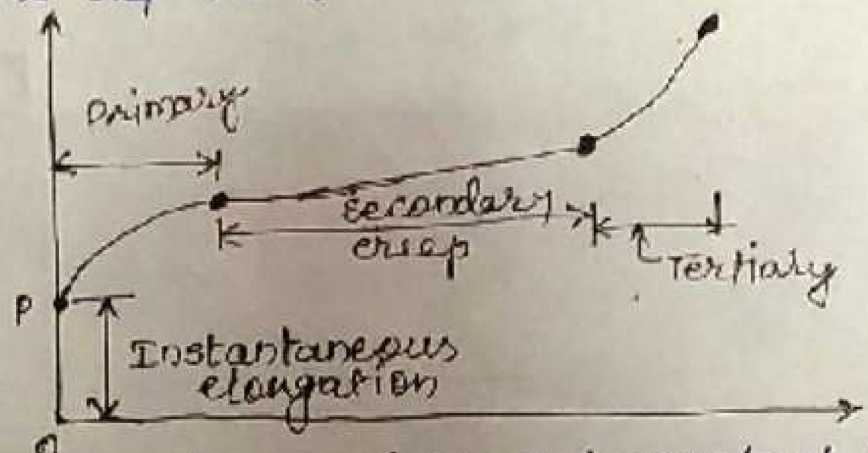
(4) Hardness :- The resistance of material to indentation including scratching or surface abrasion is termed as hardness.

(5) Strength:- It may be defined as the capability of material to withstand load.

Stiffness:- It is the ability of material to resist deformation under external load. Modulus of rigidity is measure of stiffness.
Mathematically, it is the load required to produce unit deformation.

Resilience:- The ability of material to absorb energy when deformed elastically, and to release it when unloaded, is called resilience.
This is usually measured by the modulus of resilience, which is strain energy per unit volume.

Creep:- When a component is subjected to a constant static load at elevated temperature for a period of time it undergoes progressive plastic deformation called creep.
This time dependent strain is called creep.



This property is considered important in the design of gas turbines, steam turbines, rockets, missiles.
Metal generally show creep at elevated temperature, where as plastics, rubber and soft metals are very temperature sensitive to creep.

It is obtained by dividing the load by area.

(6) <u>Toughness</u>:- It is the capacity of a structure to withstand an impact load i.e. the capacity to absorb energy without fracture. It is the measure of energy required to break a material.

(7) <u>Fatigue</u>:- Failure of materials under repeated/fluctuating/cyclic loading is known as fatigue failure.
Structures, machinery, aircrafts, ships are subjected to fluctuating loads.

(8) <u>Strength</u>:- It may be defined as the capability of a material to withstand load. It is obtained by dividing the load by area.
The ultimate strength of a material is the load required to cause fracture divided by the area of specimen.

(9) <u>Elasticity</u>:- It is that property of a material due to which it comes back to its original shape after deformation when the external load is ~~applied~~ removed. Elasticity is the ability of a material to resist permanent deformation under load.

(10) <u>Plasticity</u>:- It is the ability of the material to retain the deformation permanently. Due to this property various metals can be converted into desired shapes.

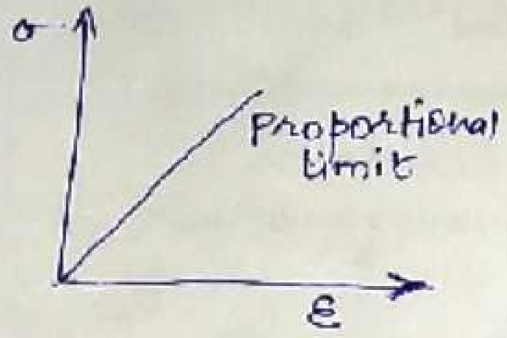
Hooke's law :-

→ When a material is loaded with in its proportional limit, the stress produced is directly proportional to the strain.

stress ∝ strain

$\sigma \propto \epsilon$

σ = Constant × ϵ or



$$\boxed{\frac{\sigma}{\epsilon} = E}$$

Modulus of Elasticity :-

The ratio of stress to the corresponding strain is a constant. This ratio is known as modulus of elasticity or Young's modulus.

It is denoted by E.

SI unit is N/mm^2.

* Tensile Test :-

→ In this test ends of test piece are fixed into grips (Jaws), connected to a straining device and to a load measuring device

→ If the load is small enough, the deformation of any solid body is entirely elastic. An elastically deformed body returns to its original shape as soon as load is removed

→ However, if the load is too large, the material can be deformed permanently.

→ A record of load acting on the specimen with extension of the specimen is obtained.

→ Tensile tests are done on fixed length called guage length.

→ elongation may be measured with the divider or ruler.

→ Test continues till the fracture occurs

→ following data is recorded

(a) Proportionality limit

(b) Elastic limit $= \frac{\text{Load at elastic limit}}{\text{original C.S. area}}$

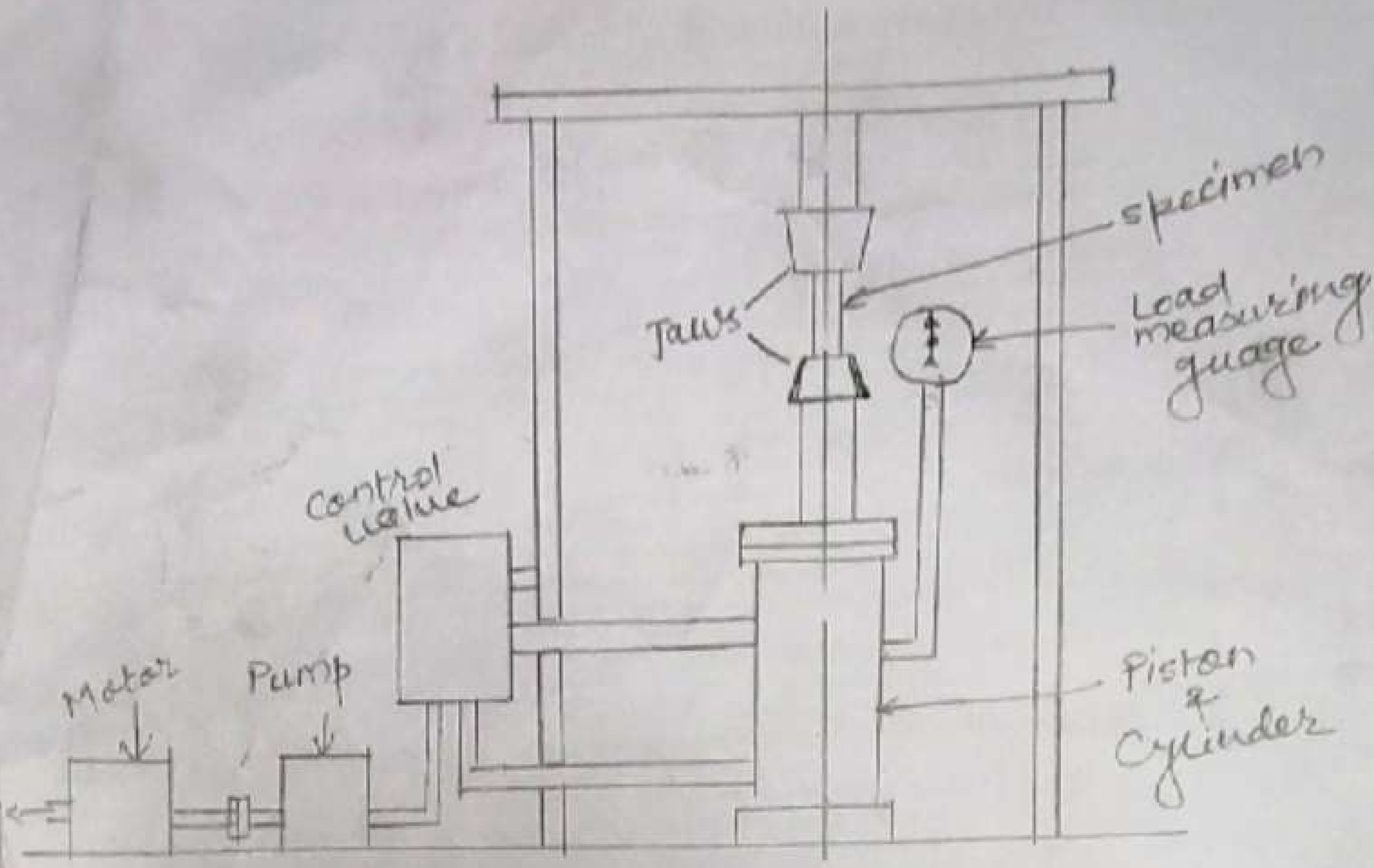
(c) yield strength

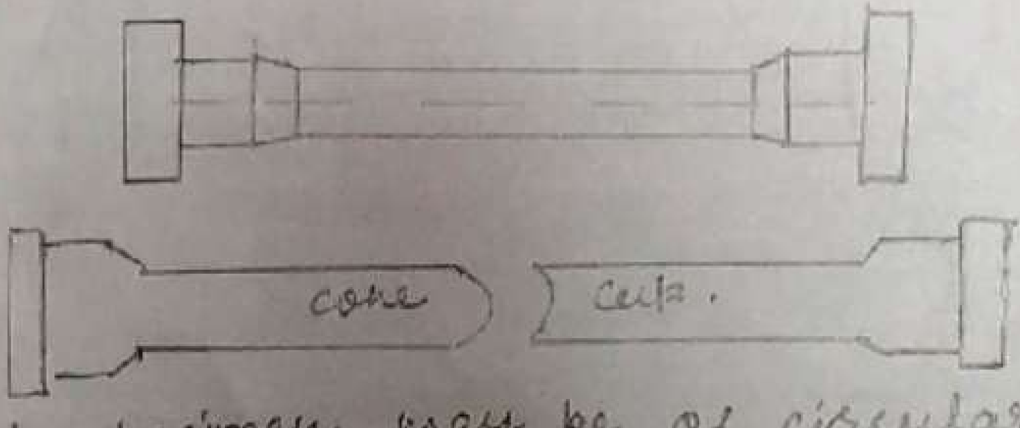
(d) Ultimate strength $= \frac{\text{maximum Tensile Load}}{\text{original C.S area}}$

(e) young's modulus =

(f) % elongation

(g) % Reduction in C.S. area.



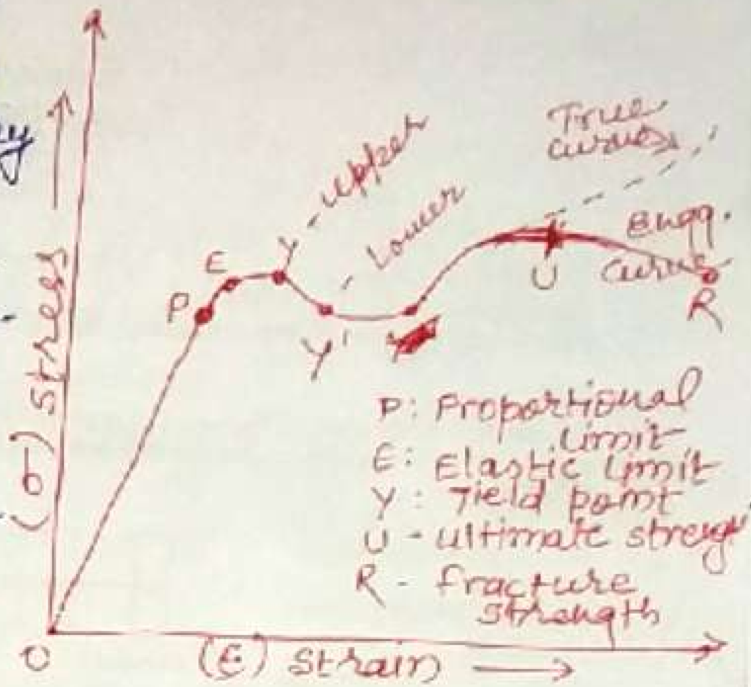


4 test specimen may be of circular, square or rectangular C.S.

* Stress - strain Diagram :-

→ The Behaviour of material subjected to an increased tensile load is studied by testing a specimen in a tensile testing machine and plotting the stress-strain diagram.

→ There are different diagrams for different materials. (Ductile - Brittle)



→ When the load is increased gradually, the strain is proportional to load or stress up to a certain value. Line OP indicates this range and is known as the line of proportionality. Hook's law is applicable in this limit.

→ If the load increased beyond proportional limit, the elongation is more rapid. On removal of the load strain vanishes. The point E depicts the elastic limit. Hook's law can not be applied in this range as the stress is not proportional to strain.

→ When the load is further increased, plastic deformation occurs i.e. on removal of load, the strain is not fully recoverable. At point Y, metal shows an appreciable strain even without further increasing the load.
Curve drops slightly to Y' ~~and the yielding goes up to point y''~~, the point Y & Y' are known as the upper and lower yield points respectively.

→ After the yield point "y", further straining is possible only by increasing the Load. The curve rises up to the point U. At point U the stress is known as ultimate stress. (Plastic state not recoverable)

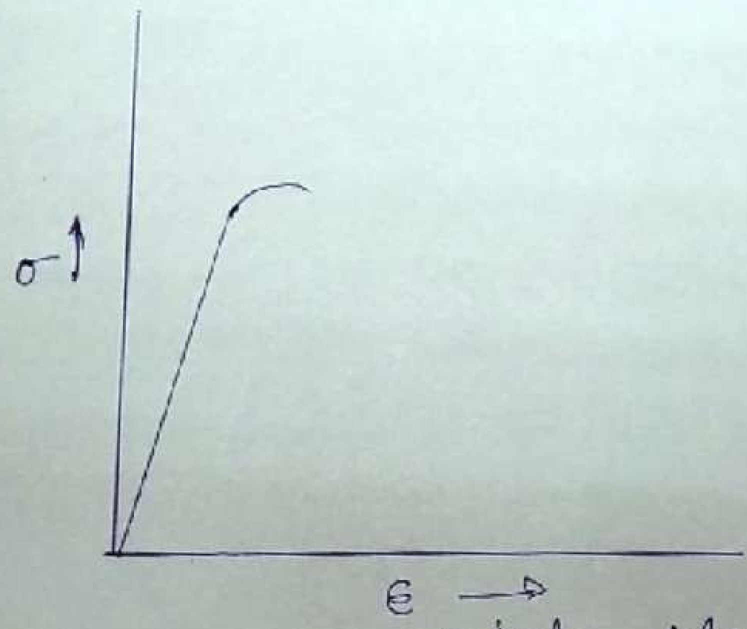
→ If the bar is stressed further, it begins to form a neck, or a local reduction in C.S. occurs. Further lower loads are sufficient to keep the specimen elongating further.

→ Ultimately, the specimen fractures at point R.

→ $$\frac{\text{Load}}{\text{original Area}} = \text{Nominal Stress}$$

This is lesser at rupture load than at the maximum load.

Stress-strain curve of Brittle Material :-



Brittle material shows negligible plastic deformation

Hardness is the property of the material by which it offers resistance to scratch, indentation, abrasion cutting etc.

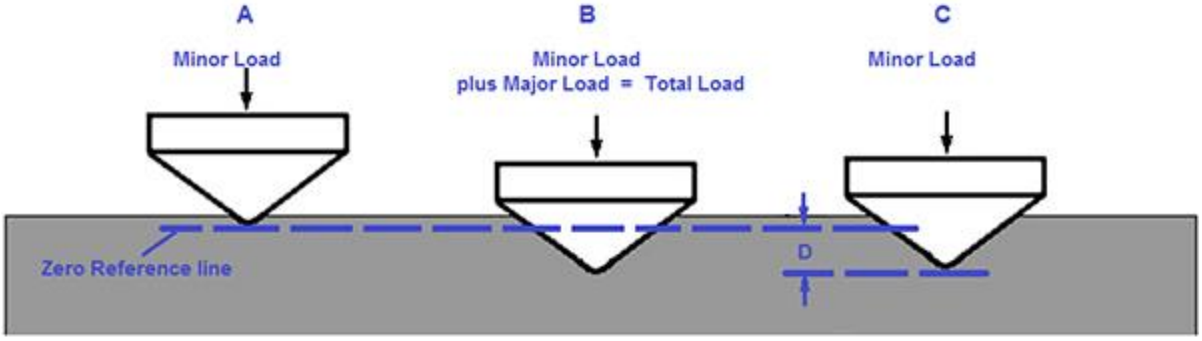
There are three general types of hardness measurements depending upon the manner in which the test is conducted. These are
1. Scratch hardness
2. Indentation hardness
3. Rebound, or dynamic, hardness.

Only indentation hardness is of major engineering interest for metals.

Hardness is measured according to the Mohs scale.
• This consists of 10 standard minerals arranged in the order of their ability to be scratched. The softest mineral in this scale is talc (scratch hardness 1), while diamond has a hardness of 10. A fingernail has a value of about 2; annealed copper has a value of 3, and martensite a hardness of 7.
• Most hard metals fall in the Mohs hardness range of 4 to 8.

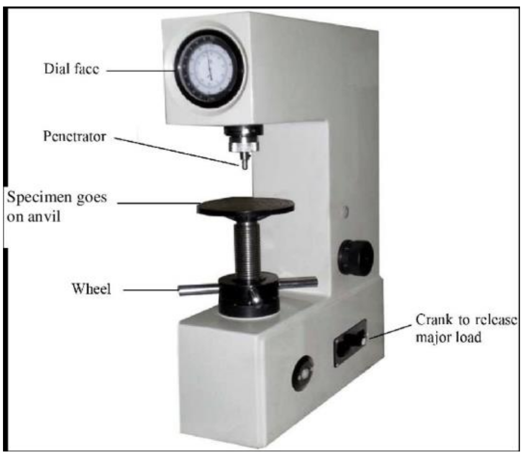
ROCKWELL HARDNESS TEST

This test is an indentation test used for smaller specimens and harder materials. In this test indenter is forced into the surface of a test piece in two operations. The indenter is forced into the test material under a preliminary minor load usually 10 kgf.
Measurement of indentation is made after removing the additional load. Indenter used is the cone having an angle of 120 degrees made of black diamond. The principle of Rockwell hardness test has to do with the application of a standard load (Based on the type of material) through a standard indenter (cone or ball indenter) for a standard duration of time. The hardness number is directly obtained in the experiment.
The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond or ball indenter. This preload breaks through the surface to reduce the effects of surface finish. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.
After the preload, an additional load, call the major load, is added to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released, returning to the preliminary load. After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured. The Rockwell hardness value is derived from the difference in the baseline and final depth measurements. This distance is converted to a hardness number. The preliminary test force is removed and the indenter is removed from the test specimen.

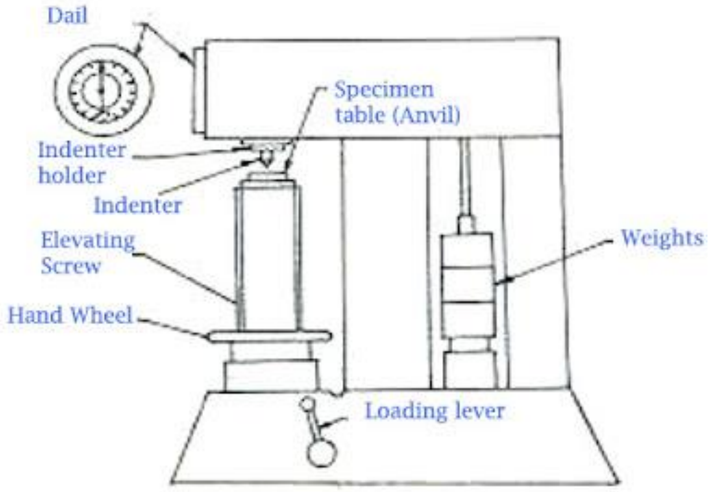


A variety of indenters may be used: conical diamond with a round tip for harder metals to ball indenters ranges with a diameter ranging from 1/16” to ½” for softer materials.
Regular Rockwell Hardness Test where the minor load is 10 kgf and major load is 60, 100, or 150 kgf.
A dial is attached to the testing machine which gives the arbitrary hardness number during the whole process. To cover a different hardness range with varying penetration, the dial has different scales like A, B, C, D etc. on the basis of indenter and load used. The most general dial has Scale C&A for Brale Indenter and load 150 &60 respectively; a B scale for steel ball (1/16 inches diameter) and 100 kg load.

Rockwell Scale Symbol	Type of Indenter/Diameter in case of Ball	Minor Load	Major Load	Typical use
HRA	Spheroconical diamond	98.07 N (10 kgf)	588.4 N (60 kgf)	Cemented carbides, thin steel and shallow case hardened steel.
HRB	Ball, 1.588 mm ($1/16$ inches)	98.07 N (10 kgf)	980.7 N (100 kgf)	Copper alloys, soft steels, aluminum alloys, malleable iron, etc.
HRC	Spheroconical diamond	98.07 N (10 kgf)	1471 N (150 kgf)	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel, and other materials harder than 100 on the Rockwell B scale.



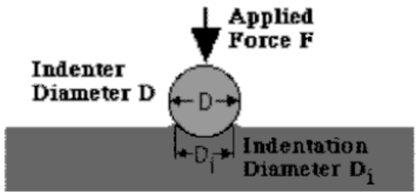
ROCKWELL HARDNESS TESTING MACHINE.



Schematic diagram of Rockwell hardness test equipment

BRINELL HARDNESS

- The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg.
- For soft metals the load is reduced to 500 kg to avoid too deep an impression, and for very hard metals a tungsten carbide ball is used to minimize distortion of the indenter.
- The load is applied for a standard time, usually 30 sec.
- The diameter of the indentation is measured with a low-power microscope after removal of the load.
- The average of two readings of the diameter of the impression at right angles should be made.
- The surface on which the indentation is made should be relatively smooth and free from dirt or scale.
- The Brinell hardness number (BHN) is expressed as the load P divided by the surface area



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_i^2})}$$

Where F= applied load, kg D = diameter of ball, mm Di = diameter of indentation, mm.

- Units of BHN are kilograms per square millimetre.

VICKERS HARDNESS TEST

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. This angle was chosen because it approximates the most desirable ratio of indentation diameter to ball diameter in the Brinell hardness test.

The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated.

The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

Vickers hardness number is defined as the load divided by the surface area of the indentation. The diamond-pyramid hardness number (DPH), or Vickers hardness number (VHN, or VPH) may be determined from the following equation,

$$DPH = 2P \sin\left(\frac{\theta}{2}\right) / L^2 = 1.854P/L^2$$

Where P = applied load, kg L = average length of diagonals, mm θ = angle between opposite faces of diamond = 136º

Vickers Hardness Testing Machine

IMPACT TEST

Toughness is a measure of the amount of energy a material can absorb before fracturing. It becomes of engineering importance when the ability of a material to withstand an impact load without fracturing is considered. In impact loading notches are made intentionally in its specimens to increase the stress concentration so as to increase tendency to fracture as most of the mechanical components have stress raisers. To with stand impact force, a notched material must be toughed.

This type of test will detect differences between materials which are not observable in a tension test.

The energy absorbed at fracture is generally related to the area under the stress-strain curve which is termed as toughness in some references.

Brittle materials have a small area under the stress-strain curve (due to its limited toughness) and as a result, little energy is absorbed during impact failure. As plastic deformation capability of the materials (ductility) increases, the area under the curve also increases and absorbed energy and respectively toughness increase.

Impact load is produced by a swinging of an impact weight W (hammer) from a height h.

Release of the weight from the height h swings the weight through the arc of a circle, which strikes the specimen to fracture at the notch.

Kinetic energy of the hammer at the time of impact is $mv^2/2$, which is equal to the relative potential energy of the hammer before its release (mgh), where m is the mass of the hammer and $v = (2gh)^{1/2}$ is its tangential velocity at impact, g is gravitational acceleration (9.806 m/s^2) and h is the height through which hammer falls. Here it is interesting to note that height through which hammer drops determines the velocity and height and mass of a hammer combined determine the energy.

Energy used can be measured from the scale given. The difference between potential energies is the fracture energy. In test machine this value indicated by the pointer on the scale.

With the increase or decrease in values, gap between marks on scale showing energy also increase or decrease. This can be seen from the attached scale with any impact machine.

Energy used in fracturing the specimen can be obtained approximately as (mgh_1- mgh_2). This energy value called impact toughness or impact value, which will be measured, per unit area at the notch.

Two standardized tests, the Charpy and Izod, were designed and used extensively to measure the impact energy.

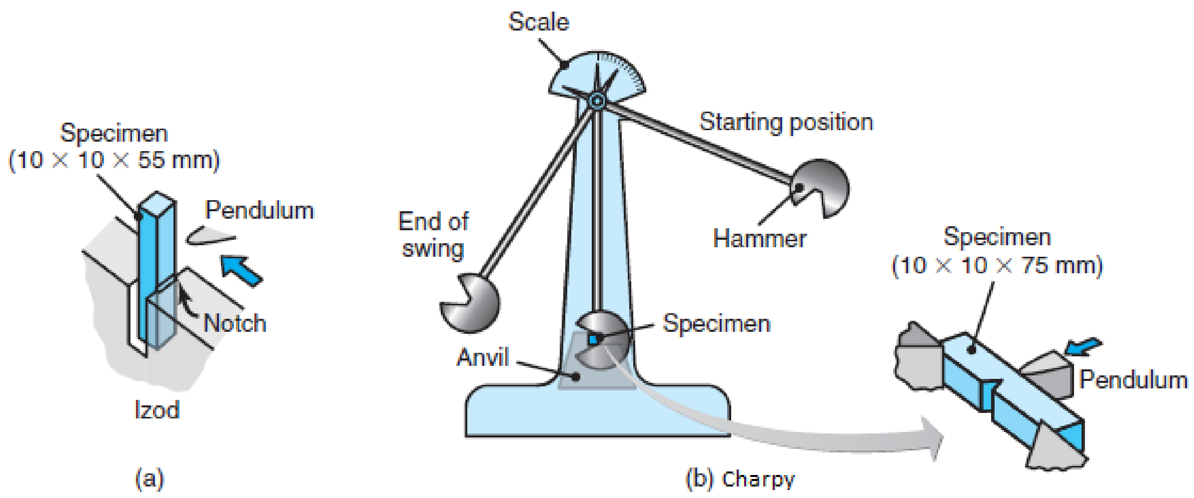
The primary difference between the Charpy and Izod techniques lies in the manner of specimen support as is indicated in Figure.

Differences between the Charpy and Izod techniques

	Izod Impact Test	Charpy Impact Test
Position of Specimen	Vertical	Horizontal
Direction of Notch-Face	In front of striker	Away from striker
Type of Notch	V-Notch	V-Notch & U-Notch
Striking Point	Upper Tip of specimen	Centre of specimen

Izod Impact test

Size of the specimen is 10mm X 10mm X 75mm Specimen is clamped to act as vertical cantilever with the notch on tension side.



Charpy Test

Size of the specimen is 10mm X 10mm X 55mm.

Specimen is clamped to act as Simply Supported Beam. Hammer is allowed to hit then specimen at the opposite face behind the notch.

Unit- II

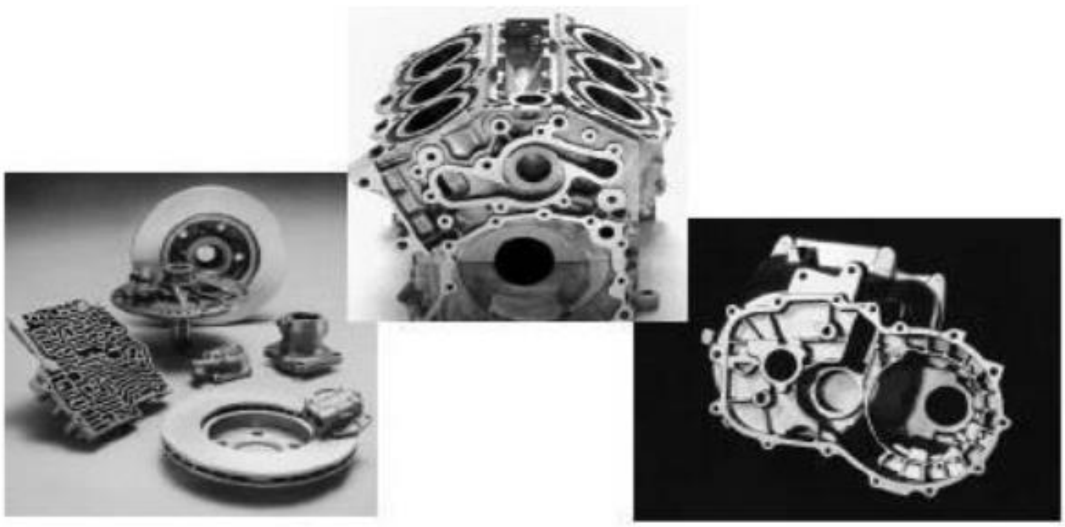
Manufacturing Processes:

Casting processes: Moulding materials and their requirements; Patterns: Types and various pattern materials. Various casting methods, viz., sand casting investment casting, pressure die casting, centrifugal casting, continuous casting, thin roll casting; Mould design; Casting defects and their remedies.

Steps: - Making mould cavity - Material is first liquefied by properly heating it in a suitable furnace. - Liquid is poured into a prepared mould cavity - allowed to solidify - product is taken out of the mould cavity, trimmed and made to shape

We should concentrate on the following for successful casting operation:

(i)Preparation of moulds of patterns (ii)Melting and pouring of the liquefied metal (iii)Solidification and further cooling to room temperature (iv)Defects and inspection



Advantages • Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized.

• Possible to cast practically any material: ferrous or non-ferrous.

• The necessary tools required for casting moulds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.

• There are certain parts (like turbine blades) made from metals and alloys that can only be processed this way. Turbine blades: Fully casting + last machining.

• Size and weight of the product is not a limitation for the casting process.

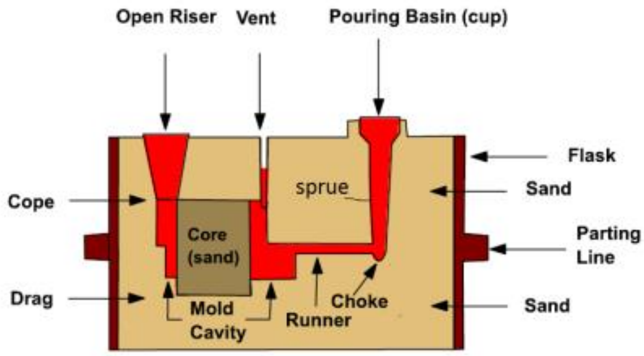
Limitations

• Dimensional accuracy and surface finish of the castings made by sand casting processes are a limitation to this technique.

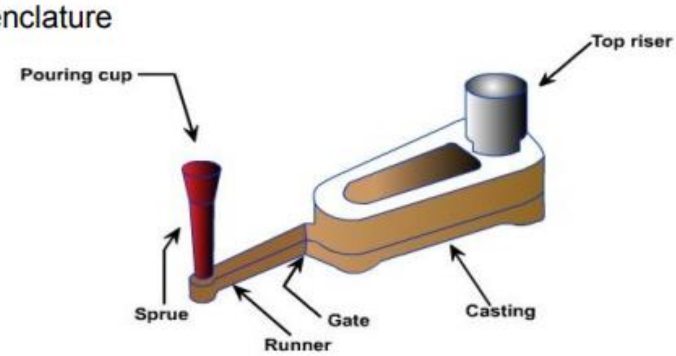
• Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed moulding process, and shell moulding process.

• Metal casting is a labour intensive process
• Automation:

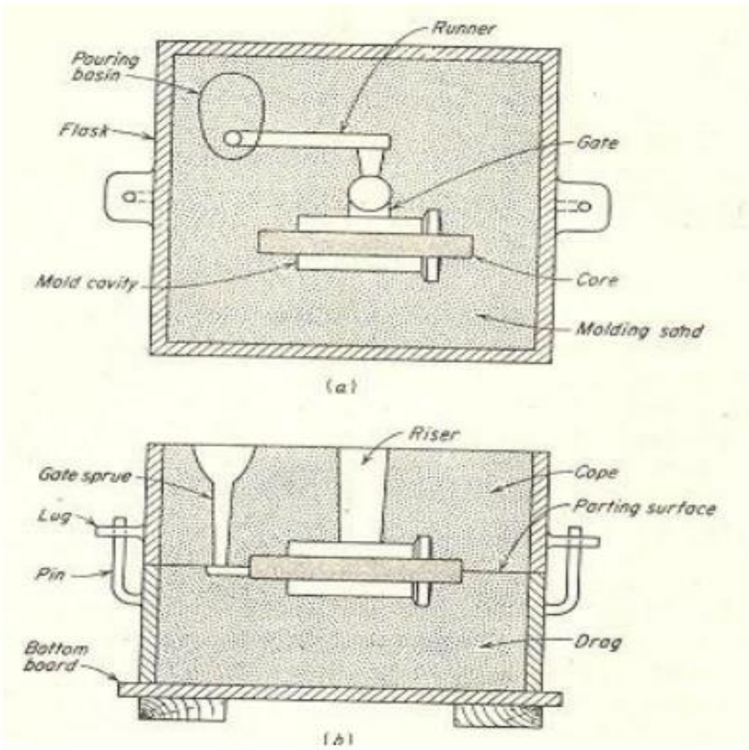
Typical sand mould



Mould Section and casting nomenclature



pattern attached with gating and risering system



Mould Section and casting nomenclature, (a) top view, (b) front view

Flask: A metal or wood frame, without fixed top or bottom, in which the mould is formed. Depending upon the position of the flask in the moulding structure, it is referred to by various names such as drag – lower moulding flask, cope – upper moulding flask, cheek – intermediate moulding flask used in three piece moulding.

Pattern: It is the replica of the final object to be made. The mould cavity is made with the help of pattern.

Parting line: This is the dividing line between the two moulding flasks that makes up the mould.

Moulding sand: Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay, and moisture in appropriate proportions.

Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mould cavity to give a better surface finish to the castings.

Core: A separate part of the mould, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.

Pouring basin: A small funnel shaped cavity at the top of the mould into which the molten metal is poured.

Sprue: The passage through which the molten metal, from the pouring basin, reaches the mould cavity. In many cases it controls the flow of metal into the mould.

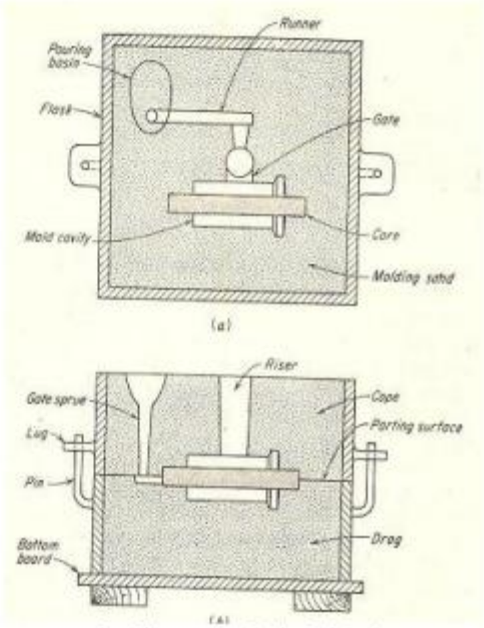
Runner: The channel through which the molten metal is carried from the sprue to the gate.

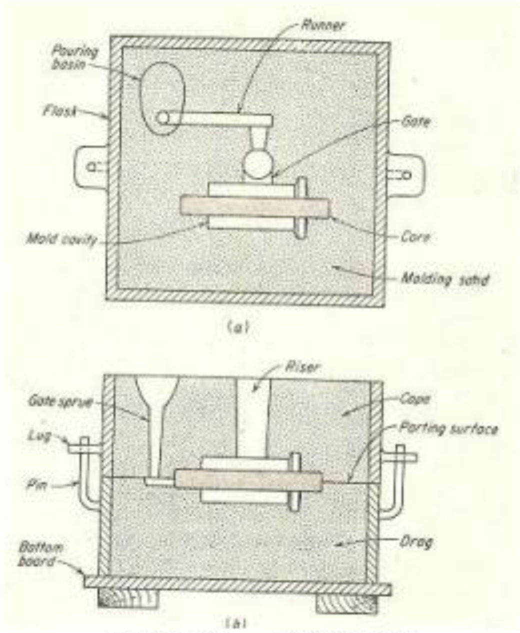
Gate: A channel through which the molten metal enters the mould cavity.

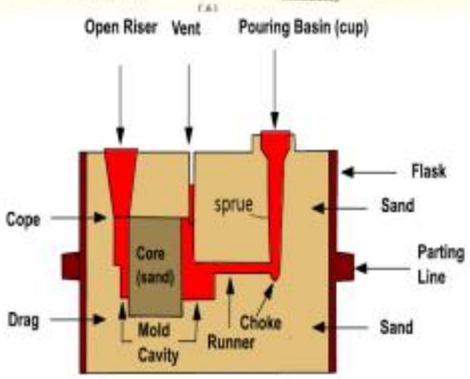
Chaplets: Chaplets are used to support the cores inside the mould cavity to take care of its own weight and overcome the metallostatic force.

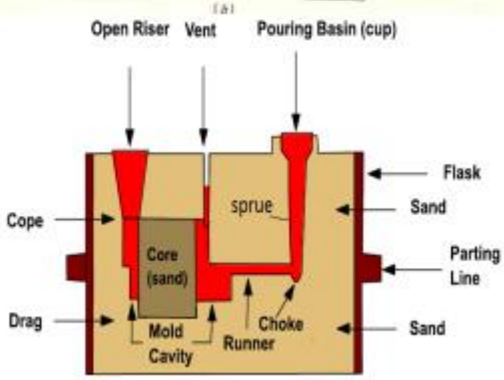
Riser: A column of molten metal placed in the mould to feed the castings as it shrinks and solidifies. Also known as “feed head”.

Vent: Small opening in the mould to facilitate escape of air and gases.



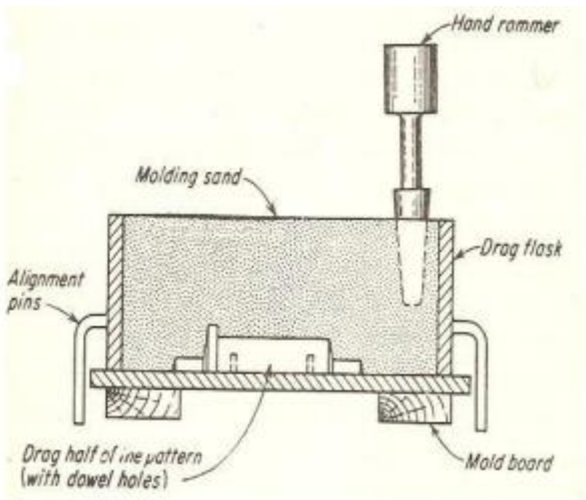






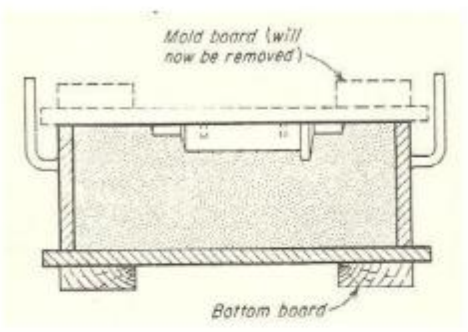
Making a simple sand mould

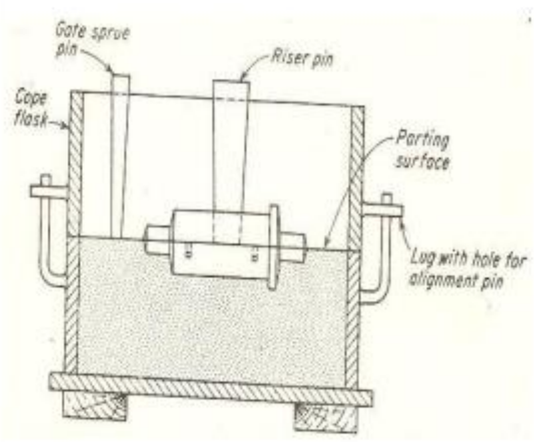
1) The drag flask is placed on the board
2) Dry facing sand is sprinkled over the board
3) Drag half of the pattern is located on the mould board. Dry facing sand will provide a non-sticky layer.
4) Molding sand is then poured in to cover the pattern with the fingers and then the drag is filled completely



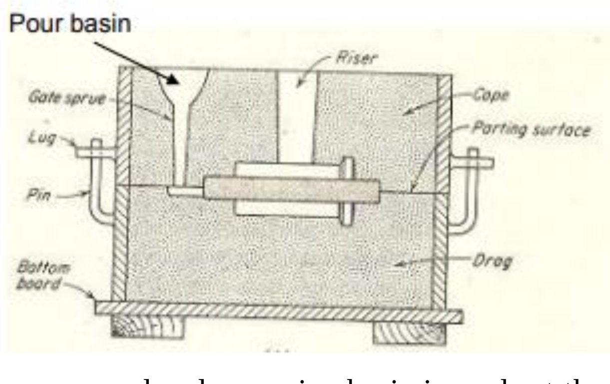
5) Sand is then tightly packed in the drag by means of hand rammers. Peen hammers (used first close to drag pattern) and butt hammers (used for surface ramming) are used.

6) The ramming must be proper i.e. it must neither be too hard or soft. Too soft ramming will generate weak mould and imprint of the pattern will not be good. Too hard ramming will not allow gases/air to escape and hence bubbles are created in casting resulting in defects called ‘blows’. Moreover, the making of runners and gates will be difficult.
7) After the ramming is finished, the excess sand is leveled/removed with a straight bar known as strike rod.





8) Vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification. Done by vent rod.
9) The finished drag flask is now made upside down exposing the pattern.
10) Cope half of the pattern is then placed on the drag pattern using locating pins. The cope flask is also located with the help of pins. The dry parting sand is sprinkled all over the drag surface and on the pattern.
11) A sprue pin for making the sprue passage is located at some distance from the pattern edge. Riser pin is placed at an appropriate place.
12) Filling, ramming and venting of the cope is done in the same manner.



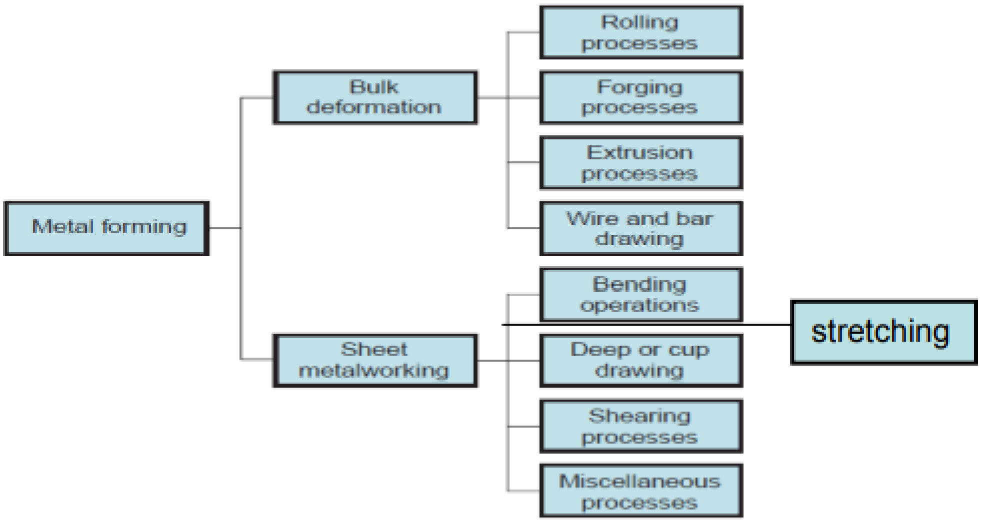
13) The sprue and riser are removed and a pouring basin is made at the top to pour the liquid metal. 14) Pattern from the cope and drag is removed.
15) Runners and gates are made by cutting the parting surface with a gate cutter. A gate cutter is a piece of sheet metal bent to the desired radius.
16) The core for making a central hole is now placed into the mould cavity in the drag. Rests in core prints.
17) Mould is now assembled and ready for pouring.

Metal forming processes: Various metal forming techniques and their analysis, viz., forging, rolling, extrusion, wire drawing, sheet metal working, spinning, swaging, thread rolling; Super plastic deformation; Metal forming defects.

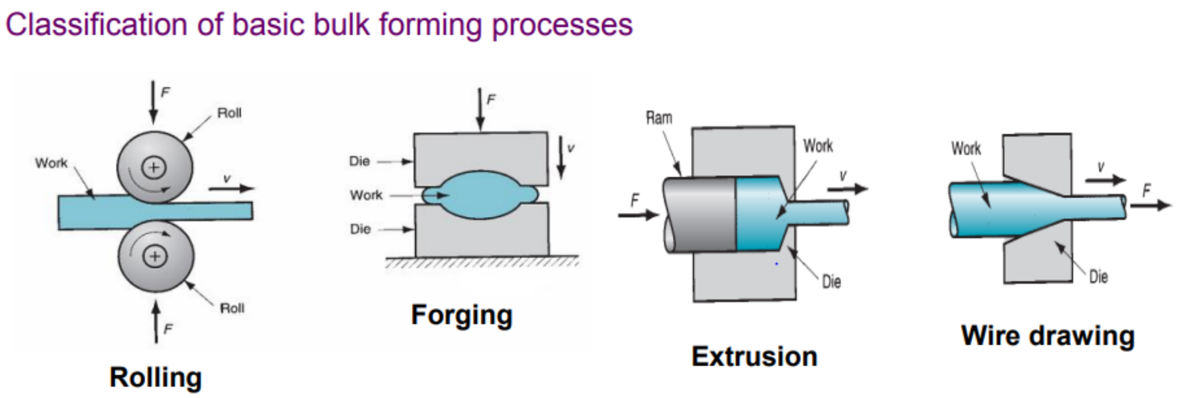
Metal forming: Large set of manufacturing processes in which the material is deformed plastically to take the shape of the die geometry. The tools used for such deformation are called die, punch etc. depending on the type of process.

Plastic deformation: Stresses beyond yield strength of the workpiece material is required.

Categories: Bulk metal forming, Sheet metal forming



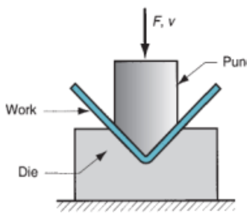
General classification of metal forming processes



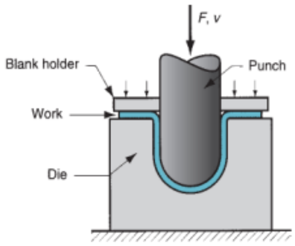
Rolling: In this process, the workpiece in the form of slab or plate is compressed between two rotating rolls in the thickness direction, so that the thickness is reduced. The rotating rolls draw the slab into the gap and compresses it. The final product is in the form of sheet.

Forging: The workpiece is compressed between two dies containing shaped contours. The die shapes are imparted into the final part.

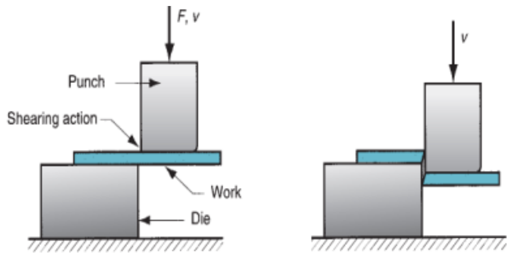
Extrusion: In this, the workpiece is compressed or pushed into the die opening to take the shape of the die hole as its cross section. Wire or rod drawing: similar to extrusion, except that the workpiece is pulled through the die opening to take the cross-section.



Bending



Deep drawing



shearing

Sheet forming: Sheet metal forming involves forming and cutting operations performed on metal sheets, strips, and coils. The surface area-to-volume ratio of the starting metal is relatively high. Tools include punch, die that are used to deform the sheets.

Bending: In this, the sheet material is strained by punch to give a bend shape (angle shape) usually in a straight axis.

Deep (or cup) drawing: In this operation, forming of a flat metal sheet into a hollow or concave shape like a cup, is performed by stretching the metal in some regions. A blank-holder is used to clamp the blank on the die, while the punch pushes into the sheet metal. The sheet is drawn into the die hole taking the shape of the cavity.

Shearing: This is nothing but cutting of sheets by shearing action.

Bulk forming processes:

Forging:

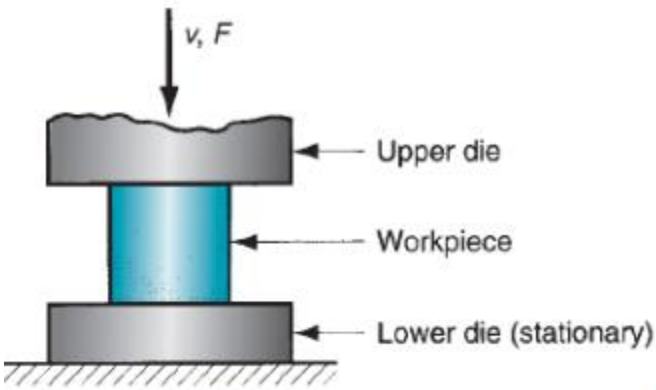
It is a deformation process in which the work piece is compressed between two dies, using either impact load or hydraulic load (or gradual load) to deform it.

• It is used to make a variety of high-strength components for automotive, aerospace, and other applications. The components include engine crankshafts, connecting rods, gears, aircraft structural components, jet engine turbine parts etc.

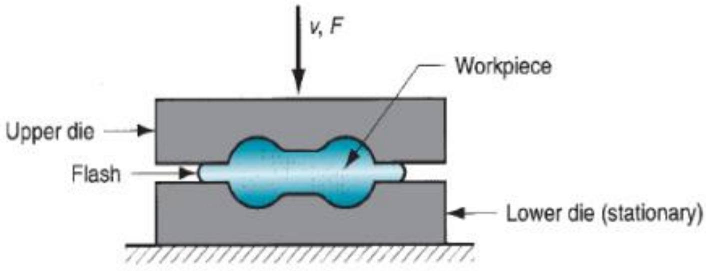
Category based on temperature : cold, warm, hot forging

Category based on presses: impact load => forging hammer; gradual pressure => forging press

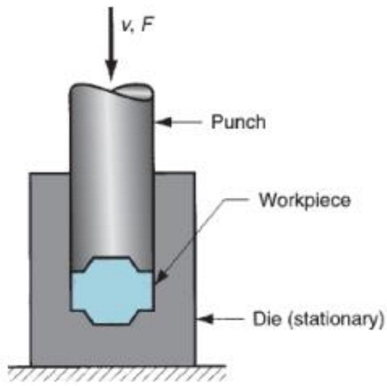
Category based on type of forming: Open die forging, impression die forging, flashless forging.



In open die forging, the work piece is compressed between two flat platens or dies, thus allowing the metal to flow without any restriction in the sideward direction relative to the die surfaces.



impression die forging



flashless forging

In impression die forging, the die surfaces contain a shape that is given to the work piece during compression, thus restricting the metal flow significantly. There is some extra deformed material outside the die impression which is called as flash. This will be trimmed off later.

In flashless forging, the work piece is fully restricted within the die and no flash is produced. The amount of initial work piece used must be controlled accurately so that it matches the volume of the die cavity.

Metal joining processes: brazing, soldering, welding; Solid state welding methods; resistance welding; arc welding; submerged arc welding; inert gas welding; Welding defects, inspection.

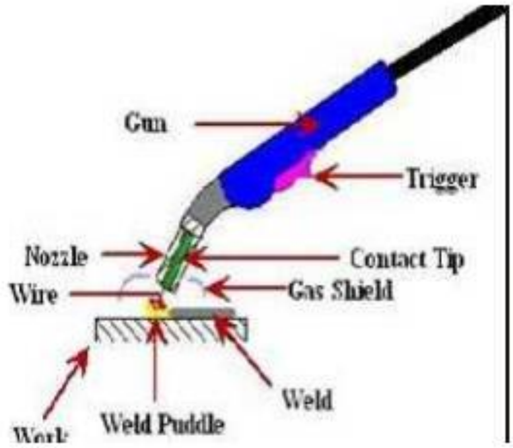
WELDING

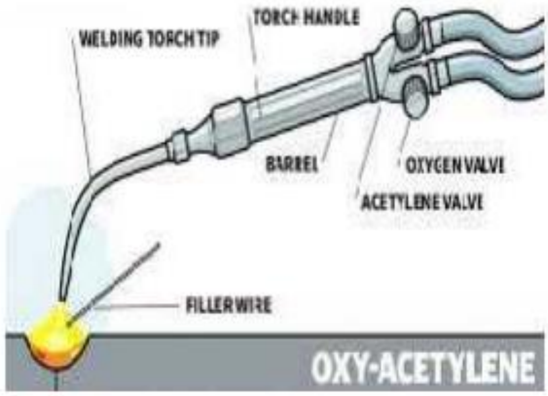
Welding: The process of joining similar metals by the application of heat is called "Welding". Welding can be obtained with or without application of pressure and with or without addition of filler metal which is known as 'electrode'.

Classification of welding process: 1. Fusion welding 2. Plastic welding. Fusion welding: The metal at the joint is heated to a molten state and then it is allowed to solidify. Pressure is not applied during the process and hence it is called "non pressure welding". Filler material is required for this welding. Plastic welding: The metal parts are heated to a plastic state and are pressed together to make the joint. It is called as "pressure welding". No filler material is required.

TYPES OF WELDING: Thermit welding Fusion welding ---- Arc welding ------ Submerged,Plasma,Automic hydrogen,MIG, Metal, Carbon, Electro slag WELDING.

Gas welding ------ Oxyacetylene, Oxyhydrogen Plastic welding ---- Explosive welding Ultrasonic welding Electric resistance—Butt, Spot, Seam, Projection,Percusion Friction welding Forge welding.





GAS WELDING:

1.Oxy – acetylene welding 2) Oxy – hydrogen welding 3) Air – hydrogen Oxy acetylene Welding: The edges of the metal to welded are melted by using a gas flame. No pressure is applied. The flame is produced at the tip of the welding torch. The welding heat is obtained by a mixture of oxygen and combustible gas. The gases are mixed in the required proportion in a welding torch which provides control for the welding flame. The gases used are acetylene, hydrogen, propane and butane. Common gas is oxy acetylene. The flame only melts the metal and additional metal to the weld is supplied by filler rod. A flux is used during welding to prevent oxidation and to remove impurities. Metal 2 mm to 50 mm thick are welded. The temperature of the flame is about 3200 oC. There are two types of oxy acetylene systems, one is High pressure and the other is Low pressure system.

GAS WELDING EQUIPMENTS: 1) Gas cylinders: Oxygen in Black colour, Acetylene in maroon colour. 2) Pressure regulators: Each cylinder is fitted with pressure regulator. It is used to control the working pressure of the gases. Oxygen 0.7 to 2.8 kg/cm2 Ace 0.07 to 1.03 kg/cm2

3) Pressure gauges: Each cylinder is fitted with two pressure gauges. One is for cylinder pressure and the other one is working pressure pressure for welding.

4) Hoses: Each cylinder is connected to the torch through two long hoses. It should be flexible, strong, and light. Oxygen is fitted with black colour and Ace in red colour.

5) Welding torch: Oxygen and ace enters the torch through the hose is separate passage. Both the gases are mixed in the mixing chamber of the torch. When it is ignited a flame will be produced at the tip of the torch called nozzle. Two control valves are used to control the quantity of oxygen and ace to adjust the flame.The nozzles are made of copper and available in different sizes depending upon the type of metal to be welded.

6) Goggles: It is used the protect eyes from the flame heat, ultraviolet and infrared rays.

7) Welding gloves: It is used to protect hand from the injury by heat and metal splashes. 8) Spark lighter: It is an igniter to start the burning of the oxy ace gases. 9) Wire brush: It is used to clean the weld joint before and after welding.

ARC WELDING: The heat is developed by an electric arc. The arc is produced between and electrode and the work. It is a process of joining two metals by melting their edges by an electric arc. The electrical energy is converted to heat energy. The gap between the electrode and the work is 3mm. The current is passed through the workpiece and the electrode to produce an electric arc. The workpiece is melted by the arc. The electrode is also melted and hence both the workpieces becomes a single piece without applying any external pressure. The temperature of the arc is 5000 to 6000 o C. A transformer or generator is used for supplying the current. The depth to which the metal is melted and deposited is called Depth of fusion. To obtain better depth of fusion the electrode is kept at 70o inclination to vertical.

COMPARISION OF ARC WELDING AND GAS WELDING:

Arc welding	Gas welding
Heat is produced by electric arc	Heat is produced by the gas flame
The arc temperature is about 4000°C	The flame temperature is about 3200°C
Filler rod is used as electrode	Filler rod is introduced separately
It is suitable for medium and thick work	It is suitable for thin work
Arc weld joints have very high strength	Gas weld joints do not have much

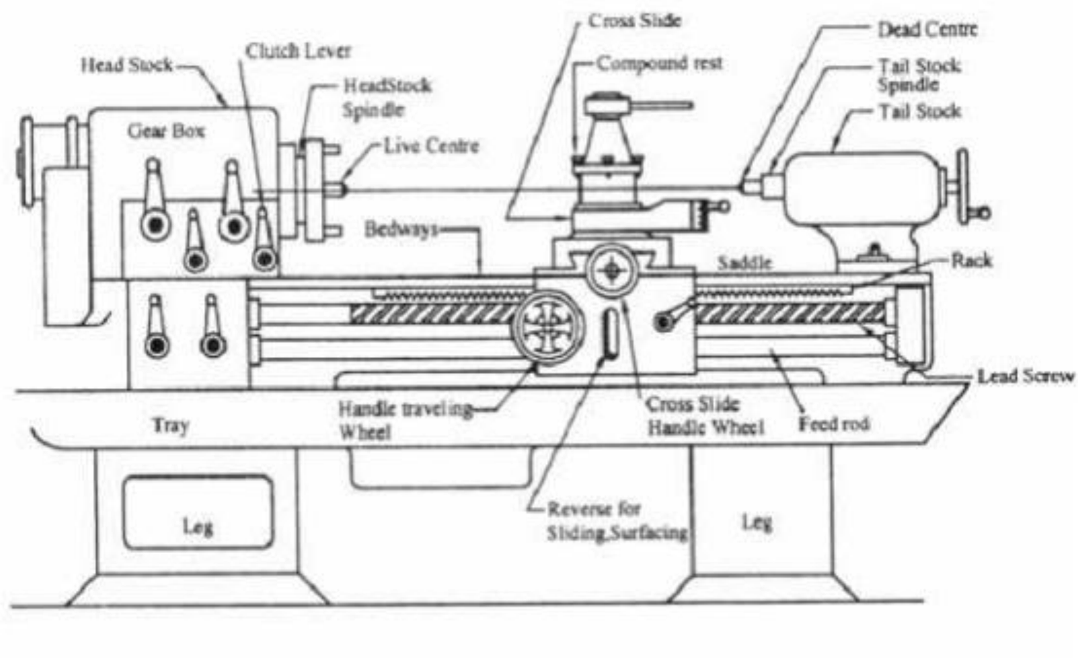
SOLDERING: Soldering is a process of joining two metal parts with a third metal. The third metal has a very low melting point. It is known as Solder. It is used as a filler rod. Most of the solders are alloys of tin and lead. They melt at a temp of about 215oC. The work pieces are not melted. Electrically heated soldering irons are available. The two sheets are properly cleaned to remove oil, grease, oxides and dirt. This is done by chemical cleaning, filing, or by emery cloth. Two sheets are positioned. A flux is applied using a brush. The flux prevents oxidation. The flux used is in the formof liquid or paste. The flux used are zinc chloride and hydrochloric acid. The soldering iron is heated to proper temp. It is dipped in the flux and then rubbed on the solder. This is known as tinning of the tip.
Applications: Used in electrical appliances, computers, automobile radiators.

BRAZING: It is the process of joining two similar or dissimilar metals by using a fusible alloy called “spelter”. Spelter is a harder filler rod. Its melting temp is about 600oC. This is below the melting point of the work materials. The most commonly used spelters are copper alloys and silver alloys. For brazing ferrous metals copper alloys made of copper, zinc and tin are used. Silver alloys made of silver and copper are used for any metals.

Comparisionof Soldering and Brazing:

Soldering	**Brazing**
Filler material is known as solder	Filler material known as spelter
Low melting point alloys used	High melting point alloys used
Alloys of tin and lead are used	Copper and silver base alloys used
Strength of the joint is relatively low	Relatively high strength
Fluxes are Zinc chloride and hcl acid	Flux is borax powder
Mostly used for elec connections, tins and cans	Joining of dissimilar metals,

Machining



Centre Lathe

Introduction:

Lathe is a machine tool, which is used to remove metal from work piece for required shape and size. This is done by holding the work piece firmly on the machine and turning it against the cutting tool, which will remove metal from the work in the form of chips.

Center lathe: This lathe is the most important member of lathe family and most widely used. This lathe is also known as engine lathe. The basic parts of center lathe are bed, headstock, tailstock, and carriages, cross slide, compound rest, tool post and apron.

Bed: It is the base of the lathe; the headstock and tailstock are located at either end of the bed and the carriage rests over the lathe bed and slides on it.

Headstock: It carries a hollow spindle .A live center can be fitted in to hollow spindle. The live center rotates with the work piece and hence called live center.

Tailstock: It is mounted on the bed at right angles end. It is used for supporting the right end of the work piece by means of a dead center. The dead center does not revolve with the work piece and hence called dead center.

Carriage: It is supported on the lathe bed ways and can move in a direction parallel to the lathe axis .It carries saddle, cross slide, compound rest, tool post and apron. It is a H- shaped casting fitted over the bed. It moves along the guide way.

Cross slide: It carries the compound rest and tool post. It is mounted on the top of the saddle. It may be moved by hand or may be given feed through apron mechanism.

Compound rest: It is mounted on the cross –slide .It carries a circular bar called swivel plate, which is graduated on degrees. The upper part is known as the compound slide, and it can be moved by means of the hand wheel.

Tool post: The tool post is fitted over the compound rest. the tool is clamped in the tool post.

Apron: Lower part of the carriage is termed as the apron. It is attached to the saddle and hangs in front of the bed .It contains gear, clutch and lever for moving the carriage by a hand wheeler power feed.

Feed mechanism: The movement of tool relative to the work is termed as feed. A lathe may have three types of feed: longitudinal, cross, and angular feed. The feed mechanisms have different units through which motion id transmitted from the head stock spindle to the carriage. Following are the units: end of bed gearing, feed gear box, feed rod and lead screw, apron mechanism.

Specification of lathe: Specifying a lathe should possess the following details: The length of the bed

- The length between centers
- The height of centers from the bed
- The swing diameter of work over bed.
- The swing diameter of work over bed
- The swing diameter of work over carriage
- The maximum bar diameter which will pass through the hole of ϖ head stock spindle.

Important operations of a lathe:

Turning: The work piece is held in the chuck or between the centers. The turning tool is held parallel to the axis of the lathe spindle and a cylindrical surface is produced. For rough turning, the rate of feed of the tool is fast and the depth of cut is heavy. For rough turning the depth of cut may be from 2 to 5mm.For finishing turning the feed and depth of cut will be small. For this a finish turning tool is used and the depth of cut may be from 0.5 to 1mm.

Facing: Facing is the machining of the end face of the work piece to make it flat. The work piece may be held in the chuck as between the centers. A facing too is fed perpendicular to the axis of operation of the work piece. Only the face of the tool is machined in this processes and hence called facing.

Chamfering: It is the process of leveling extreme end of the work piece. This is done to protect the end of the work piece from getting damaged. This operation is performed after turning, drilling, boring etc., It is a critical operation to be performed after thread cutting so that the end may pass firstly on the threaded work piece.

Knurling: The adjustment screw of a micrometer is not smooth either axis cross or diamond shaped pattern is seen. The process by which such patterns are made is call knurling. It is done to give good gripped surface on the work piece. The teeth may be fine, medium or coarse. Very slow speeds are adapted for knurling.

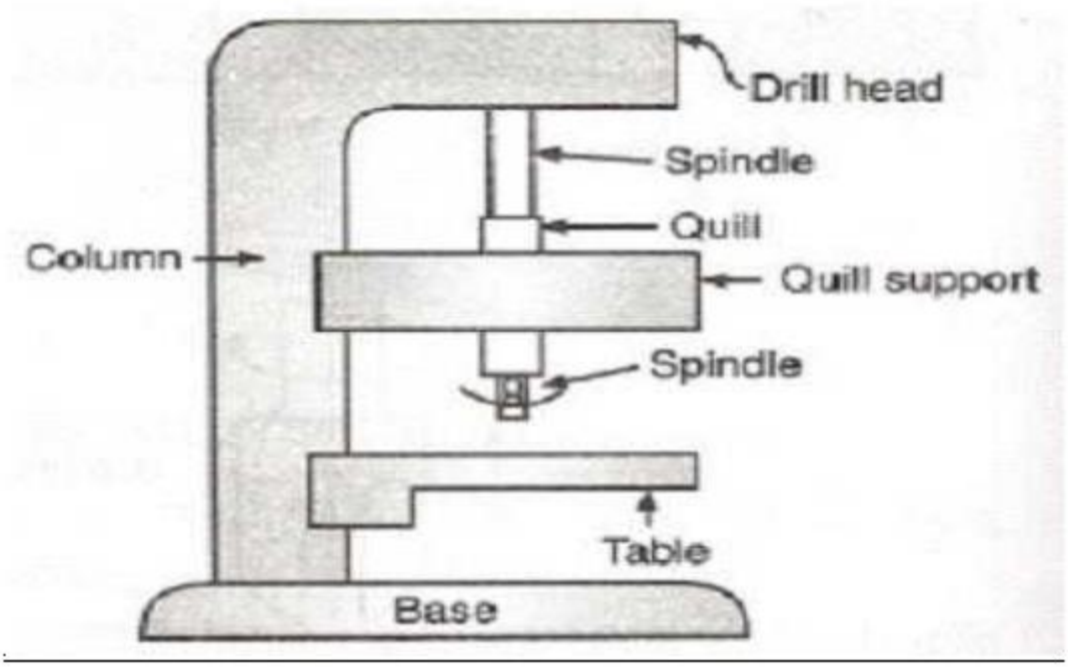
Reaming: The operations for finishing a drilled or bored hole for smooth finishing are called as reaming. The tool used is called as reamer. It has multiple cutting edges. The reamer is fitted in the tail stock spindle.

Drilling: It is an operation for making a hole on a work piece. For drilling, work piece is held in the chuck on one side where as the other side remains free. The tool for drilling is called drill. The drill is inserted on the tailstock. When the job rotates, the drill bit is inserted in the tailstock by rotating the hand wheel.

Boring: It is a process for enlarging a hole produced by drilling. Boring itself cannot produce a hole. The work piece is held in a chuck or face plate. The boring tool is fixed and fed into the job.

Taper turning: A large number of components used in engineering have a conical shape or a tapered shape. A taper is defined as the uniform change in diameter measured along its length.

DRILLING MACHINE



DRILLING MACHINE

Introduction: In a drilling machine holes may be drilled quickly and at a low cost. The hole is generated by the rotating edges of a cutting tool known as the drill, which exerts large force on the work clamped on the table.

Types of drilling machine: 1. Portable
2. Sensitive
3. Upright
4. Radial
5. Gang
6. Multiple spindle
7. Automatic
8. Deep hole

Principle parts of Radial drilling machine:

Base: The base is a large rectangular casting that it is mounted on its one end vertically it supports radial arm, electrical motor. Which impacts vertical adjustment of the arm by rotating a screw. **Column:** The column is a cylindrical casting, it supports radial arm which may slide up or down on its face. An electric motor is mounted at the top of the column, which impacts vertical adjustments of the arm by rotating a screw passing through a nut to the arm.

Radial arm: Radial arm is mounted on the column horizontally over the base; the arm may be swung round the column. In some machines this movement is controlled by a separate motor.

Drill Head: Drill Head is mounted on the radial arm and drills spindle is driven. All the mechanism is housed with in a small drill head. The drill head is properly adjusted and clamped on the radial arm.

Measurement, Measurement Concept, Measurement Errors, Measurement of Temp., Pressure, Velocity, Flow strain, force and torque, Study of Vernier-caliper, Micrometer, Dial gauge, Slip gauge, Sine-bar and Combination set

Production Engineering, Production related theoretical aspects, Study of processes like casting, carpentry, and welding etc Introduction of Lathe and Drilling machines with their different operations.

Measurement Types

1) **Direct measurement**: In this the value of measured quantity is measured directly without doing any calculations. *Example:* Weight of a substance is measured directly using a physical balance.

2) **Indirect measurement**: The value of the quantity is obtained from measurements carried out by direct method of measurement. *Example:* Weight of a substance can be measured by measuring the length, breadth & height of the substance directly and then by using the relation

Weight = Length x Breadth x Height x Density

3) **Measurement without contact**: The sensor is not placed in contact with the object whose characteristics are being measured like infrared sensors.

4) **Measurement by comparison**: In it measured value of any quantity is compared with a known value of the same quantity.

5) **Method of differential measurement**: Based on the comparison of the quantity to be measured with a quantity of the same kind, with a value known to be slightly difference from that of the quantity to be measured, and the measurement of the difference between the values of these two quantities.

Precision & Accuracy for Measurement

Precision: It is the process in which degree of repetition is counted for the same quantity measurement. It is also known as repeatability of the measuring process. It exists only when a set of observations is gathered for the same quantity under common conditions.

Accuracy: It shows the agreement between the measured and true value. The difference b/w the measured & true value is known as measurement error.

To understand the difference between Precision and Accuracy, the following simple example can be said. A watch will give Precision readings (same time) all the times, but will give Accurate readings (correct time) only 2 times in a day.

Factors affecting the accuracy of measuring system

a) Factors affecting the standard of measurement:

Co-efficient of thermal expansion

Elastic properties

Stability with time

Geometric compatibility

b) Factors affecting the work piece to be measured:

Co-efficient of thermal expansion

Elastic properties

Arrangement of supporting work piece

Hidden geometry

Surface defects such as scratches, waviness, etc.

c) Factors affecting the inherent characteristics of instrument:

Repeatability & readability

Calibration errors

Effect of friction, backlash, etc
Inadequate amplification for accuracy objective
Deformation in handling or use

d) Factors affecting person:
Improper training / skill
Inability to select proper standards / instruments
Fewer attitudes towards personal accuracy measurements

e) Factors affecting environment:
Temperature, humidity, atmospheric pressure, etc
Cleanliness
Adequate illumination
Heat radiation from lights / heating elements

Errors during Measurement
It is the difference between the measured and the true value of the measured Quantity
Error = Measured quantity – True quantity

The error during measurement is expressed as an absolute error.
1) **Absolute error:** It is the algebraic difference between the measured value and the true value of the quantity measured.
2) **Relative error:** It is the result of the absolute error and the value of comparison used for the calculation of that absolute error.

Types of Errors

A) Error of Measurement
1) **Systematic error:** It is the error which happens during several measurements, made under the same conditions, of the same value of a certain quantity, remains constant in absolute value and sign or varies in a predictable way in accordance with a specified law when the conditions change.
The causes of these could be known or unknown.
Random error: This error comes in an unpredictable sequence in absolute value and in sign when a large number of measurements of a quantity are made under practically identical conditions. Random errors are non-consistent.
3) **Parasitic error:** This error comes in measurement because of improper handling of equipment.

B) Instrumental error
1) **Physical measure Error:** It is the difference between the nominal & the conventional value reproduced by the physical measurement
2) **Measuring mechanism Error:** It is the difference b/w the value indicated by the measuring system and the conventional true value of the measurement.
3) **Zero error:** It is the indication of a measuring instrument for the zero value for the measurement.
4) **Calibration error for a physical measure:** It is the difference b/w the conventional value measured by the physical measure and the nominal value of that measurement.
5) **Error due to temperature:** When the temperature of instrument does not maintain its reference value Then this error arises.
6) **Error due to friction:** It is the error due to the friction between the moving parts of the measuring instruments.
7) **Error due to inertia:** It is the error due to mechanical, thermal parts of the measuring instrument.

C) Error of observation

1) Reading error: It is the error of observation resulting from wrong reading of the indication by the observer for the instrument.

2) Parallax error: It is the reading error which is produced, when the index at a certain distance from the surface of scale, and reading is not in the correct direction.

3) Interpolation error: It is the reading error which is the result of the inexact evaluation of the position of the index

D) Based on nature of errors

1) Illegitimate error: It should not exist. These include mistakes and blunders, or computational errors they create chaos in the final results.

E) Based on control

1) Controllable errors: The source of error is known and it is possible to have a control on these sources.

2) Calibration errors: This is caused due to variation in the calibrated scale from its normal value.

3) Environmental Errors: International agreement has been reached on ambient condition which is at 20^0C temperature, 760 mm of Hg pressure and 10 mm of Hg humidity. Instruments are calibrated at these conditions. If there is any variation in the ambient condition, errors may creep into final results, of the three, temperature effect is most considerable.

4) Stylus pressure errors: Excess pressure during measurement is the cause of this error.

5) Avoidable errors: These errors may occur due to parallax in the reading of measuring instruments.

Causes of Errors

1) Errors due to deflection: When long bars get deformed or deflected. This elastic deformation occurs under their weight. The amount of deflection depends up-on the positions of the supports.

2) Errors due to misalignment: According to Abbes' principle, "the axis or line of measurement of the measured part should coincide with the line of measuring scale or the axis of measurement of the measuring instrument".

3) Error due to contact pressure: The variations in contact pressure, is the main cause of this error. The deformation of the work piece and the anvils of instrument depend upon the contact pressure and the shape of the contact surfaces.

4) Error due to vibrations: This could be because of moving body or part.

5) Error due to dirt: Because of improper maintenance dirty instruments gives wrong values.

6) Error due to poor contact: Because of improper handling the instrument gives the wrong value.

7) Error due to wear in gauges: Wear of measuring surfaces of instrument occurs due to repeated use.

8) Error due to looseness: This happens because of improper contact between the measuring part and the measuring device.

Temperature, Pressure, Velocity, Flow strain, Force and torque measurement:

Temperature Measurement

Temperature measurement, also known as thermometry, describes the process of measuring a temperature for immediate or later evaluation. There are following types of the engineer devices used for temperature measurement: thermocouples, resistive temperature devices (RTDs and thermostats), infrared radiators, bimetallic devices, change-of-state devices.

Thermocouple

Thermocouples made of different metals and joined at one end. Change in the temperature at that junction creates a change in electromotive force (emf) between the other ends. As temperature goes up, this output emf of the thermocouple is measured.

RTDs and thermostats

It works on the concept that the electrical resistance of a material changes as its temperature changes.

Infrared radiators

Infrared sensors are non-contacting devices. They infer temperature by measuring the thermal radiation emitted by a material.

Bimetallic devices

It works on the difference in rate of thermal expansion between different metals. Strips of two metals are joined together. When heated, one side will expand more than the other, and the resulting bending is translated into a temperature reading by mechanical linkage to a pointer. These devices do not require a power supply.

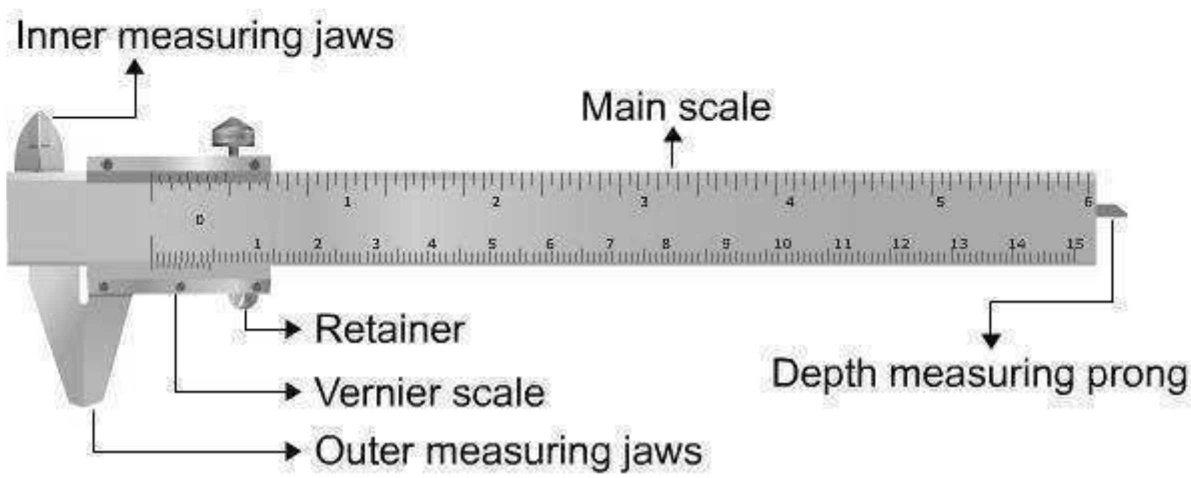
Change-of-state devices

Change-of-state temperature sensors consist of labels, pellets whose appearance changes once a certain temperature is reached. They are used, for instance.

Vernier caliper, Micrometer, Dial gauge:

Vernier caliper

It is an instrument that measures internal or external dimensions and distances. Parts of a Vernier Caliper



It consists of a main scale fitted with a jaw at one end, another jaw, having the Vernier scale, moves over the main scale. When jaws are in contact, the zero of the main scale and the zero of the Vernier scale should coincide. If both the zeros do not coincide, there will be a + or - zero error.

Least Count

It is the smallest reading which the instrument can calculated,

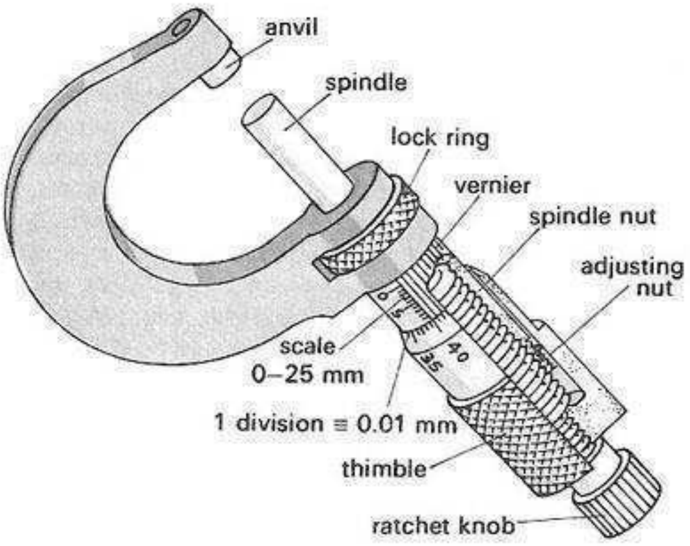
Least count = One Main scale division / Number of divisions in Vernier scale

Micrometer

A micrometer sometimes known as a **micrometer screw gauge** is a device widely used for precise measurement of components in mechanical engineering and machining as well as most mechanical trades, along with other metrological instruments. It is used for measuring dia. of objects like wires, with an accuracy of 0.001cm.

The least count of micrometer can be calculated using the formula:

Least count = Pitch / Number of divisions on the circular scale = 0.5 mm / 50 = 0.01 mm



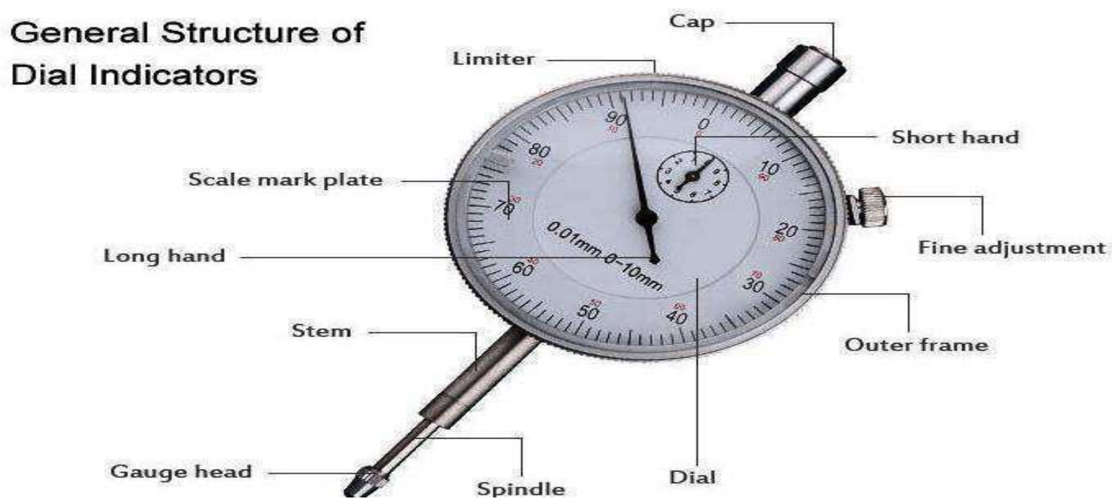
Dial gauge

Dial indicators are important devices used in manufacturing and metal engineering. These devices measure small linear distances that are important in the establishment of precision and accuracy. Dial gauge having following parts.

Graduated dial and needle- These are responsible for recording the minor increments that result out of the measurement procedure.

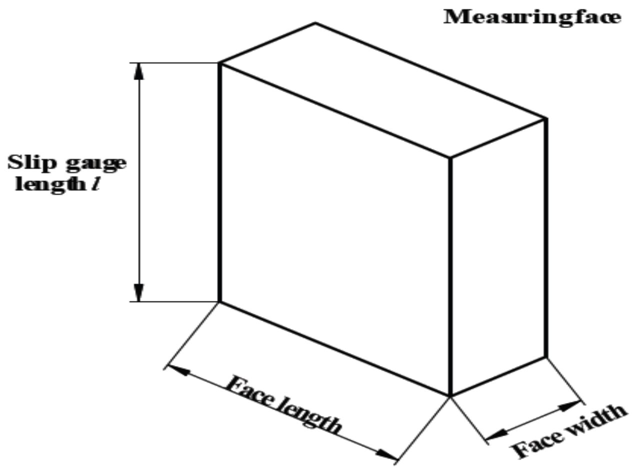
Embedded clock face and needle- These are smaller than the graduated dial and needle and are used for recording the number of needle rotations in the main dial.

Plunger- It is the moving part of a dial indicator that moves perpendicular to the testing object.



Slip gauges

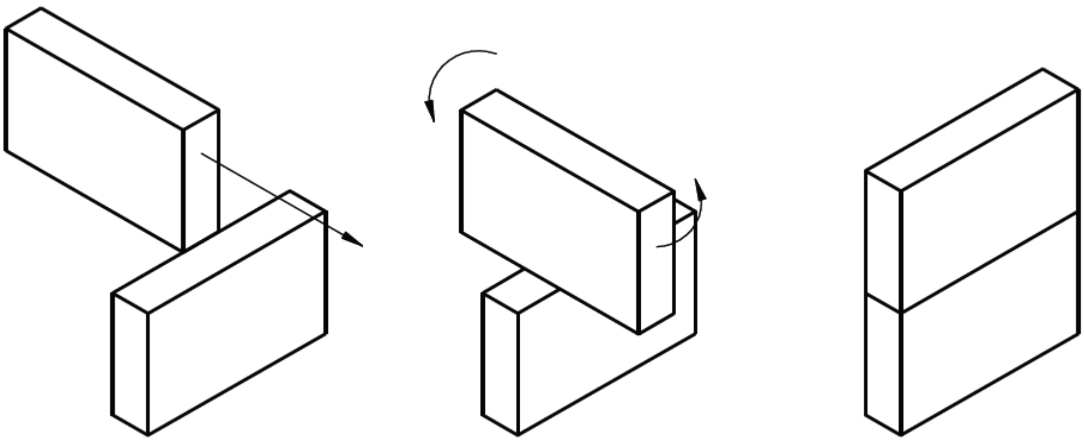
These are the rectangular blocks of steel having cross section of 30 mm face length & 10 mm face width



These blocks of steel have been hardened and stabilized by heat treatment. They are of size to very high standards of accuracy and surface finish. Correctly cleaned and wrung together, the slip gauges adhere to each Other by molecular attraction. They should then be cleaned, Smeared with Vaseline and returned to their case after use.

Wringing of Gauges:

Slip gauges are wrung together to give a height of the required dimension.

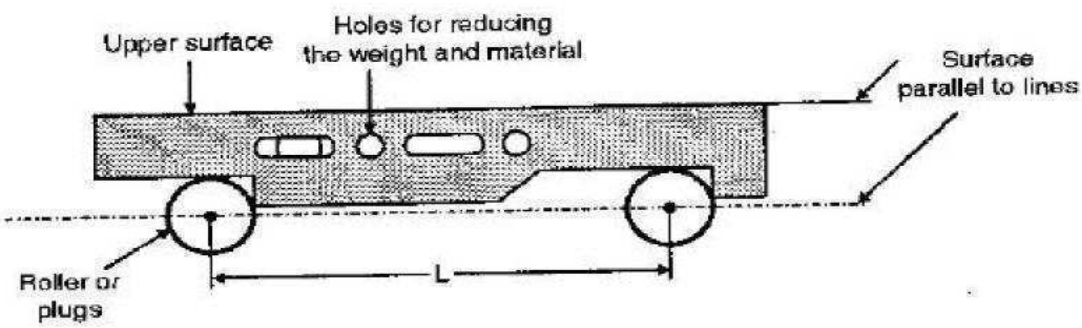


Wringing of Slip Gauges

Sine Bar:

It is a precision measuring instrument and is an excellent example of combination of linear and angular measurement. Consists of a bar carrying a suitable pair of rollers set at a known centre distance. It is made of high carbon, high chromium corrosion resistant steel.

If l is the linear distance between the axes of the rollers and *h* is the height of the slip gauge, then $\sin \theta = h/l$



Sine bar working principle:

First kept it on the surface plate, the work piece is then placed on the sine bar such that the surface whose angle is to be measured is facing upwards. Place the set of slip gauges below one end of the roller of sine bar such that the upper surface of the work piece is approximately parallel with the table surface. Place the plunger of the dial gauge on the upper surface of the work piece, Take readings with the dial gauge and note their difference.

Advantages of sine bar:

1. It is used for accurate and precise angular measurement.
2. It is available easily.
3. It is cheap.

Disadvantages:

1. The application is limited for a fixed centre distance between two plugs or rollers.
2. It is difficult to handle and position the slip gauges.
3. If the angle exceeds 45°, sine bars are impracticable and inaccurate.
4. Large angular error may results due to slight error in sine bar.

Combination Set :

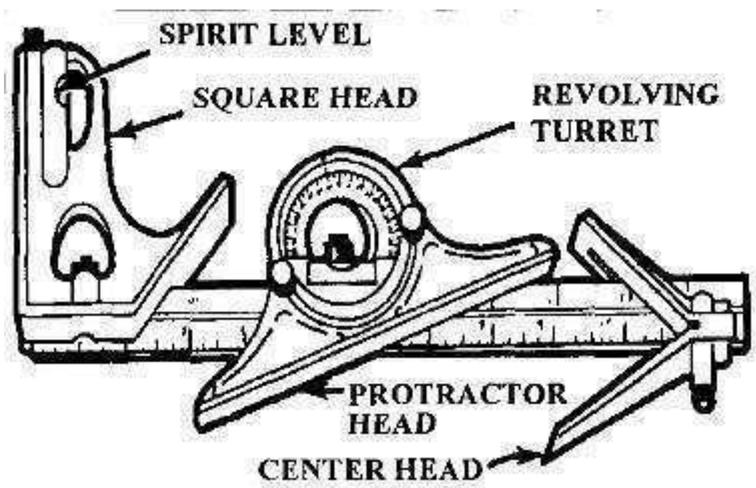
This is the most commonly used non-precision instrument in layout and inspection work.

It consists of scale, squaring-head, protractor and centre-head. One surface of the squaring head is always perpendicular to the scale and it can be adjusted at any place by a locking bolt and nut.

The squaring head also contains a spirit level which is used to test the surfaces for parallelism. It can also slide to any position and be locked there. A scribing point is also inserted into the rear of the base for scribing purposes.

The squaring head and scale can be used for height and depth measurements, inside and outside squaring operations.

The protractor is also capable of sliding along the scale. It contains a semi-circular disc graduated from 0 to 90° on either side of centre. With the help of protractor, the correct angle of the work can be checked.



Unit- III

Fluid:- Fluid may be defined as a substance which is capable of flowing.

It has (does not) a definite shape of its own, but conforms to the shape of the containing vessel.

Further even a small amount of shear force exerted on a fluid will cause it to undergo a deformation which continues as long as the force continues to be applied.

→ Ideal fluids are those fluids have no viscosity and surface tension and they are incompressible.

→ Incompressible means volume of the fluid does not changes with the application of pressure.

1. Properties of Fluids.

Fluid Statics :- Fluids at rest.

Kinemetics :- study when fluids are in motion and pressure force is not considered.

Dynamics :- Motion + Pressure forces.

* Properties of Fluids :-

Density :

$$\rho = \frac{\text{mass of fluid}}{\text{volume of fluid}} = \frac{m}{V}$$

~~Spe~~ mass density ρ = mass of the fluid to the per unit volume.

In SI unit, kg/m^3.

→ Density of fluid is constant, while density of gases change with temp. and pres.

→ water, $1000\ kg/m^3$ or $1\ g/cm^3$

→ air, $1.205\ kg/m^3$

* Specific weight or weight Density :-

→ w

→ weight per unit volume of fluid.

→ mathematically, $w = \frac{m \times g}{V} = \rho \times g$
$= \rho g$

- weight density for water is $9.81 \times 1000 \ N/m^3$ in SI units, at 4°C.

*** Specific Volume:-** specific volume

- $v = \frac{V}{m} = \frac{\text{volume of fluid}}{\text{unit mass}}$.

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

- SI unit, m^3/kg,

*** Specific Gravity:-**

→ S

→ specific gravity is defined as the ratio of the weight density (or density) of fluid to the weight density of the standard fluid.

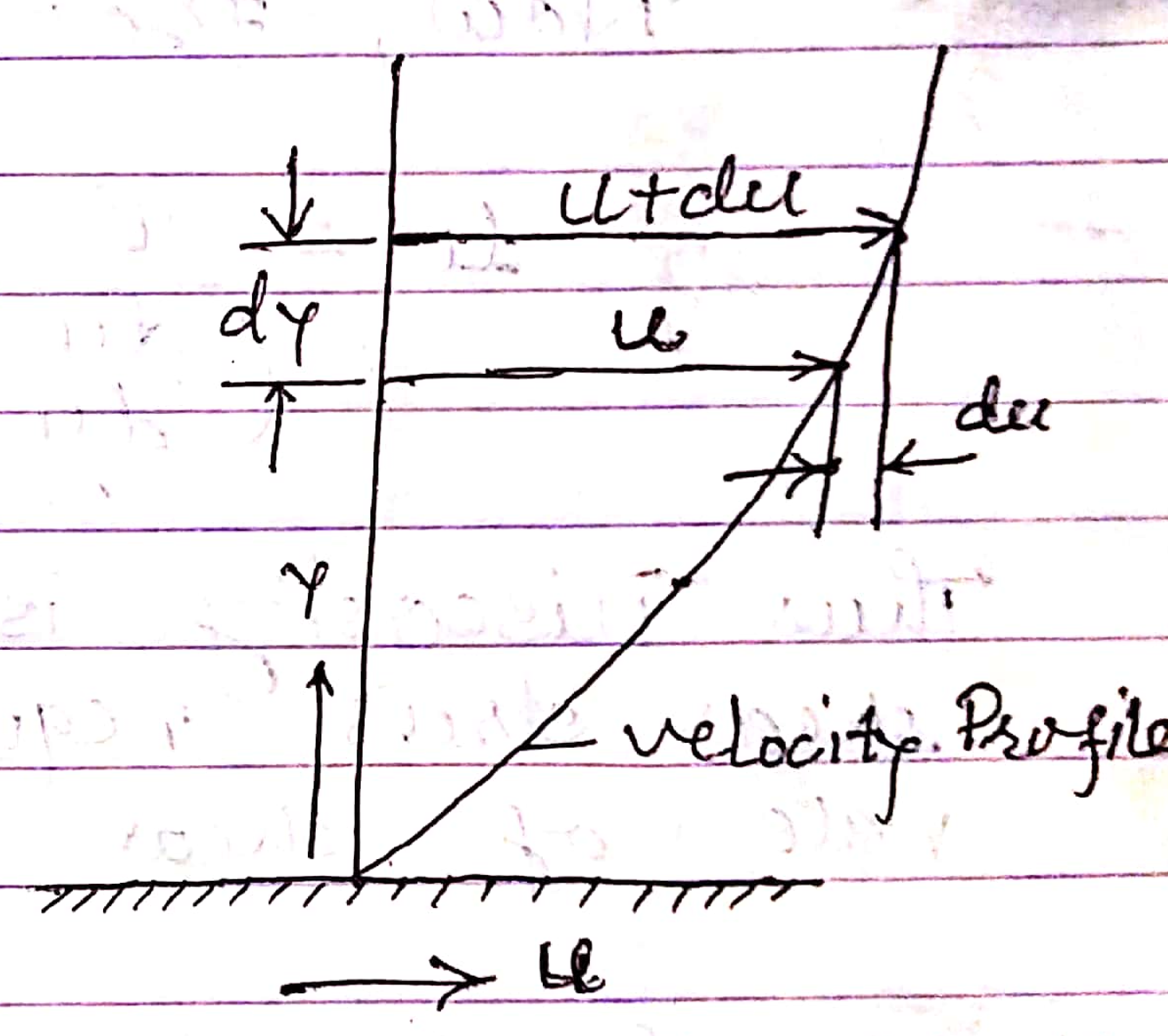
→ Specific gravity is also called relative density.

→ For liquid, water & for Gases, air is taken as standard fluid.

* **Viscosity:-** Viscosity is the property of fluid by virtue of which, it offers resistance to the movement of one layer of fluid over another adjacent layer of fluid. It is primarly due to cohesion and molecular momentum exchange between fluid layers, and as flow occurs, these effects appear as shearing stresses between the moving layers of fluid.

Now, when the two layers of any fluid, a distance 'dy' apart, move one over another at different velocities, say u and u+du, the viscosity together with relative velocity causes a shear stress acting between the fluid layers.

~~Mutually, top and bottom layer, causes a shear stress~~



Top layer causes a shear stress on adjacent lower layer, while lower layer causes a shear stress ~~over~~ on the adjacent top layer.

Now this shear stress is proportional to the velocity gradient or rate of change of velocity with respect to y.

→ Shear stress is given by τ (Tau)

i.e: $\tau \propto \frac{du}{dy}$

or $\tau = \mu \frac{du}{dy}$ — (1)

→ μ is called as the coeff. of dynamic viscosity or only viscosity. $\frac{du}{dy}$ represents the rate of shear strain.

Now, from eqn (1), we have,

$$\mu = \frac{\tau}{\left(\frac{du}{dy}\right)}$$

Thus viscosity is also defined as the shear stress required to produce unit rate of shear strain.

Units of Viscosity :-

$$\mu = \frac{\text{shear stress}}{\left(\frac{\text{change of velocity}}{\text{change of distance}}\right)}$$

$$= \frac{(\text{Force}/\text{Area})}{\left(\frac{\text{length}}{\text{Time}}\right) \times \frac{1}{\text{Time}}} = \frac{\text{Force}/(\text{length})^2}{\frac{\text{length } 1}{(\text{Time})^2}}$$

$$= \frac{\text{Force} \times \text{Time}}{(\text{length})^2}$$

Now, in MKS, unit of

$$\text{viscosity } \mu = \frac{\text{kgf} \times \text{sec}}{(m)^2}$$

in CGS, unit of viscosity,

$$\mu = \frac{\text{dyne} \times \text{sec}}{(cm)^2} = 1 \text{ Poise},$$

in SI, unit of viscosity,

$$\mu = \frac{N \times s}{m^2} = Pa \times s$$

Now, relation between all three units,

$$\frac{\text{kgf} - \text{sec}}{m^2} = \frac{9.81 \, NS}{m^2} = 9.81 \text{ poise}.$$

∴ 1 poise can be given as,

$$= \frac{\text{dyne} - \text{sec}}{cm^2} \quad (C.GS)$$

$$= \frac{1}{9.81} \frac{\text{kgf} - \text{sec}}{cm^2} \quad (MKS)$$

$$= \frac{1}{10} \frac{N\text{-}s}{m^2} \quad (SI)$$

* The viscosity of water at 20°C is 0.01 poise

* **Kinematic Viscosity :-**

(ν) nu = $\frac{\text{Viscosity (dynamic)}}{\text{Density of Fluid}}$

$$\nu = \frac{\mu}{\rho}$$

MKS,

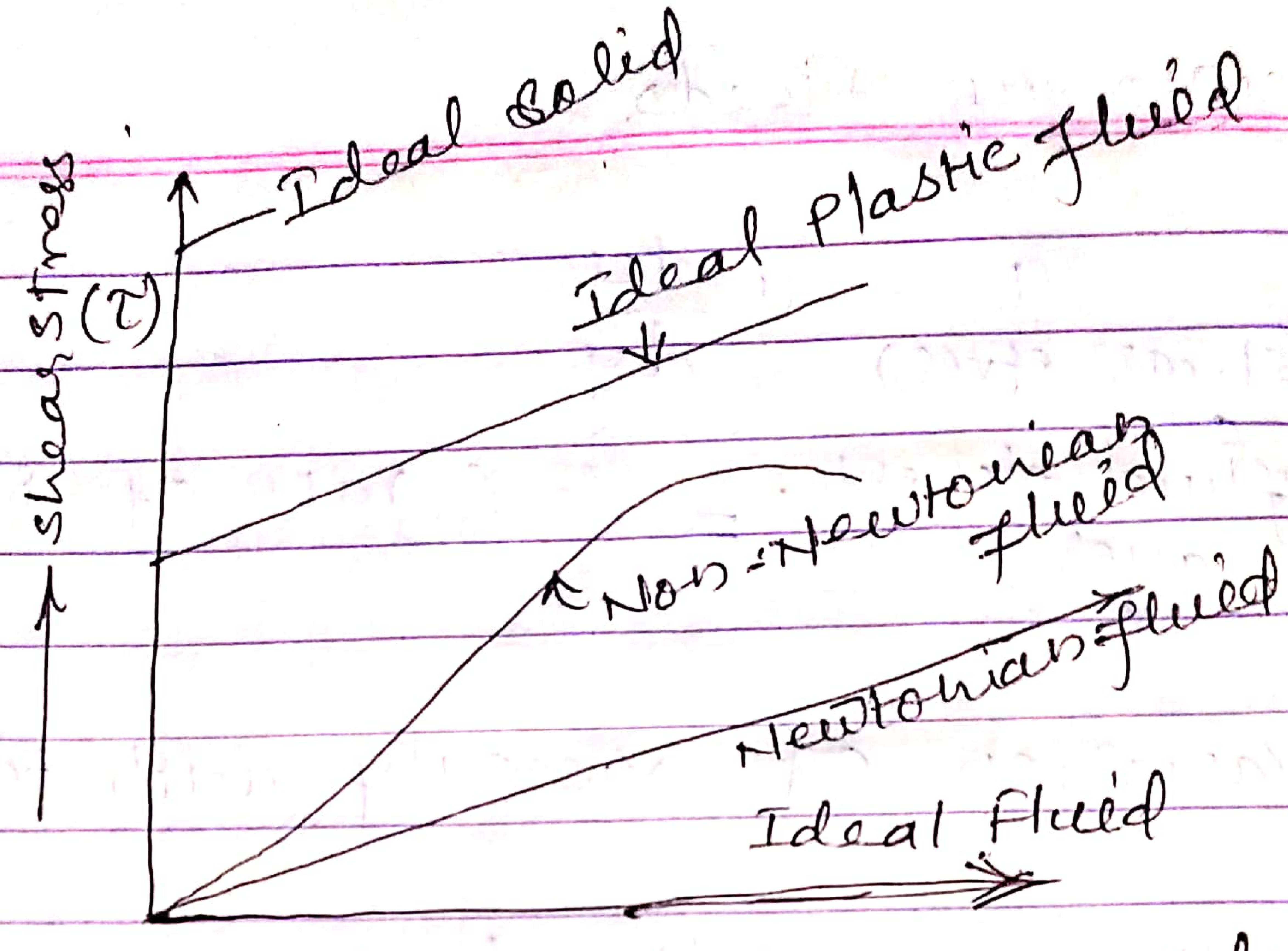
$$\nu = \frac{kgf\text{-}sec}{m^2 \times \frac{kgf}{m^3}}$$

$$= \frac{kgf\text{-}sec \times m}{kg}$$

$$= \frac{kg \times \frac{m}{s^2} \times sec \times m}{kg}$$

$$= m^2/s$$

CGS = cm^2/s , (= stoke)



→ velocity Gradient ($\frac{du}{dy}$)

* Types of Fluids:-

(1) Ideal fluid :- Incompressible, No viscosity

(2) Real fluid :- Having viscosity.

(3) Newtonian :- Shear stress ∝ rate of shear strain.

(4) Non-Newtonian :- not ∝

(5) Ideal-Plastic fluid :-

A Fluid in which, shear stress is more than the yield value and shear stress is proportional to the shear strain.

* Types of Fluids :-

* Newtonian Fluid :-

Ex :- Air, water, alchohol, Kerosene, Glycerine & all gases.

* Non Newtonian fluid (Rheological fluid) :-

→ Not follow Newton's viscosity equation. Such fluids are relatively uncommon e.g. Printer ink, blood, mud, slurries, polymer solution, etc

Non-Newtonian Fluids $[\tau \neq \mu \frac{du}{dy}]$

Purely-Viscous fluids		Visco-elastic fluids
Time Independent	Time - dependent	
1. Pseudoplastic fluids → common → viscosity decreases with increasing velocity gradient. ex:- Polymer soln. blood, gums, slurries, milk. → Also called shear thinning fluids → $\tau = \mu (\frac{du}{dy})^n ; n < 1$ n = flow behaviour index.	1. Thixotropic $\tau = \mu (\frac{du}{dy})^n + f(t)$ f(t) is decreasing → for which the dynamic viscosity decreases with the time for which shearing forces are applied. → Printer ink, crude oil, lipstick.	$\tau = \mu \frac{du}{dy} + \alpha E$ Ex :- liquid solid combination in pipe flow. egg white. Some fluids have elastic properties which allows them to spring back when shear force is released.
2. Dilatant (shear thickening) → Viscosity increases with increasing velocity gradient	2. Rheopectic fluids $\tau = \mu (\frac{du}{dy})^n + f(t)$	

→ Suspension of starch and sand; butter, sugar

$\tau = \mu\left(\frac{du}{dy}\right)^n ; n > 1$

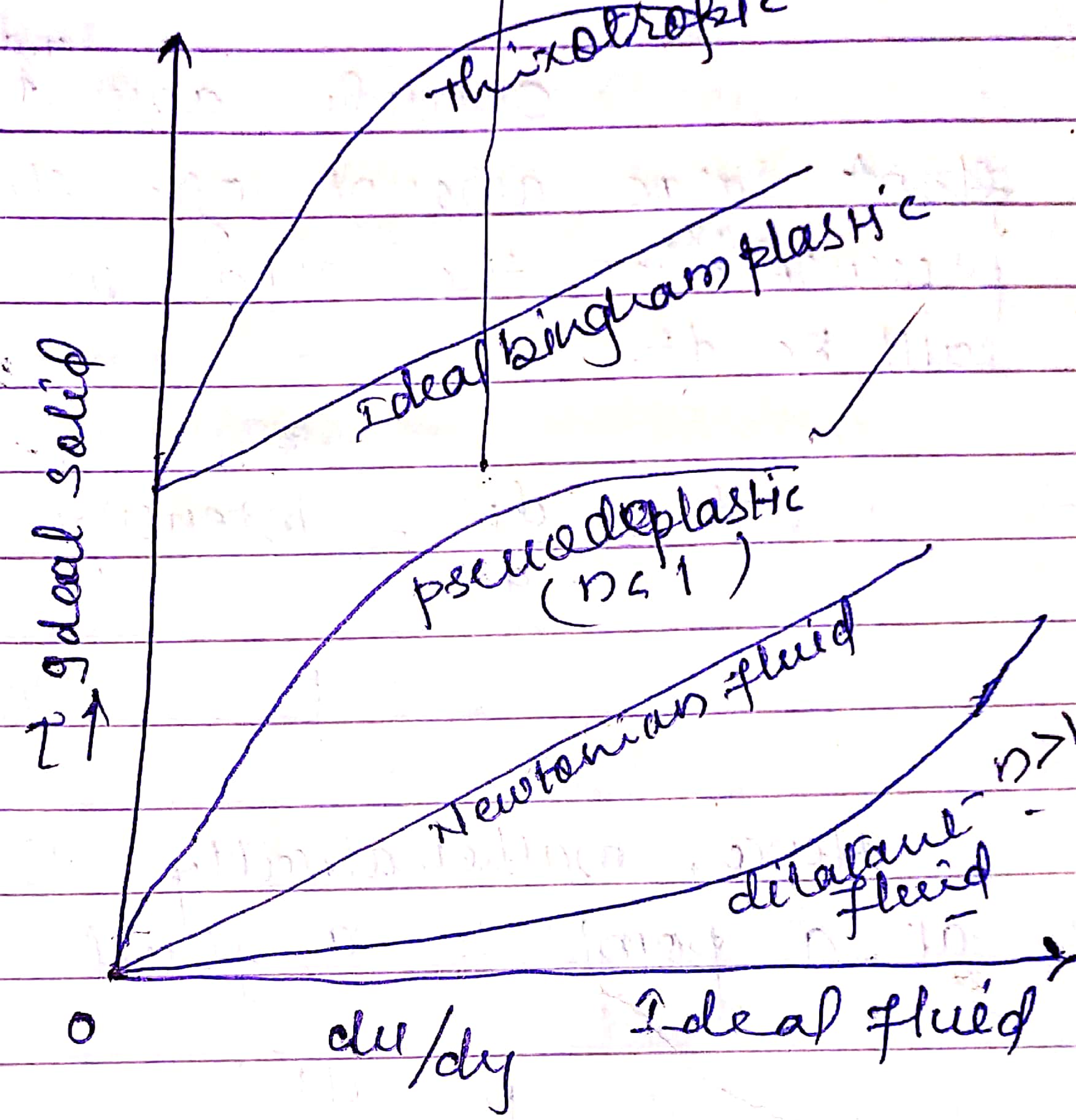
ex:- Gypsum suspension in water.

3. Bingham or Ideal plastic

→ Possesses a definite yield stress but after that relation is linear -

$\tau = \tau_y + \mu\left(\frac{du}{dy}\right)$

→ ex - water suspension of clay & flyash, oil paint, jellies, apple sauce,



η = Apparent viscosity

$= \left(\frac{du}{dy}\right)^{n-1}$

which is defined as the slopes,

Pressure & Its measurement

* Fluid Pressure at a point :-

Consider any small area 'dA' in the ~~fluid~~ large amount of fluid, so the pressure force on the area in normal direction will be dF.

Then $\frac{dF}{dA}$ = intensity of pressure

$= p$

Hence, mathematically the pressure at a point in a fluid at rest is

$$p = \frac{dF}{dA}$$

If the force is uniformly distributed over the area A and pressure at any point will be given by

$$p = \frac{F}{A}$$

Units	MKS	SI	
	kgf/m^2 or kgf/cm^2	N/m^2 & N/mm^2	one Pascal Pa = $1000 N/m^2$ and 1 bar = $10^5 N/m^2$

* Pascal's law :-

It states that the pressure or intensity of pressure at a point in a static fluid will be same in all direction.

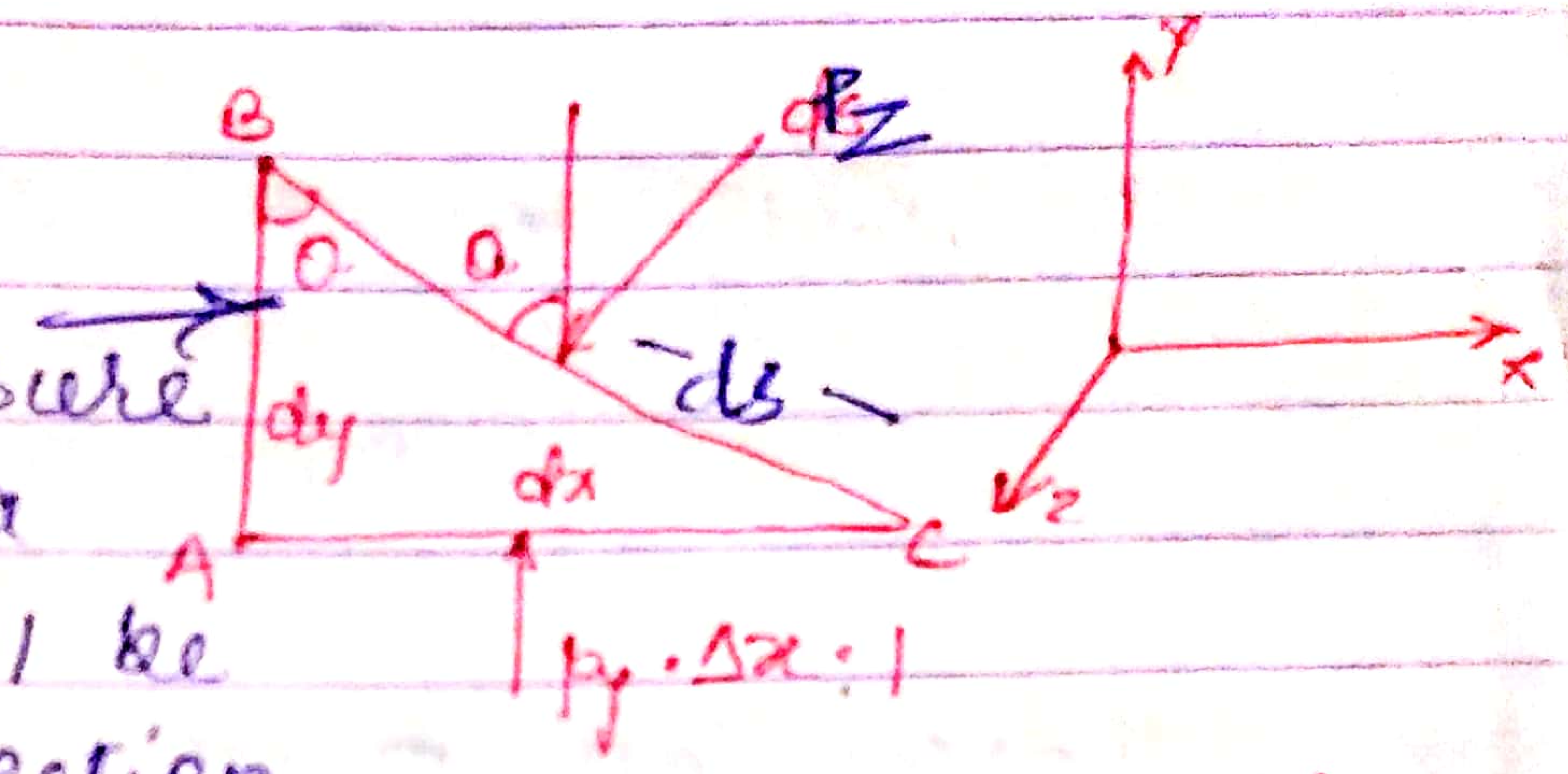


fig :- forces on fluid element.

Proof :- The fluid element is of very small dimension dx, dy & ds

Consider any fluid element of wedge shape in a fluid mass at rest.
Let the width of the element perpendicular to the plane of paper is unity and p_x, p_y & p_z are the pressures or intensity of pressure acting on the face AB, AC & BC respectively.
Let ∠ABC = θ.
Then the forces acting on the element are:

(1) pressure force normal to the surface.
(2) weight on the element in the vertical direction.

The forces on the faces are:

Force on face AB

$$= p_x \times \text{Area of face AB}$$

$$= p_x \times dy \times 1$$

Similarly forces on the face AC

$$= p_y \times dx \times 1$$

Force on BC

$$= p_z \times ds \times 1$$

∴ weight of element

$$= (\text{mass of element}) \times g$$

$$= (\text{Volume} \times \rho) \times g$$

$$= \left(\frac{AB \times AC}{2} \times 1\right) \times \rho \times g$$

where, ρ = density of fluid

Resolving the forces in x - direction, we have,

$$p_x \times dy \times 1 - p_z (ds \times 1) \sin(90 - \theta) = 0$$

or

$$p_x \times dy \times 1 - p_z (ds \times 1) \cos\theta = 0$$

Now, from fig.

$$AB = dy = ds\cos\theta$$

$$\therefore \quad p_x \times dy \times 1 - p_z \times dy \times 1 = 0$$

$$\therefore \quad p_x = p_z \qquad -(1)$$

Similarly, resolving the forces in y-direction, we get

$$p_y \times dx \times 1 - p_z \times ds \times 1 \cos(90-\theta) - \frac{dx \times dy}{2} \times 1 \times \rho \times g = 0 \qquad -(3)$$

$$\text{or,} \quad p_y \times dx - p_z\, ds \sin\theta - \frac{dx\,dy}{2} \times \rho \times g = 0$$

but, $dx = ds \sin\theta$

and also the element is very small and hence weight is negligible,

$$\therefore \quad p_y\,dx - p_z \times dx = 0$$

$$\text{or} \quad p_y = p_z \qquad -(2)$$

(1) & (2) gives

$$p_x = p_y = p_z$$

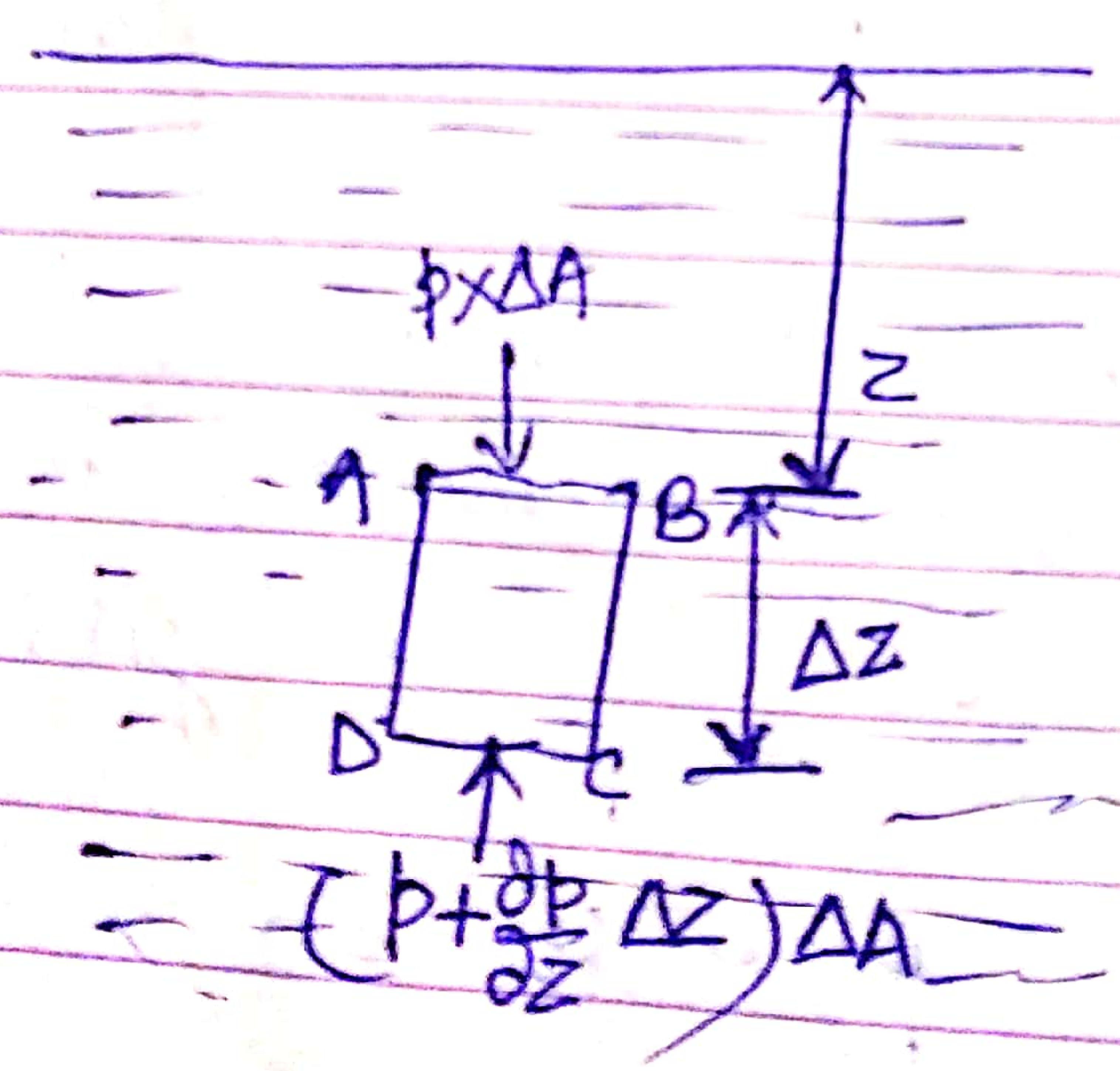
So, pressure at a point is equal in all direction

Since, the choice of fluid element was completely arbitrary, which means the pressure at any point is the same in all direction.

* Pressure Variation in fluid at rest

According to hydrostatics law which states that "rate of increase of pressure in a vertically downward direction must be equal to the specific weight of the fluid at that point."

The pressure at any point in a fluid at rest is obtained by this law.



Let, ΔA = cross-sectional area of element

Δz = Height

p = pressure on face AB

z = distance of fluid element from free surface

The force acting on the fluid elements are.

- pressure force on AB $= p \times \Delta A$ and acting perpendicular to face AB in downward direction

- pressure force on CD

$$= \left(p + \frac{\partial p}{\partial z}\Delta z\right) \times \Delta A$$, acting perpendicular to face CD, vertically upward direction.

- weight of fluid element

$$= \text{Density} \times g \times \text{volume}$$

$$= \rho \times g \times (\Delta A \times \Delta z)$$

- Pressure forces on surface BC & AD are equal and opposite.

Now, for equilibrium of fluid element we have.

$$p\Delta A - \left(p + \frac{\partial p}{\partial z}\Delta Z\right)\Delta A + \rho \times g \times (\Delta A \Delta Z) = 0$$

or $$-\frac{\partial p}{\partial z}\Delta Z \Delta A + \rho \times g \times \Delta A \Delta Z = 0$$

or $$\frac{\partial p}{\partial z}\Delta Z \Delta A = \rho \times g \times \Delta A \Delta Z$$

$$\therefore \boxed{\frac{\partial p}{\partial z} = \rho \times g = \omega} \quad \text{— (1)}$$

where, ω = weight density of fluid.

Above eqn gives Hydrostatic law

Integrating eqn for fluid

$$\int dp = \int \rho g z$$

or $$\boxed{p = \rho g z} \quad \text{— (2)}$$

where, p = pressure above atmos. pressure & z = Height of the point from free surfaces.

from (2) we have,

$$\boxed{z = \frac{p}{\rho \times g}}$$

z = ...

* Euler's Equation of Motion:-

In Euler's equation of motion only two forces, pressure force & the fluid weight or in general the body force, are assumed to be acting on the mass of fluid in motion.

Consider a stream line along which flow is taking place in S-direction. Consider a cylindrical fluid element of c.s. dA and length ds.

The forces acting on the cylindrical element are -

① $p\,dA$ in the direction of flow.

② $\left(p + \frac{\partial p}{\partial s} ds\right) dA$ opposite to direction of flow.

③ weight of the element $\rho g\, dA\, ds$.

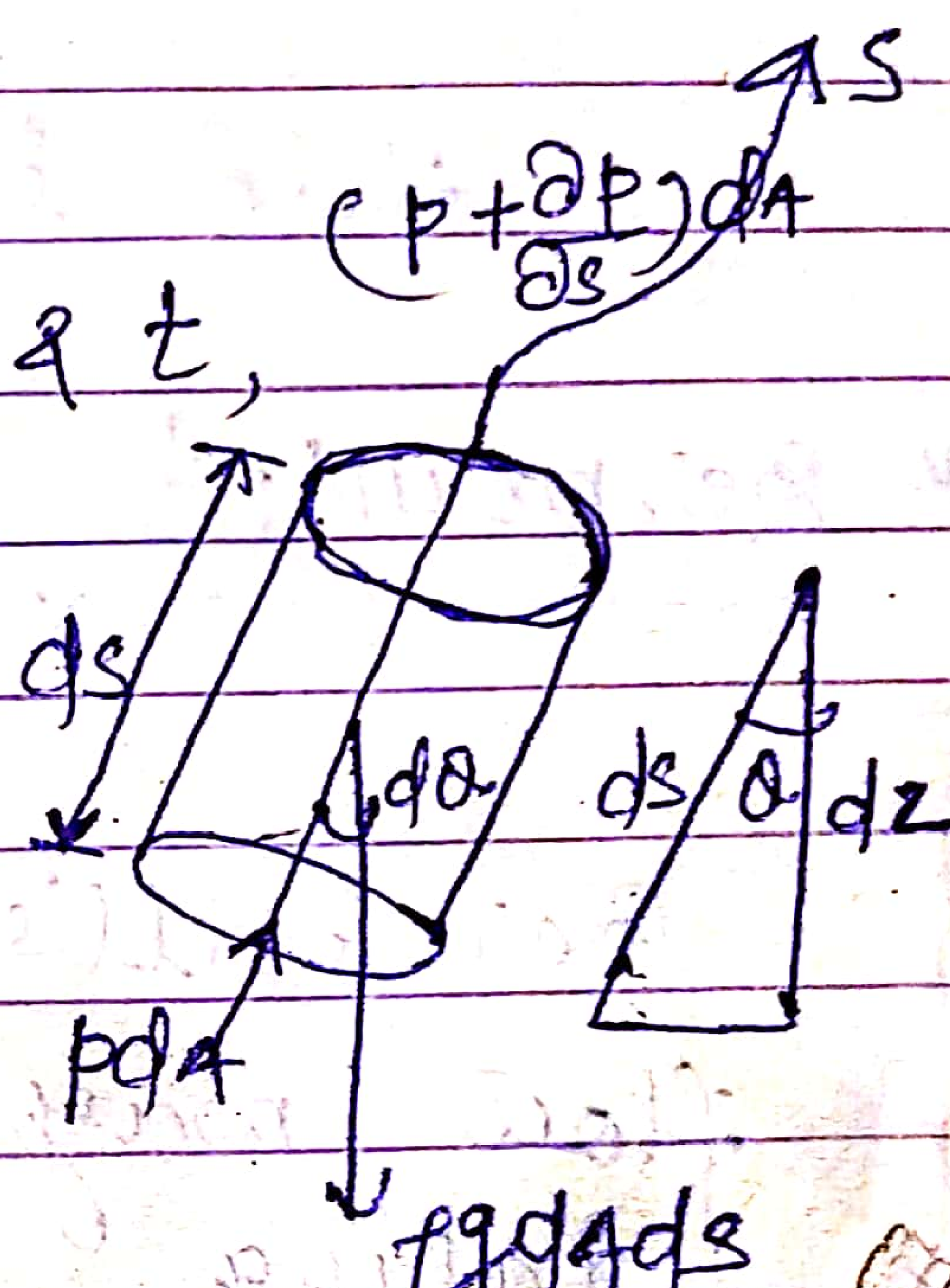
let θ, being the angle between the direction of flow, and the line of action of weight of the element.

Now, the resultant force on the fluid element in the direction of S, must be equal to the mass of of the fluid element × acc. in s-direct-

$$p\,dA - \left(p + \frac{\partial p}{\partial s} ds\right) dA - \rho g\, dA\, ds \cos\theta$$

$$= \rho\, dA\, ds \times a_s \qquad \text{— (1)}$$

∵ $a_s = \frac{dv}{dt}$



where, v is fn of s & t,

$$= \frac{\partial v}{\partial s} \frac{ds}{dt} + \frac{\partial v}{\partial t} \qquad \left(\frac{ds}{dt} = v\right)$$

$$= v\frac{\partial v}{\partial s} + \frac{\partial v}{\partial t}$$

if flow is steady, $\frac{\partial v}{\partial t} = 0$

∴ $a_s = v\frac{\partial v}{\partial s}$

So, from eqn (1), we have,

$$p\,dA - \frac{\partial p}{\rho\,\partial s} ds\, dA - \rho g\, dA\, ds \cos\theta = \rho\, dA\, ds \times v\frac{\partial v}{\partial s}$$

$$-\frac{\partial p}{\rho\,\partial s} - g\cos\theta = v\frac{\partial v}{\partial s}$$

or $$\frac{\partial p}{\rho\,\partial s} + g\cos\theta + v\frac{\partial v}{\partial s} = 0$$

from fig. we also have,

$$\cos\theta = \frac{dz}{ds}$$

~~$\frac{\partial p}{\partial s} + \rho g \frac{dz}{ds} + \rho v \frac{\partial v}{\partial s} = 0$~~

Or $\frac{1}{\rho}\frac{\partial p}{\partial s} + g\frac{dz}{ds} + \frac{v \partial v}{\partial s} = 0$

Force/unit mass caused by press. distri. — Force due to grav. pull — measure of convective acc.

or $\frac{\partial p}{\rho} + g\,dz + v\,\partial v = 0$

this is the Euler's eqn of motion.

* Bernoulli's Equation of flow :-

Bernoulli's equation for fluid flow may be obtained by integrating the Euler's equation of motion.

$$\int \frac{\partial p}{\rho} + \int g\,dz + \int v\,dv = \text{constant}$$

or $\frac{p}{\rho} + gz + \frac{v^2}{2} = \text{constant}$

or $\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$

$\frac{P}{\rho g}$ = pressure energy / unit weight
pressure head. (3)

$\frac{v^2}{2g}$ = kinetic energy / unit weight
or kinetic head

z = potential energy / unit weight
or potential head. (4)

Statement :-

In steady, ideal flow, of an incompressible fluid, the total energy of the fluid is always constant.

Assumptions :-

1. Fluid should be incompressible
2. Flow should be steady.
3. Fluid viscosity must be zero. (5)
4. Flow is irrotational.

Limitations :-

1. It is only applicable for ideal incompressible fluid.

(6)

2. The velocity of fluid particle is maximum at centre and gradually decreases towards the walls of pipe due to friction.

So only the mean velocity is taken into account.

③ **Steady flow:-** It is only applicable for steady flow, so it can't be used during the transient start up and shut down periods or during periods of change in the flow conditions.

④ **Negligible viscous effects:-**

Practically all fluids have some amount of viscosity.

Frictional effects are usually significant in long and narrow flow passages.

So, Bernoulli's eqn usually applicable along a streamline in the core region of flow not ~~along~~ along the stream line near the surface.

⑤ ~~Shaft work~~ :- **Negligible heat transfer:-**

The density of gas is inversely ∝ Temp. So, the Bernoulli's eqn should not be used for flow sections that involve significant temp. change.

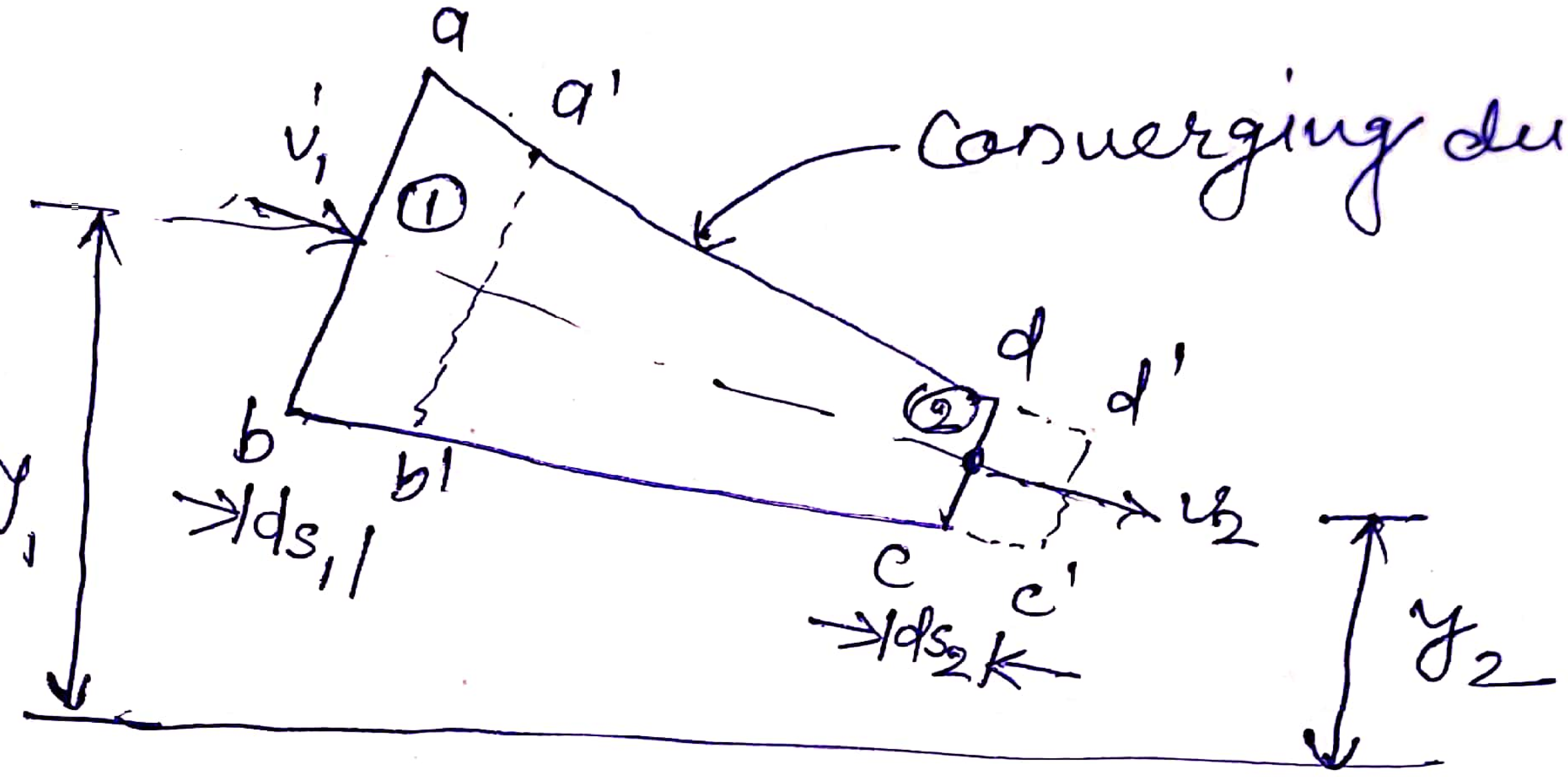
⑥ As the Bernoulli's ~~energy~~ equation is derived ~~for~~ from ~~stream tube~~ a force balance on a particle moving along a stream ~~tube~~ line.

So, it can't be apply in the region that involves a pump turbine, fan or any other m/c.

* Bernoulli's theorem :-

→ consider steady flow of incompressible liquid through a non-uniform pipe (a converging stream tube) lying entirely in the xy-plane.

→



→ The fluid mass has an area A_1, velocity v_1 & pressure p_1 at entrance. At exit A_2, v_2, p_2

→ During small interval of time mass shifts to abcd to net position a'b'c'd'

→ Energy change in the area abb'a' & cc'd'd have to be considered.

(i) considering the principle of mass conservation, applying continuity eqn.

fluid mass within the region abb'a'
= fluid mass within the region cc'd'd

$$m = \rho A_1 ds_1 = \rho A_2 ds_2$$

(ii) workdone during displacement of fluid mass from ab to a'b'

= Force × displacement

$$= p_1 A_1 ds_1$$

the displacement ds_1 is so small that any variation in fluid properties can be neglected.

The work done at exit equals

$$= -p_2 A_2 ds_2$$

This work done is in opposit direction hence negative.

Net flow work (WD by pressure)

$$= p_1 A_1 ds_1 - p_2 A_2 ds_2$$

$$= \frac{m}{\rho}(p_1 - p_2) \quad [\because A_1 ds_1 = A_2 ds_2 = \frac{m}{\rho})$$

(iii) The fluid flows downwards

So, loss of potential energy $= mg(y_1 - y_2)$

(iv) the fluid mass accelearates from velocity v_1 to v_2, so gain in KE

$$= \frac{m}{2}(v_2^2 - v_1^2)$$

From the principle of conservation of energy,

Loss of PE + WD by pressure = gain in KE

$$mg(y_1 - y_2) + \frac{m}{\rho}(p_1 - p_2) = \frac{m}{2}(v_2^2 - v_1^2)$$

Dividing by mg using $w = \rho g$ we get

$$(y_1 - y_2) + \left(\frac{p_1 - p_2}{\rho g}\right) = \frac{v_2^2 - v_1^2}{2g}$$

Re-arranging gives

$$\boxed{\frac{v^2}{2g} + \frac{p}{w} + y = \text{constant}}$$

HYDRAULIC TURBINES

Turbines are defined as the hydraulic machines which converts hydraulic energy in to mechanical energy. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of Turbine. Thus mechanical energy is converted in to electrical energy. The electric power which is obtained from the hydraulic energy is known as the Hydro-electric power.

CLASSIFICATION OF HYDRAULIC TURBINES:

The Hydraulic turbines are classified according to the type of energy available at the inlet of the turbine, direction of flow through the vanes, head at the inlet of the turbine and specific speed of the turbine. The following are the important classification of the turbines.

1. According to the type of energy at inlet:

(a) Impulse turbine and

(b) Reaction turbine

2. According to the direction of flow through the runner:

(a) Tangential flow turbine

(b) Radial flow turbine.

(c) Axial flow turbine

(d) Mixed flow turbine.

3. According to the head at inlet of the turbine:

(a) High head turbine

(b) Medium head turbine and

(c) Low head turbines.

4. According to the specific speed of the turbine:

(a) Low specific speed turbine

(b) Medium specific speed turbine

(c) High specific speed turbine.

If at the inlet of turbine, the energy available is only kinetic energy, the turbine is known as **Impulse turbine**. As the water flows over the vanes, the pressure is atmospheric from inlet to outlet of the turbine. If at the inlet of the turbine, the water possesses kinetic energy as well as pressure energy, the turbine is known as **Reaction turbine**. As the water flows through runner, the water is under pressure and the pressure energy goes on changing in to kinetic energy. The runner is completely enclosed in an air-tight casing and the runner and casing is completely full of water.

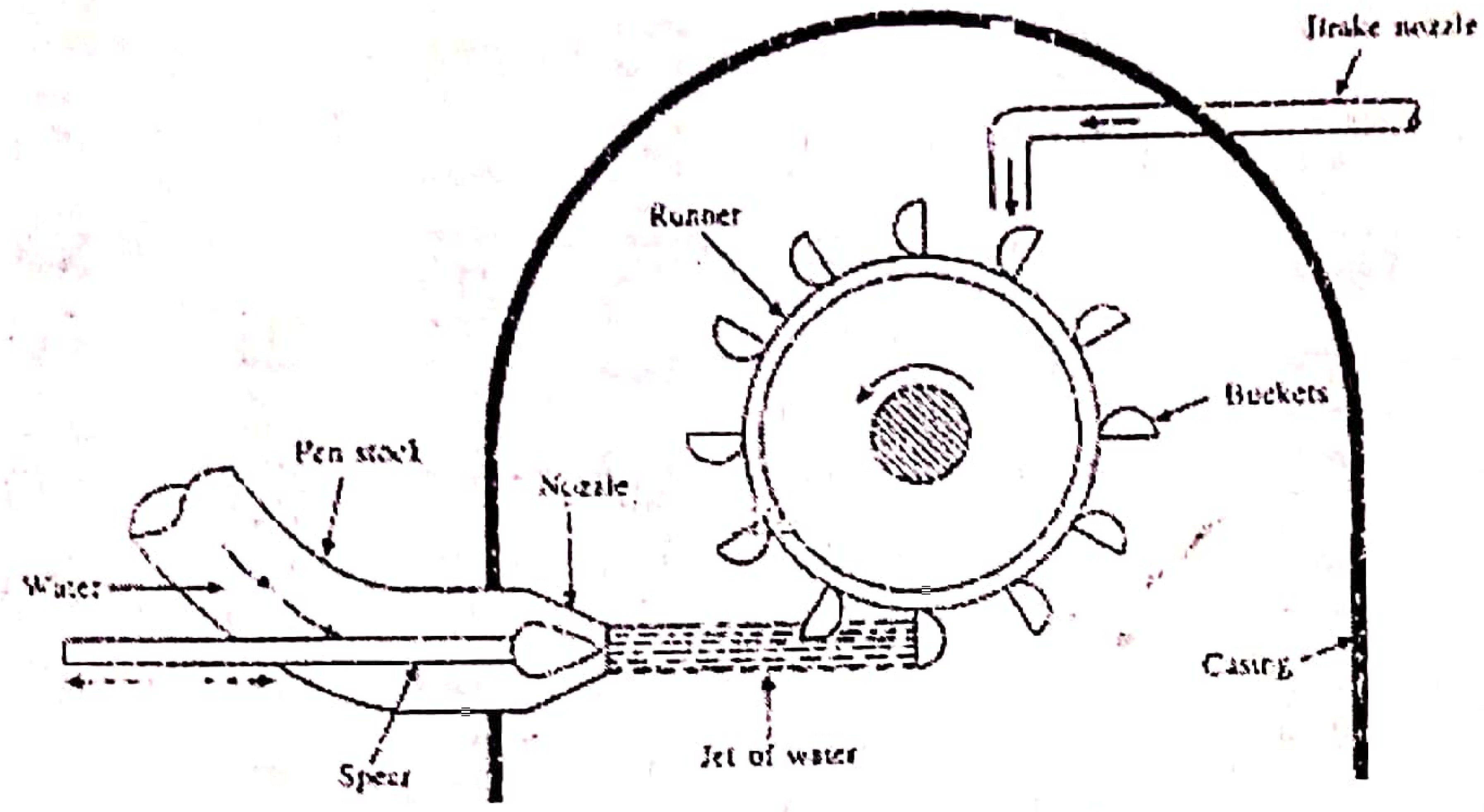
If the water flows along the tangent of runner, the turbine is known as **Tangential flow turbine**. If the water flows in the radial direction through the runner, the turbine is called **Radial flow turbine.** If the water flows from outward to inwards radially, the turbine is known as **Inward** radial flow turbine, on the other hand, if the water flows radially from inward to outwards, the turbine is known as **outward** radial flow turbine. If the water flows through the runner along the direction parallel to the axis of rotation of the runner, the turbine is called **axial flow** turbine. If the water flows through the runner in the radial direction but leaves in the direction parallel to the axis of rotation of the runner, the turbine is called **mixed flow** turbine.

PELTON WHEEL (Turbine)

It is a tangential flow impulse turbine. The water strikes the bucket along the tangent of the runner. The energy available at the inlet of the turbine is only kinetic energy. The pressure at the inlet and out let of turbine is atmospheric. This turbine is used for high heads and is named after L.A.Pelton an American engineer.

The water from the reservoir flows through the penstocks at the out let of which a nozzle is fitted. The nozzle increases the kinetic energy of the water flowing through the penstock. At the outlet of the nozzle, the water comes out in the form of a jet and strikes the buckets (vanes) of the runner. The main parts of the Pelton turbine are:

1. Nozzle and flow regulating arrangement (spear)
2. Runner and Buckets.
3. Casing and
4. Breaking jet



1. **Nozzle and flow regulating arrangement:** The amount of water striking the buckets (vanes) of the runner is controlled by providing a spear in the nozzle. The spear is a conical needle which is operated either by hand wheel or automatically in an axial direction depending upon the size of the unit. When the spear is pushed forward in to the nozzle, the amount of water striking the runner is reduced. On the other hand, if the spear is pushed back, the amount of water striking the runner increases.

2. **Runner with buckets:** It consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed. The shape of the buckets is of a double hemispherical cup or bowl. Each bucket is divided in to two symmetrical parts by a dividing wall, which is known as splitter.

The jet of water strikes on the splitter. The splitter divides the jet in to two equal parts and the jet comes out at the outer edge of the bucket. The buckets are shaped in such a way that the jet gets deflected through an angle of 160 or 170 . The buckets are made of cast Iron, cast steel, Bronze or stainless steel depending upon the head at the inlet of the turbine.

3. **Casing:** The function of casing is to prevent the splashing of the water and to discharge the water to tailrace. It also acts as safeguard against accidents. It is made of Cast Iron or fabricated steel plates. The casing of the Pelton wheel does not perform any hydraulic function.

4. **Breaking jet:** When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero. But the runner due to inertia goes on revolving for a long time. To stop the runner in a short time, a small nozzle is provided, which directs the jet of water on the back of the vanes. This jet of water is called Breaking jet.

Working Principle

The working principle is water is coming from the storage reservoir through a penstock to the Inlet of the nozzle which is the inlet of the turbine so the hydraulic energy of the water is mainly converted into kinetic energy. The water releases in the form of a jet from the nozzle and strikes on the vanes for a very small time duration. Since a very high force is exerted on the vanes by the jet of water for a very small time duration so these turbines are known as Impulse turbines.

Bucket changes the direction of run/flow of water jet and momentum transfer takes place.

RADIAL FLOW REACTION TURBINE

In the Radial flow turbines water flows in the radial direction. The water may flow radially from outwards to inwards (i.e. towards the axis of rotation) or from inwards to outwards. If the water flows from outwards to inwards through the runner, the turbine is known as inwards radial flow turbine. And if the water flows from inwards to outwards, the turbine is known as outward radial flow turbine.

Reaction turbine means that the water at the inlet of the turbine possesses kinetic energy as well as pressure energy. As the water flows through the runner, a part of pressure energy goes on charging into kinetic energy. Thus the water through the runner is under pressure. The runner is completely enclosed in an air-tight casing and the runner is always full of water.

Main parts of a Radial flow Reaction turbine:

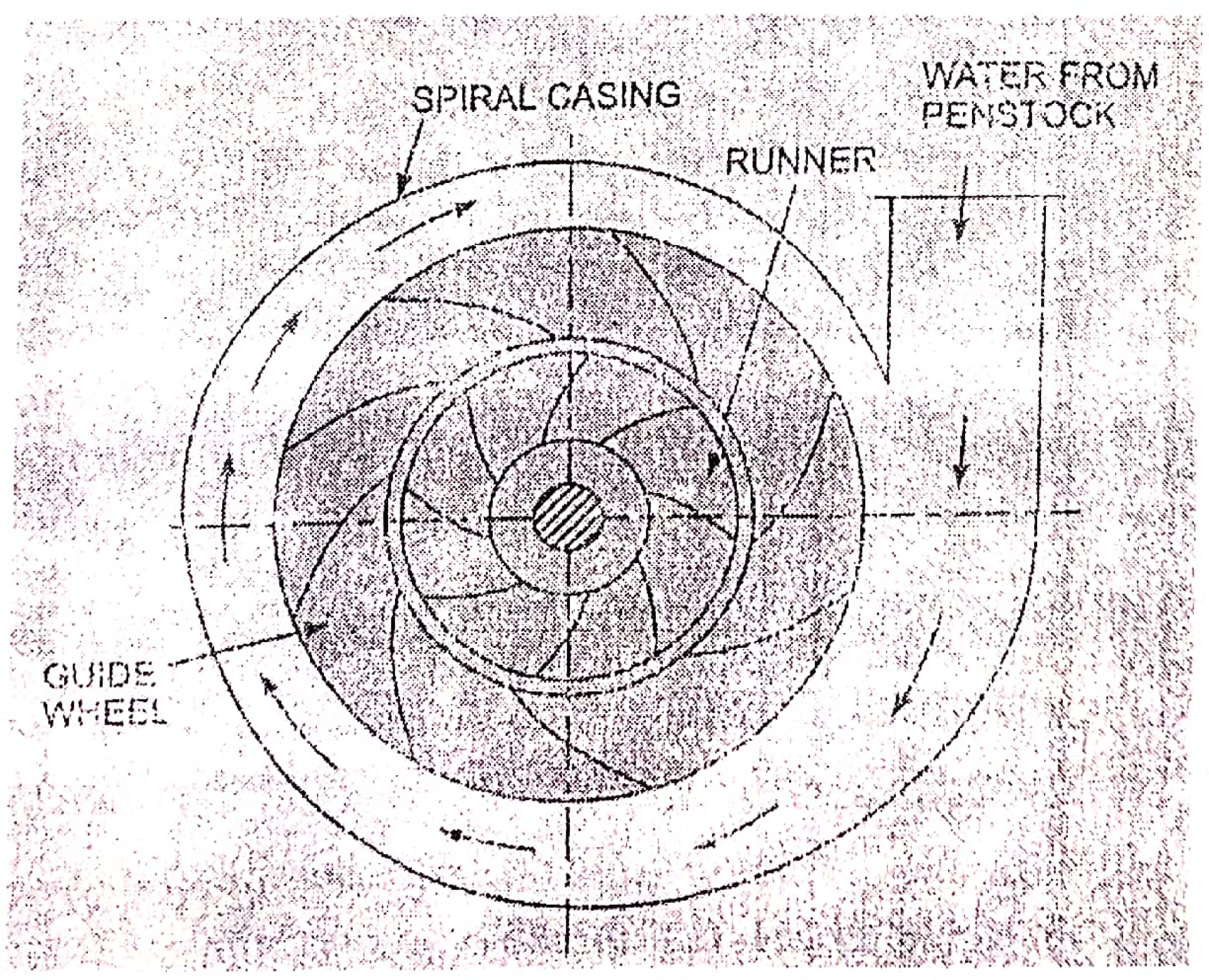
1. Casing
2. Guide mechanism
3. Runner and
4. Draft tube.

1. Casing: in case of reaction turbine, casing and runner are always full of water. The water from the penstocks enters the casing which is of spiral shape in which area of cross-section one of the casing goes on decreasing gradually. The casing completely surrounds the runner of the turbine. The water enters the runner at constant velocity throughout the circumference of the runner.

2. Guide Mechanism: It consists of a stationary circular wheel all around the runner of the turbine. The stationary guide vanes are fixed on the guide mechanism. The guide vanes allow the water to strike the vanes fixed on the runner without shock at inlet. Also by suitable arrangement, the width between two adjacent vanes of guide mechanism can be altered so that the amount of water striking the runner can be varied.

3. Runner: It is a circular wheel on which a series of radial curved vanes are fixed. The surfaces of the vanes are made very smooth. The radial curved vanes are so shaped that the water enters and leaves the runner without shock. The runners are made of cast steel, cast iron or stain less steel. They are keyed to the shaft.

4. Draft - Tube: The pressure at the exit of the runner of a reaction turbine is generally less than atmospheric pressure. The water at exit can't be directly discharged to the tail race. A tube or pipe of gradually increasing area is used for discharging the water from the exit of the turbine to the tail race. This tube of increasing area is called draft-tube.



Inward Radial Flow Turbine: In the inward radial flow turbine, in which case the water from the casing enters the stationary guiding wheel. The guiding wheel consists of guide vanes which direct the water to enter the runner which consists of moving vanes. The water flows over the moving vanes in the inward radial direction and is discharged at the inner diameter of the runner. The outer diameter of the runner is the inlet and the inner diameter is the outlet.

Time: 2:30 H

The important types of axial flow reaction turbines are:

1. Propeller Turbine

2. Kaplan Turbine

When the vanes are fixed to the hub and they are not adjustable the turbine is known as propeller turbine. But if the vanes on the hub are adjustable, the turbine is known as Kaplan turbine. This turbine is suitable, where large quantity of water at low heads is available.

The main parts of the Kaplan turbine are:

1. Scroll casing

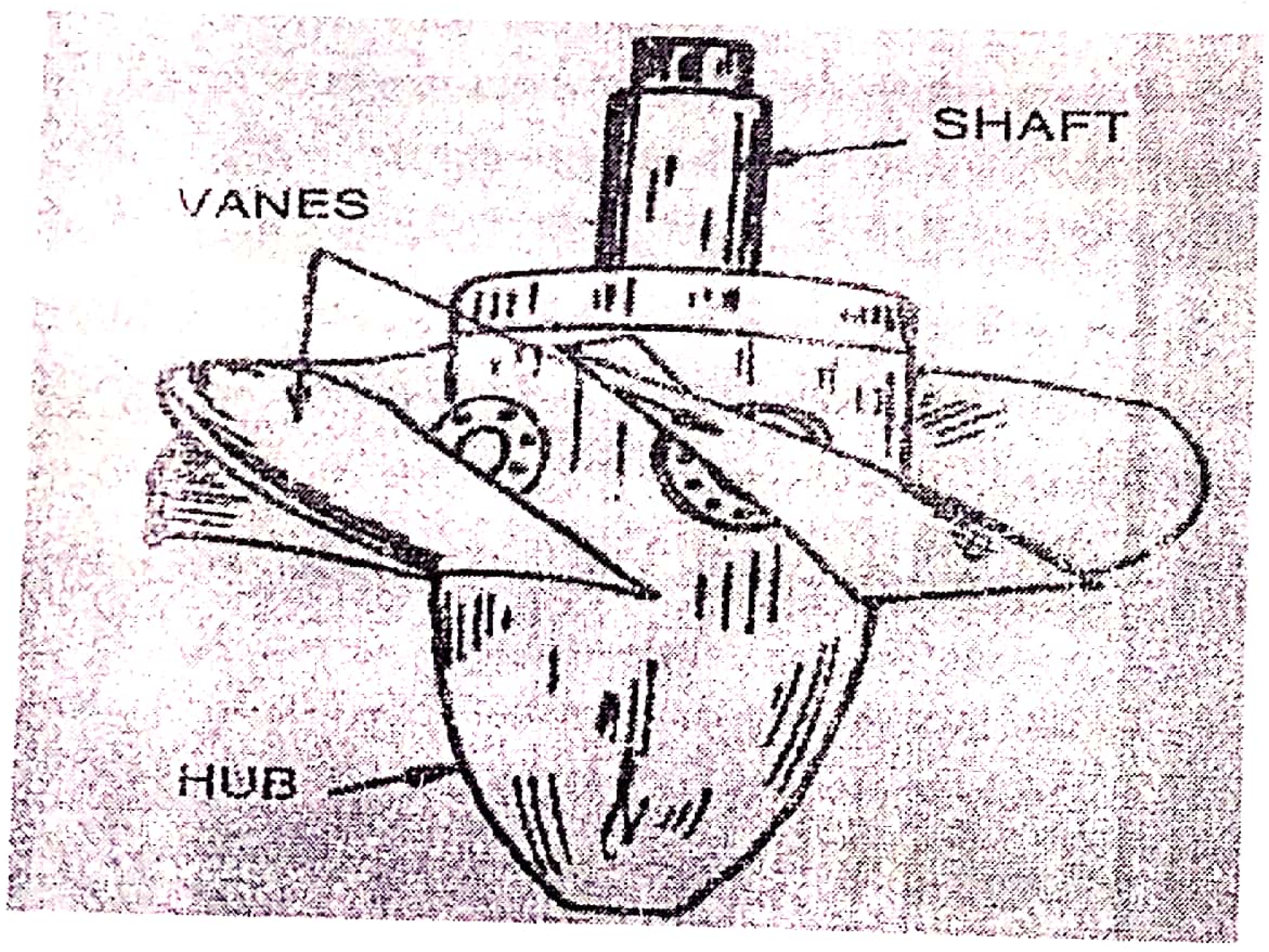
2. Guide vanes mechanism

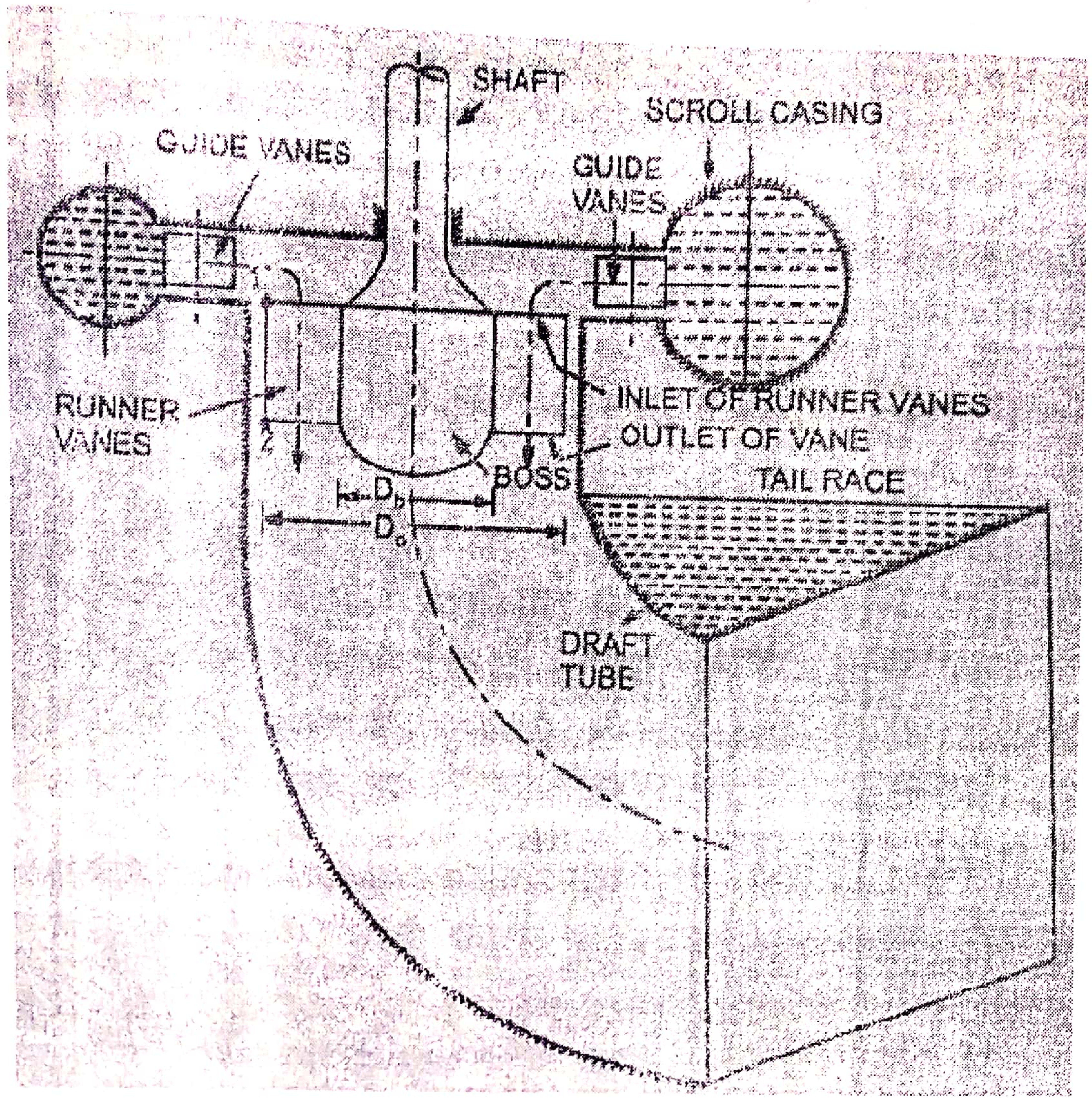
3. Hub with vanes or runner of the turbine

4. Draft tube

Between the guide vanes and the runner the water in the Kaplan turbine turns through a right angle in to the axial angle direction and then posses through the runner. The runner of the Kaplan turbine has four or six or eight in some cases blades and it closely resembles a ships propeller. The blades (vanes) attached to a hub or bosses are so shaped that water flows axially through the runner.

The runner blades of a propeller turbine are fixed but the Kaplan turbine runner heads can be turned about their own axis, so that their angle of inclination may be adjusted while the turbine is in motion. The adjustment of the runner blades in usually carried out automatically by means of a servomotor operating inside the hollow coupling of turbine and generator shaft.

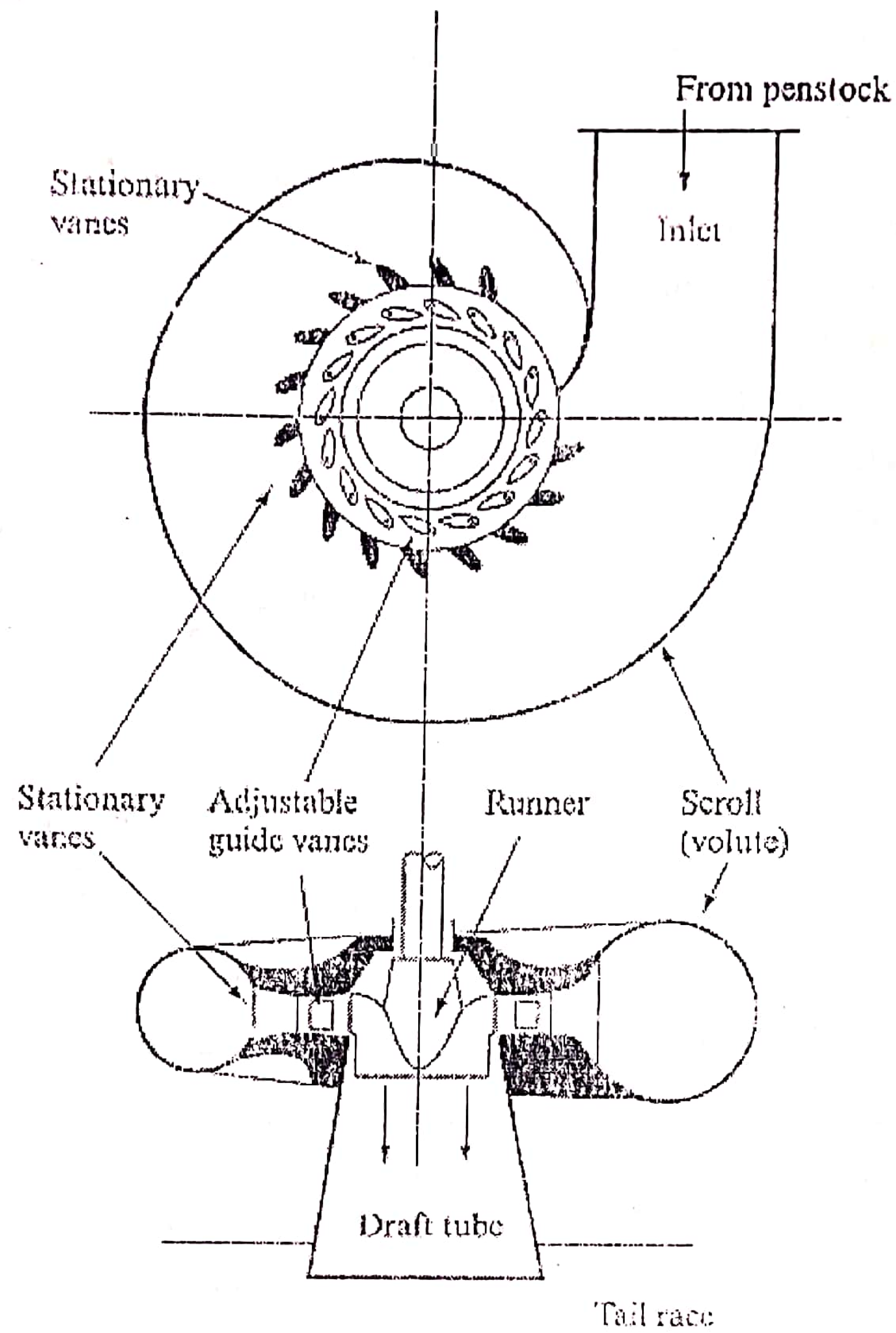




When both guide vane angle and runner blade angle may thus be varied a high efficiency can be maintained over a wide range of operating conditions. i.e. even at part load, when a lower discharge is following through the runner a high efficiency can be attained in case of Kaplan turbine. The flow through turbine runner does not affect the shape of velocity triangles as blade angles are simultaneously adjusted, the water under all the working conditions flows through the runner blades without shock. The eddy losses which are inevitable in Francis and propeller turbines are completely eliminated in a Kaplan Turbine.

FRANCIS TURBINE:

The inward flow reaction turbine having radial discharge at outlet is known as Francis Turbine. The water enters the runner of the turbine in the radial direction at outlet and leaves in the axial direction at the inlet of the runner. Thus the Francis turbine is a mixed flow type turbine.



Working principles of Francis turbine

- The water is admitted to the runner through guide vanes or wicket gates. The opening between the vanes can be adjusted to vary the quantity of water admitted to the turbine. This is done to suit the load conditions.
- The water enters the runner with a low velocity but with a considerable pressure. As the water flows over the vanes the pressure head is gradually converted into velocity head.
- This kinetic energy is utilized in rotating the wheel Thus the hydraulic energy is converted into mechanical energy.
- The outgoing water enters the tailrace after passing through the draft tube. The draft tube enlarges gradually and the enlarged end is submerged deeply in the tailrace water.
- Due to this arrangement a suction head is created at the exit of the runner.

AXIAL FLOW REACTION TURBINE:

If the water flows parallel to the axis of the rotation shaft the turbine is known as axial flow turbine. If the head at inlet of the turbine is the sum of pressure energy and kinetic energy and during the flow of the water through the runner a part of pressure energy in converted in to kinetic energy, the turbine is known as reaction turbine.

For axial flow reaction turbine, the shaft of the turbine is vertical. The lower end of the shaft is made longer known as "hub" or "boss". The vanes are fixed on the hub and acts as a runner

Centrifugal Pump

Hydraulic machine that converts mechanical energy into hydraulic energy (pressure energy) called pump.

If this conversion takes place due to centrifugal force acting on the pump called centrifugal pump.

→ Reverse action of inward flow reaction turbine.
→ Works on the principle of forced vortex.
→ Rise in pressure head $= \frac{V^2}{2g} = \frac{\omega^2 r^2}{2g}$
→ So, for a high pressure, radius should be large.

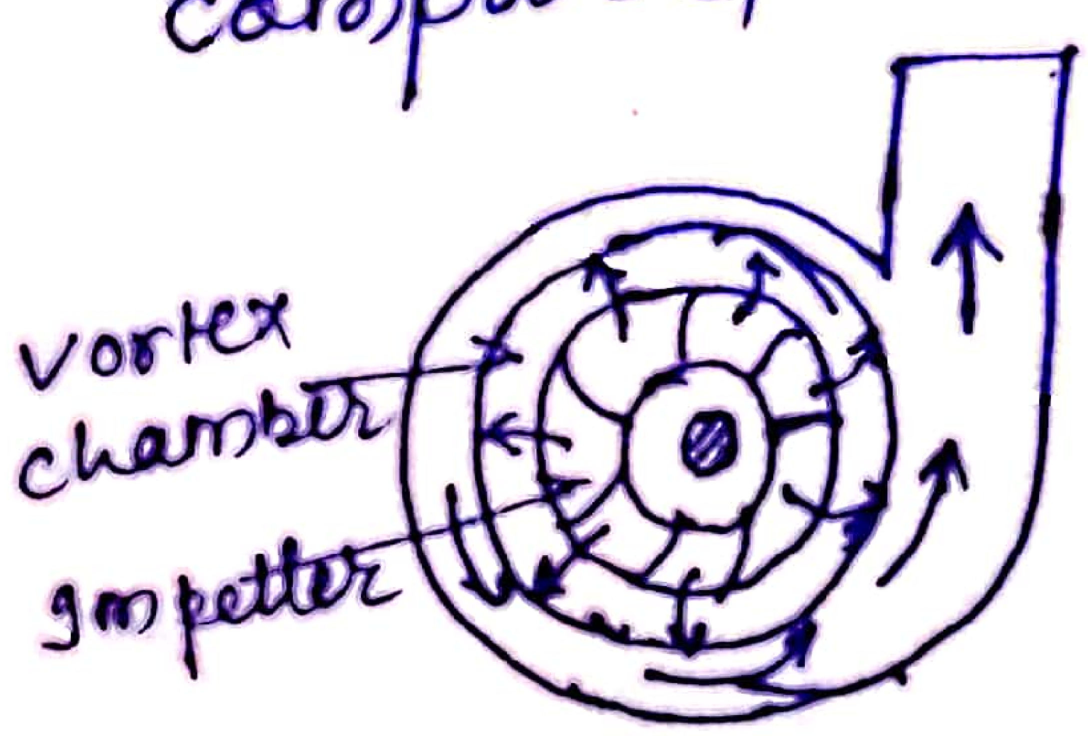
* **Parts :-**

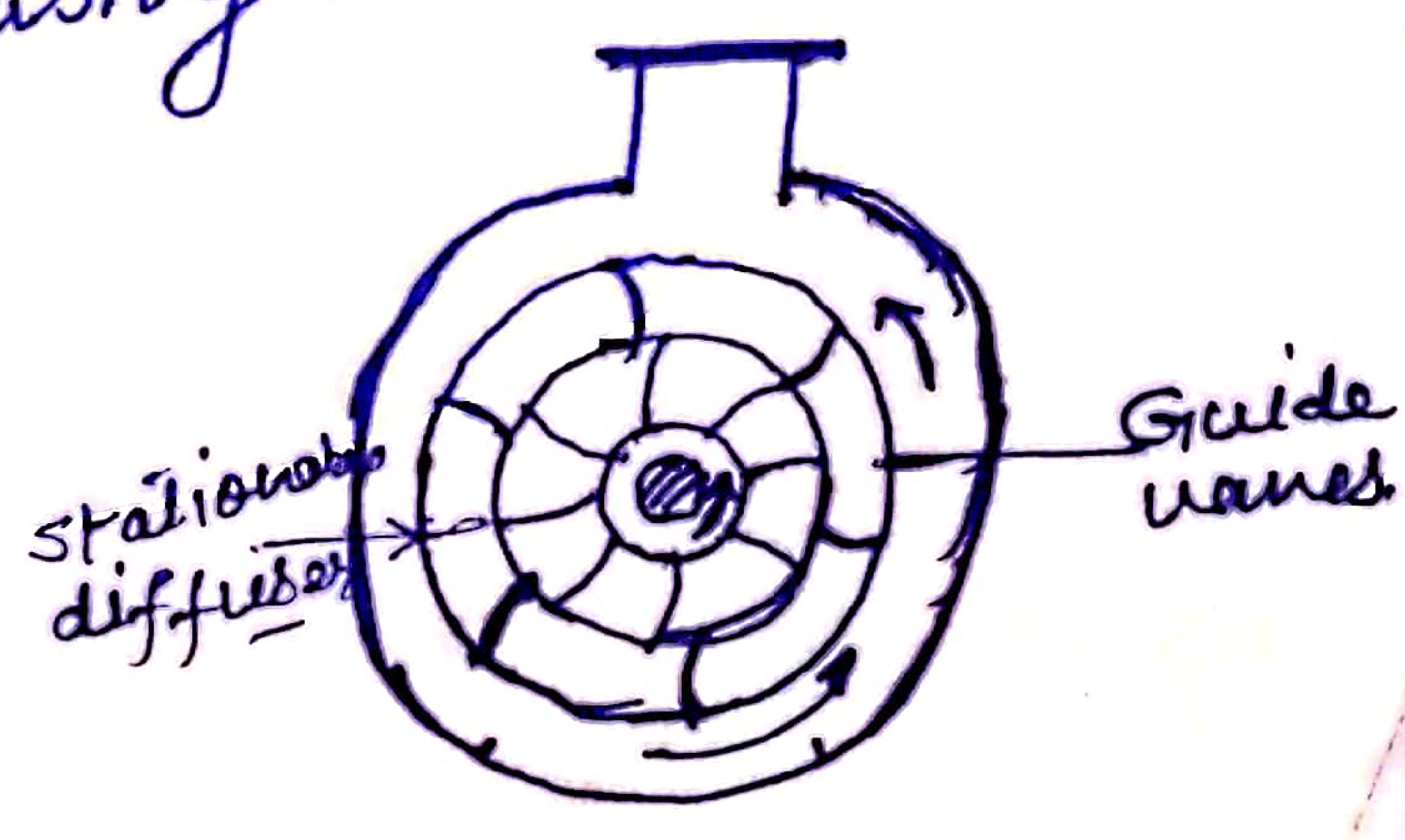
Impeller :- The rotating part consist of backward vanes. Its shaft is connected to motor. (vanes varies 6 - 12)

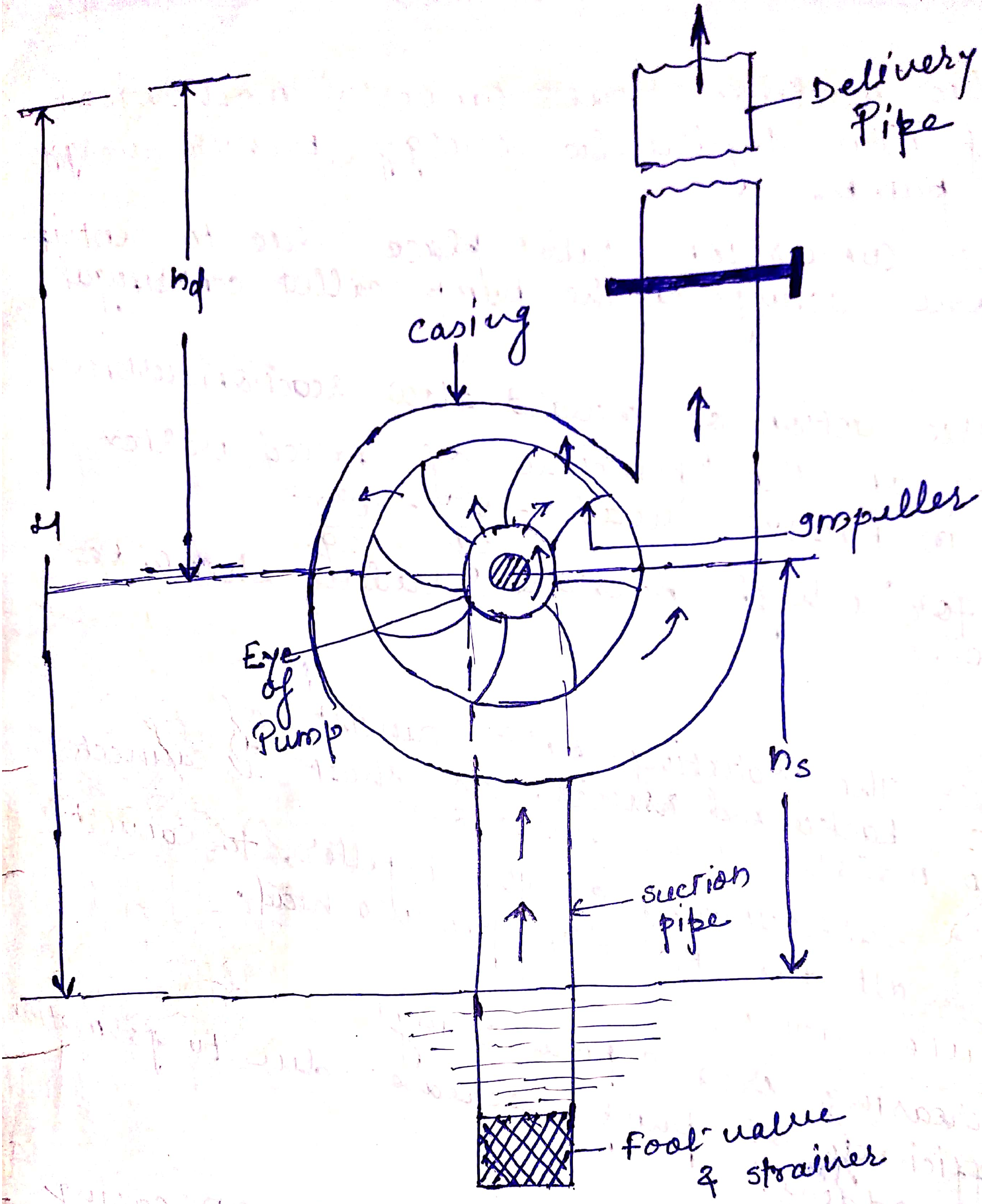
Casing :- surrounding of the impeller, to convert all the KE into pressure head.

ⓐ **Volute casing :-**
→ Increasing area (spiral casing)
→ Efficiency of pump decreases due to formation of eddies.

ⓑ **Vortex casing :-**
→ casing with a circular chamber betn casing and impeller.
→ Efficiency of the pump is increased as compared to volute casing.






Delivery Pipe
casing
h_d
H
Impeller
Eye of Pump
h_s
suction pipe
Foot valve & strainer

Casing with Guide vanes:-

Fixed stationary guide vanes (diffuser) coupling

As area increases, velocity decreases and

pressure head increases.

Suction Pipe with a foot valve and strainer

→ foot valve is a one way valve

→ strainer prevents entry of foreign material.

1) Delivery Pipe :-

→ connected between impeller ~~eye~~ & outlet and other end at required height.

Q. With the help of neat sketch discuss the main parts of reciprocating pump. (8)

Solution 5C) :-

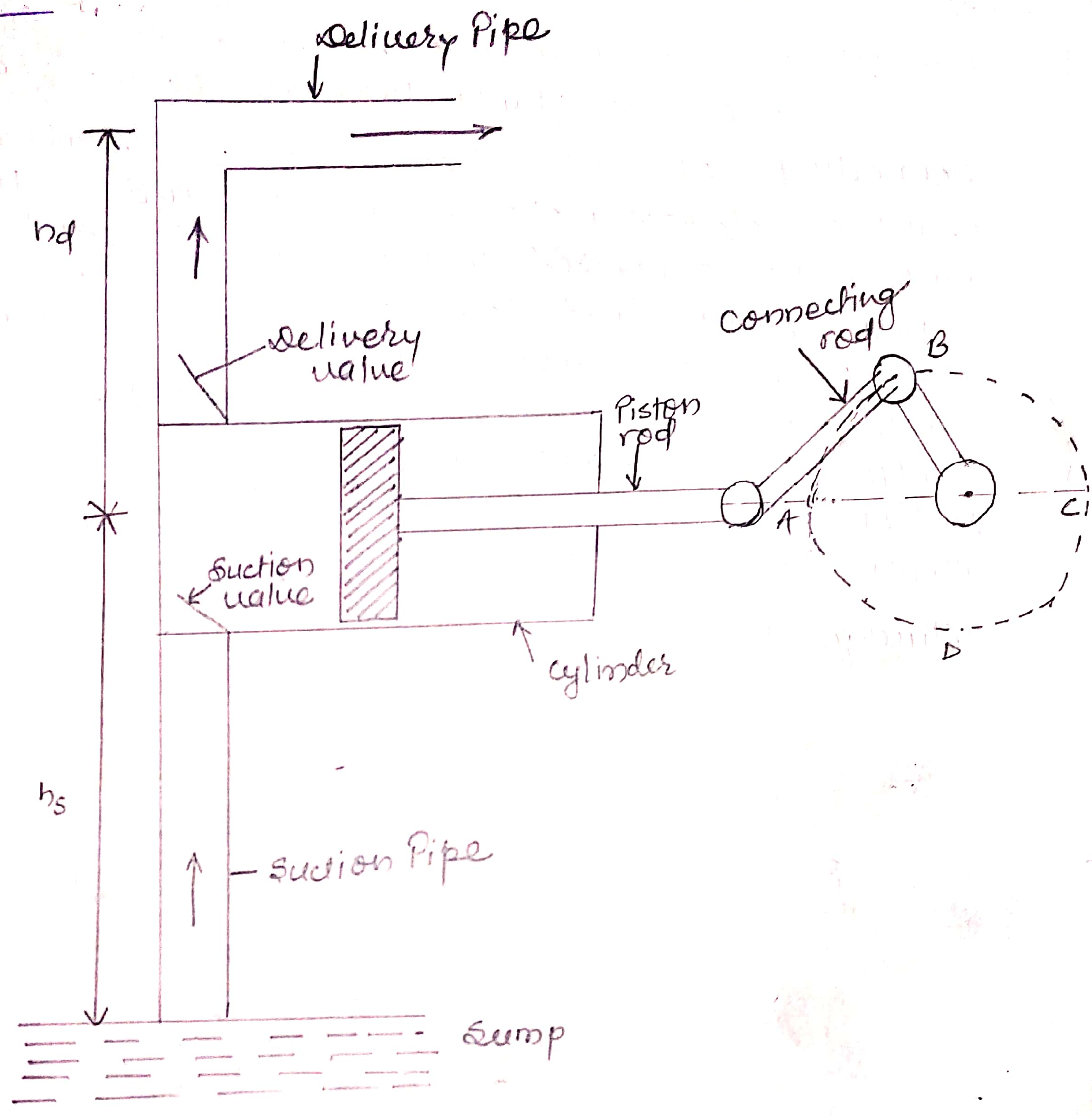


Figure :- Reciprocating pump.

The main components of a reciprocating pump are:

(1) The cylinder with suitable values for inlet (suction) and delivery (delivery value)
(2) Plunger or piston with piston rings
(3) Connecting rod and crank mechanism
(4) Suction pipe (5) Delivery pipe

A reciprocating pump consists of a piston or plunger inside a cylinder. The piston is connected to the crankshaft through piston rod and connecting rod. The crankshaft is rotated by means of electric motor. Suction and delivery pipes are connected to the cylinder with non-return suction and delivery valves. Non-return valves are one way valves which allow the liquid to flow in one direction only. Here, suction valve allows liquid to flow from the suction pipe to the cylinder, while delivery valve allows liquid to flow from the cylinder to the delivery pipe.

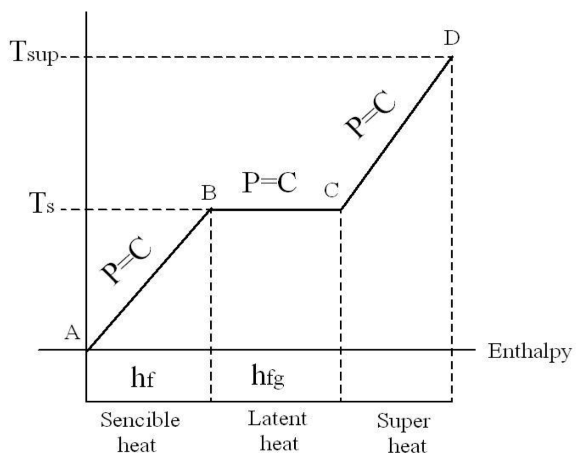
Unit- IV

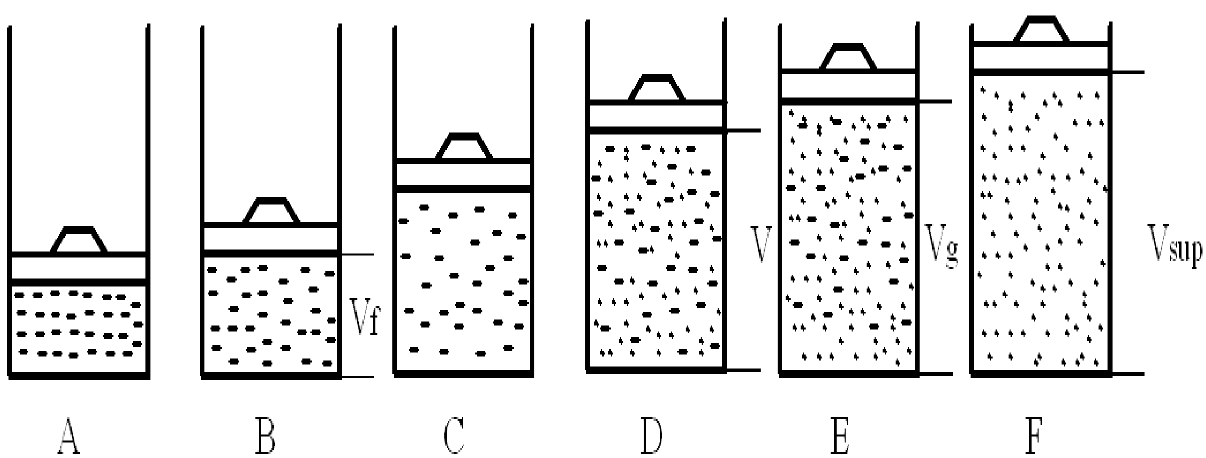
FORMATION OF STEAM:

The process of generation of steam can be represented through a temperature – enthalpy diagram as shown in the figure

Consider 1 kg of water at 0^0 C taken in a cylinder with a pressure P applied by a weight 'w' on a free frictionless piston as shown in the figure When it is heated keeping the pressure constant, its volume increases with increase of temperature, until it reaches a point (point B in the figure when steam begins to form. This temperature (T_s) at which steam begins to form is called the **saturation temperature**. The saturation temperature is different for different pressures and it increases with rise of pressure. The saturation temperature at atmospheric pressure of 1 bar is 100^0 C.

When steam begins to form at saturation temperature, some water particles may be present in it (Fi). If the steam contains water particles in suspension, it is called **wet steam**.





On further heating beyond the point 'B', the whole amount of water will be converted to steam without any further rise of temperature. At the saturation temperature if the steam contains no water particles, it is **dry saturated steam**.

If the dry saturated steam is further heated beyond point 'C', at the same pressure the temperature of steam rises above the saturation temperature. The steam which is at a temperature greater than saturation temperature is called **superheated steam**.

Thus, during the formation there are three states of steam namely wet steam, dry steam and superheated steam.

(i) Enthalpy of Water:

The total amount of heat required to raise the temperature of 1 kg of water which is initially at 0^0 C to its saturation temperature, at a given constant pressure is called the **enthalpy of water**. It is also called **sensible heat**. It is denoted by '$\mathbf{h_f}$' and expressed in '**kJ / kg**'.

(ii) Enthalpy of Evaporation:

The total amount of heat required to convert 1 kg of water which is initially at its saturation temperature to dry saturated steam at the same saturation temperature and at the given constant pressure is called **enthalpy of evaporation**. It is also called the **latent heat of vaporization of steam**. It is denoted by '$\mathbf{h_{fg}}$' and is expressed in '**kJ / kg**'.

(iii) Enthalpy of Steam:

The total amount of heat required to generate 1 kg of dry saturated steam from 1 kg of water which is initially at 0^0 C and at a given constant pressure is called the **enthalpy of steam**. It is denoted by '$\mathbf{h_g}$' and expressed in '**kJ / kg**'. Enthalpy of steam is equal to the sum of enthalpy of water (h_f) and enthalpy of evaporation (h_{fg}).

Thus it can be expressed as $\mathbf{h_g = h_f + h_{fg}}$ kJ / kg

(iv) Enthalpy of Wet Steam:

Enthalpy of wet steam is defined as the "total amount heat of required to generate 1 kg of water which is initially at 0˚C to 1 kg of wet steam at the specified dryness fraction". It is denoted by '$\mathbf{h_w}$' and expressed in '**kJ / kg**'

Enthalpy of wet steam, $\mathbf{h_w = h_f + x\, h_{fg}}$ kJ / kg

Where, x = dryness fraction of steam

(v) Enthalpy of Superheated Steam:

The total amount of heat required to generate 1 kg of superheated stream at the stated superheated temperature from 1 kg of water which is initially at 0^0 C and at a given constant pressure is called the **enthalpy of superheated steam**. It is denoted by '$\mathbf{h_s}$' and expressed in '**kJ / kg**'.

Enthalpy of superheated steam, $\mathbf{h_s = h_g + h_{sup}}$

Where, '$\mathbf{h_{sup}}$' is the heat supplied during superheating, i.e., the heat supplied to the dry saturated steam to attain superheated temperature '$\mathbf{t_{sup}}$'.

'$\mathbf{h_{sup}}$' is also called the **enthalpy of superheat**. It can be determined by using the equation

$$\mathbf{h_{sup} = C_p\,(t_{sup} - t_s)} \quad \text{kJ / kg}$$

The difference between the superheated temperature (t_{sup}) and the saturation temperature (t_s) is called the **degree of superheat**.

(vi) Dryness fraction:

Dryness fraction of steam is defined as the ratio of mass of dry steam actually present in a wet steam to the total mass of wet steam".

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

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

Where, m_d — Mass of dry steam.

m_w — Mass of suspended water molecules. (x should always be less than 1)

(vii) Specific Volume:

The volume of a unit mass of steam at a given pressure is called the *specific volume of steam*. It is expressed in m^3 / kg.

As steam exists in three states, the specific volume is considered for all the three states.

(viii) Specific volume of dry saturated steam:

The volume of a unit mass of dry saturated steam at a given pressure is called the *specific volume of a dry saturated steam*. It is denoted by '$\mathbf{v_g}$' and expressed in '$\mathbf{m^3 / kg}$'.

(ix) Specific volume of wet steam:

The volume of a unit mass of wet steam at a given pressure is called *specific volume of wet steam*. It is denoted by '$\mathbf{v_w}$' and expressed in '$\mathbf{m^3 / kg}$'.

Wet steam consists of saturated liquid in suspension. If in 1 kg of wet steam there is 'x' kg of dry steam, then '(1 – x)' kg will be the saturated liquid. Therefore specific volume of wet steam $v_w = xv_g + (1-x)\, v_f \quad m^3/\text{kg}$

Since '$(1-x)\, v_f$' is too small quantity it is neglected. Hence

Specific volume of wet steam, $\mathbf{v_w = xv_g} \quad m^3 / \text{kg}$

(x) Specific volume of the superheated steam: The volume of a unit mass of superheated steam at a given pressure is called the *specific volume of superheated steam*.

Since superheated steam behaves like a perfect gas, its specific volume can be determined by using Charles law as follows:

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

$$V_{sup} = V_g \frac{T_{sup}}{T_s}$$

where, v_g —Specific volume of dry saturated steam at pressure 'p'

T_s —Saturation temperature, K

T_{sup} —Specified superheated temperature, K

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

(xi) Internal energy of steam: When water vaporizes and gets converted into steam there is a considerable increase in its volume. Thus some amount of external work is done during vaporization. This external work can be expressed as product of pressure and volume of steam. Thus the external work done, for the three states of steam are as follows:

pv_g for dry saturated steam

pv_w for wet steam

pv_{sup} for superheated steam

Internal energy of steam is the actual energy stored in steam which can be utilized for doing external work. It is equal to the difference between the total heat of steam and the external work done during vaporization. It is denoted by '**U**' and expressed in '**kJ / kg**'. Thus,

Internal energy of dry saturated steam	:	$U_g = h_g - pv_g$	kJ / kg
Internal energy of wet steam	:	$U_w = h_w - pv_w$	kJ / kg
Internal energy of superheated steam	:	$U_{sup} = h_s - pv_{sup}$	kJ / kg

Where 'p' is in 'kN / m^2'

THERMODYNAMICS:

1. **System boundary:** The real or imaginary surface which surrounds the system is called system boundary
2. **Surrounding**: The region outside the system is called the surrounding.

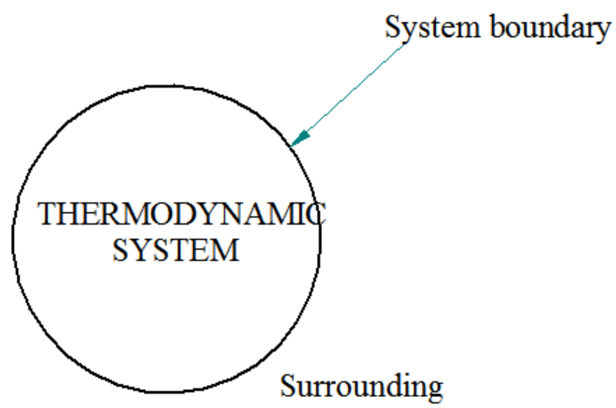
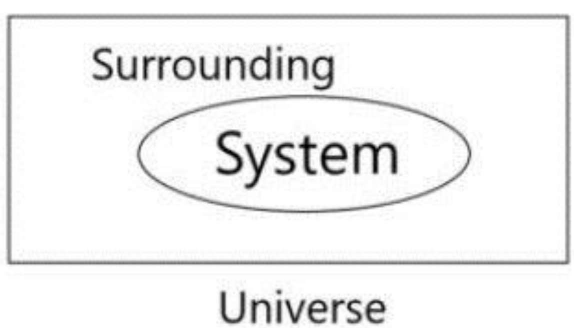


Fig: Thermodynamic system

3. **Universe**: System and Surrounding put together is known as **Universe**



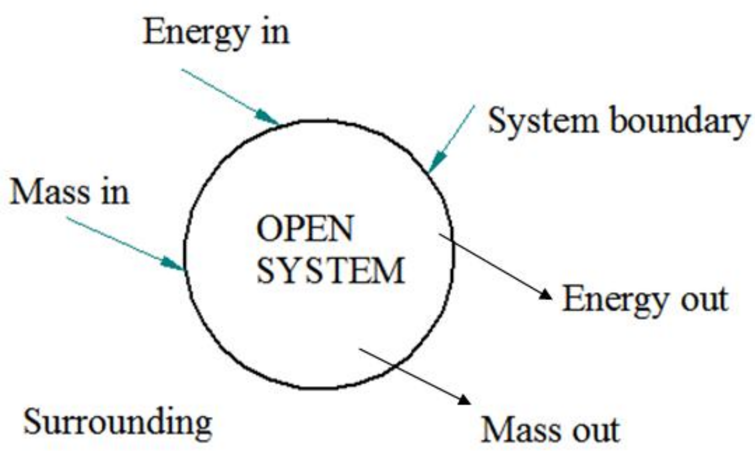
TYPES OF THERMODYNAMICS SYSTEMS:

a) Open system

b) Closed system

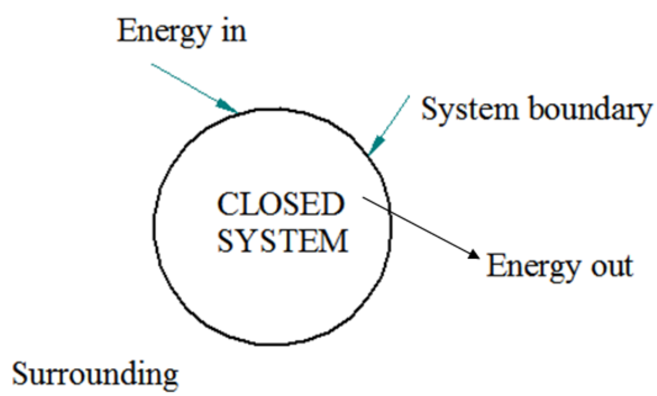
c) Isolated system

a) **Open system:** The open system is one in which both mass and energy (heat/work) cross the boundary of the system.



Examples of open system: Water Pump, scooter engine

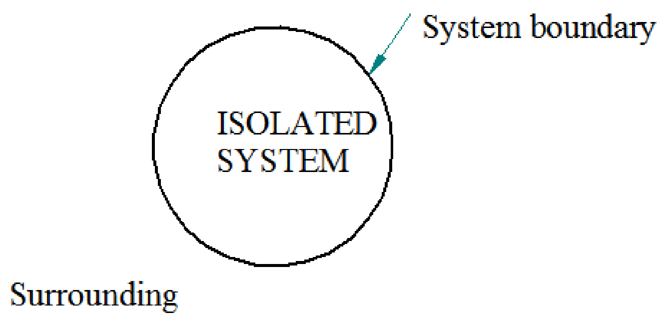
b) **Closed system:** The closed system is one in which only energy (heat/work) crosses the boundary of the system. It has fixed mass



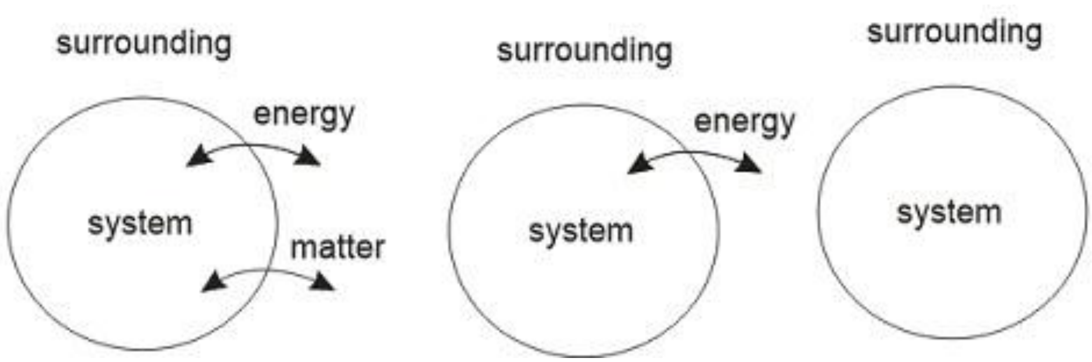
Example of closed system: Car battery, Tea kettle, Water in a tank

c) **<u>Isolated system</u>:** The isolated system is one in which neither energy(heat/work) nor mass crosses the boundary of the system. This system does not interact with the surrounding. Therefore it has fixed mass and energy.

- No such system physically exists. Universe is the only example, which is perfectly isolated system



NOTE:



Open system Closed system Isolated system

THERMODYNAMIC STATE: The condition of a system at a particular moment is called its state.

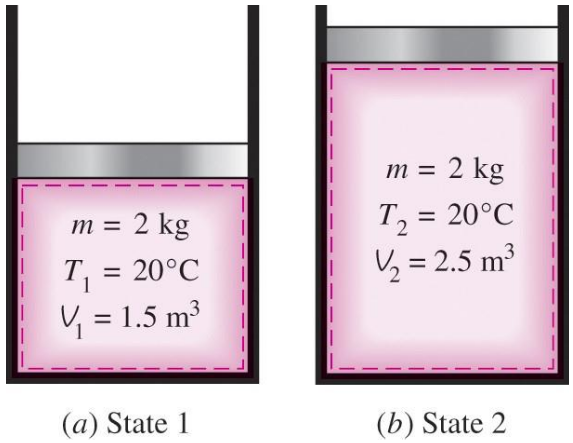


Fig: A system at two different states

THERMODYNAMIC PROPERTIES: The properties describing the state of a system are called thermodynamic properties. These are pressure (P) , Volume (V) , temperature (T) etc

Types of Thermodynamic properties

Thermodynamic properties are generally divided into two types based on their dependence on mass

Intensive properties: A thermodynamic property which is independent of mass is called intensive property. For e.g. Temperature, Pressure etc.

For example if we take one liter of hot water at 50 degree Celsius, then at each and every point of that one liter water temperature will be same. It does not depends on whether the water is one liter or ten liters.

Extensive properties: A thermodynamic property which is dependent on mass is called an extensive property. For e.g. volume, energy, entropy etc.

For example if we take water, then its volume which is a property depends on mass, for half kg of mass volume will be different and for one kg it would be different.

Specific property= Extensive property/mass.

Example:

- Specific volume (v) = Volume(V)/mass(m)
- Specific enthalpy (h) = Enthalpy(H)/mass(m)
- Specific entropy (s) = Entropy(S)/mass(m)

PROCESS AND CYCLE: When a system undergoes changes from one equilibrium state to another is called a *process. A process has a start and end point.*

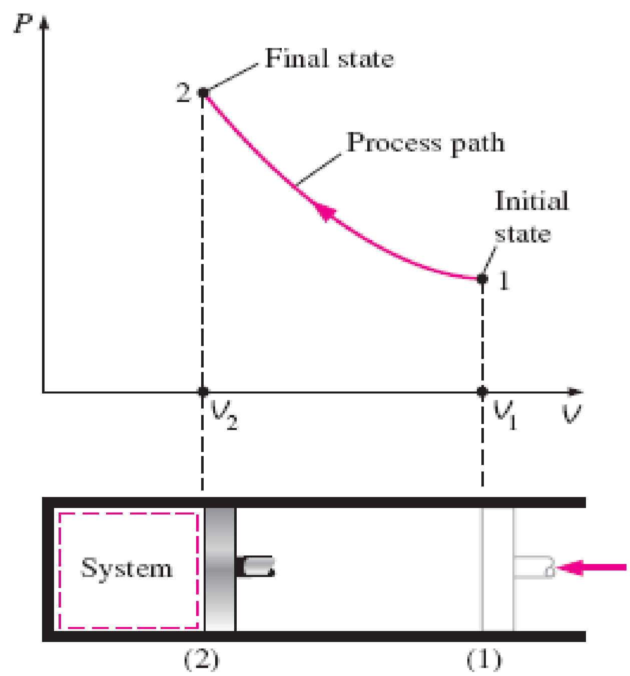


Fig: Process and path

From the above fig it clears that STATE1:P1,V1,STATE 2:P2,V2,PROCESS :1- 2

Types of Process:

a. Isobaric process or Constant pressure process
b. Isochoric process or Constant volume process

c. Isothermal process or Constant temperature process

d. Adiabatic process

e. Quasi-static process

THERMODYNAMIC EQUILIBRIUM

A system is said to be in thermodynamic equilibrium, it should satisfy following three equilibrium

a. Mechanical equilibrium

b. Chemical equilibrium

c. Thermal equilibrium

a. **Mechanical equilibrium**: A system is said to be in mechanical equilibrium when there are no unbalanced forces within the system and also between the system and the surrounding, the system is said to be under mechanical equilibrium

b. **Thermal Equilibrium:** A system is said to be in thermal equilibrium when there is no temperature difference within the system and also between system and surroundings.

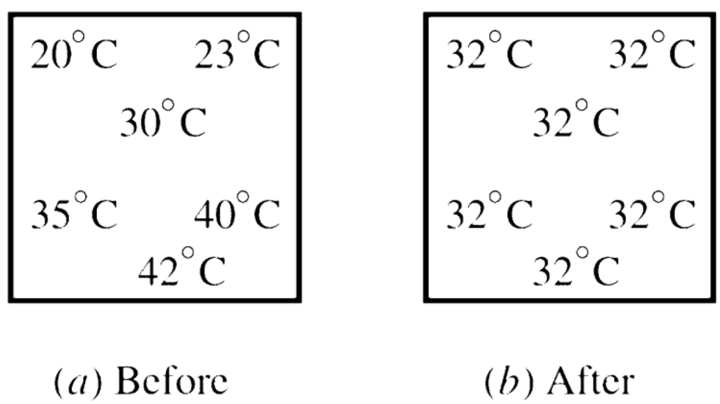


Fig: A closed system reaching thermalequilibrium.

c. **Chemical Equilibrium:** A system is said to be in chemical equilibrium when there is no Chemical reaction within the system

When all the conditions of Mechanical, Chemical and Thermal equilibrium are satisfied, the system is said to be in Thermodynamic equilibrium

LAWS OF THERMODYNAMICS:

1. ZEROTHLAW OF THERMODYNAMICS:

- The Zeroth Law of Thermodynamics states that if two systems are each in thermal equilibrium with third system, then they are also in equilibrium with each other. Thermal equilibrium means
- Let us consider we have system A, system B and System C as shown in following figure.

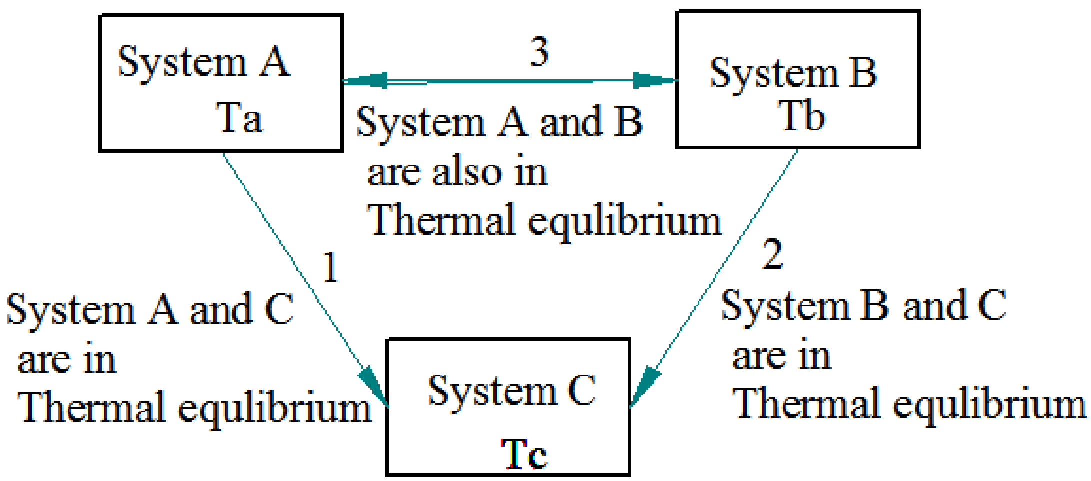


Fig: Zeroth law of thermodynamics

Let temperature of system A is Ta,

Temperature of system B is Tb

Temperature of system C is Tc.

If Ta = Tc and Tb = Tc

If system A is in thermal equilibrium with system C and system B is also in thermal equilibrium with system C. Then according to Zeroth law of thermodynamics, system A and system B will also be in thermal equilibrium with each other.

That is , Ta = Tb

2. FIRST LAW OF THERMODYNAMICS:

First law of thermodynamics for cyclic process

- First law of thermodynamics states that, when a closed system executes a cyclic process then the cyclic integral of the heat is equal to the cyclic integral of the work

Mathematically, the first law of thermodynamics is stated as

- $\oint dQ = \oint dW$
- $\oint dQ - \oint dW = 0$

Extension of First law of thermodynamics for Non cyclic process:

When a closed system undergoes a non-cyclic process, the difference between the net heat transfer and the net work transfer is equal to the change in the energy of the system

$\delta Q - \delta W = dE$

$\delta Q = \delta W + dE$

OR

$Q = W + \Delta U$

Where $E = KE + PE + U$

Total energy content=E= Internal Energy(U) + Kinetic energy + Potential energy

In most of the situations the changes in KE and PE are very small, Thus KE and PE changes can be neglected.

Therefore $\Delta E = \Delta U$

$\Delta E = Q - W$ becomes

$\Delta U = Q - W$

$Q = W + \Delta U$

For e.g. of 10 J of heat supplied to a system out of which 5 J used for doing work work and the remaining 5 J will be stored in the system in the form of energy.

TOTAL ENERGY CONTENT OF A CLOSED SYSTEM

- ΔE= Total energy=Q–W
- Q=ΔE+W
- 'W' amount of work is done by the system
- 'Q' amount of heat absorbed by system
- ΔE refers to the energy change of the system. The net energy transfer (Q – W) would be stored in the system.

CONCEPT OF INTERNAL ENERGY:

Internal energy (U):

- Internal energy is the energy stored in a substance.
- Internal energy is the energy due electron spin and vibrations, molecular motion and chemical bond.
- It is denoted by U
- From first law of thermodynamics we have
- $\Delta E = Q-W$
- $Q=W +\Delta U$

Where E = KE + PE +U

- KE= Kinetic energy
- PE= Potential energy
- U = Internal energy. Therefore,
- In most of the situations the changes in KE and PE are very small, Thus KE and PE changes can be neglected.

Therefore $\Delta E = \Delta U$

ΔE = Q-W becomes

$\Delta U = Q - W$

- For e.g. of 10 J of heat supplied to a system out of which 5 J used for doing work work and the remaining 5 J will be stored in the system in the form of internal energy.

CONCEPT OF ENTHALPY (H):

- Enthalpy, the sum of the internal energy(E) and the product of the pressure(P) and volume(V) of a thermodynamic system. It is expressed in kJ/kg
- Enthalpy, denoted by the symbol 'H',
- The enthalpy of a thermodynamic system is given by

$$H=U+PV$$

Where

- H is the enthalpy of the system,
- U is the internal energy of the system,
- P is the pressure of the system,
- V is the volume of the system

Heat Engine

- Heat engine is a device operating in a cycle, which converts heat into work continuously
- Ex: Internal combustion engine, Gas turbine
- The parts of heat engine are Source, Working substance and Sink
- **Source**: It is a reservoir of heat at high temperature. Heat engine absorbs the heat from the source
- **Sink:** It is a reservoir of heat at low temperature. Heat engine rejects the heat to the sink
- Working substance may be steam or petrol

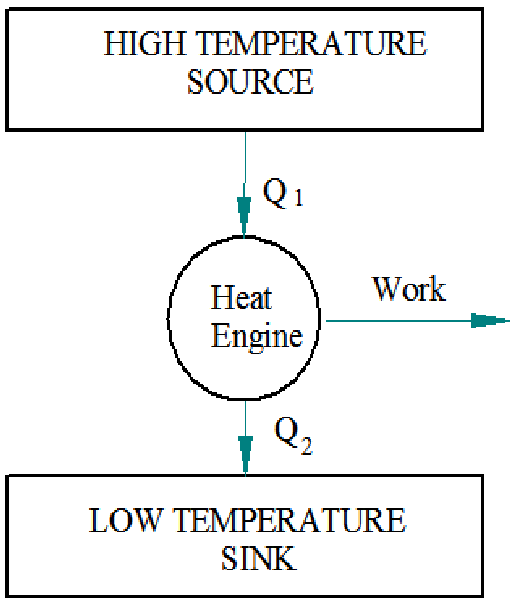


Fig: Heat engine

- Consider a heat engine
- Heat engine absorbs Q1 amount of heat from the source at T1 and converts the part of heat received into mechanical work(W)
- The remaining part of the heat Q2 is rejected to the sink

Expression for the Efficiency of a Heat engine:

$\eta = W/Q1$

- Where, W is the work done by the engine and Q1 is the heat absorbed from the source.

- According to first law net heat transfer=net work transfer
- i.e W=Q1
- η =100%
- So efficiency will be 100% but in actual, this is not possible because there will be some loss of energy in the system. Hence for every engine, there is a limit for its efficiency.

Heat Pump

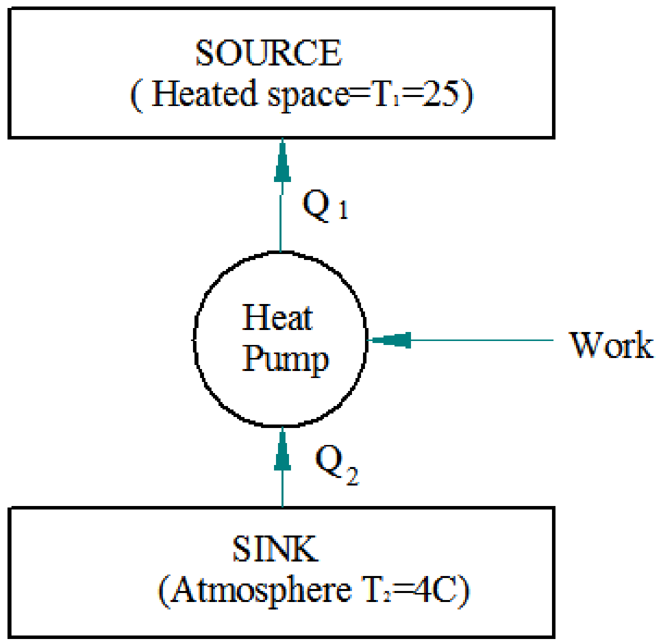


Fig: Heat Pump

- The heat pump is a device used to pump heat into the system.
- It is basically used for heating purpose(maintaining temperature higher than the surrounding)
- Heat pump keeps your home warm rather than just burning fuel in a fireplace or furnace is that a heat pump supplies. It runs on electricity, so you can save substantially on fuel consumption.
- Consider a heat pump as shown in the fig
- Heat pumps transfer heat from a low-temperature source to a high-temperature sink
- Heat Pump takes the mechanical work(W) like electric motor and transfer heat from sink to source

Efficiency of heat pump is known as Coefficient of Performance(CoP)

CoP=Q1/W

If W=0, CoP becomes infinity which is not possible

So some external work must be supplied to the heat pump

<u>SECOND LAW OF THERMODYNAMICS: KELVIN PLANK'S STATEMENT</u>:

- According to Kelvin Plank's Statement "*It is impossible to construct a heat engine that operates in a cycle, whose sole purpose is to convert heat energy from a single thermal reservoir into an equivalent amount of work*"
- Thus according to this statement, there is no engine that can convert all the heat taken from the source into work, without giving any heat into the sink.
- This means that for obtaining continuous work, a sink is necessary.
- In the heat engine, the working substance takes heat from the hot body, converts a part of it into work and gives the rest to the cold body.

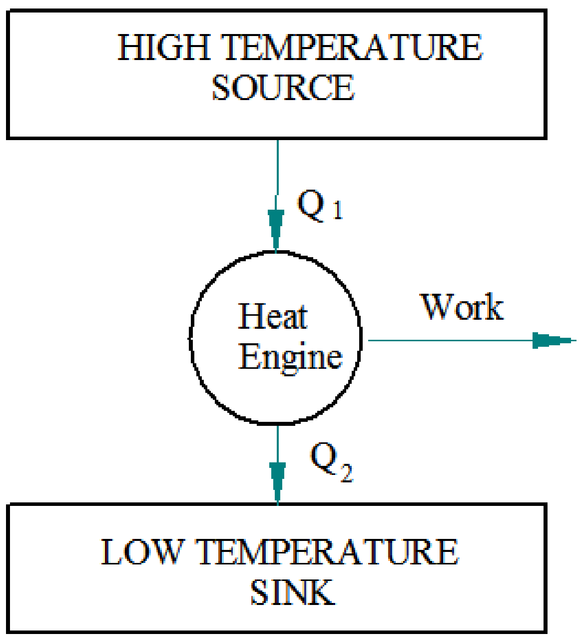


Fig a (Possible)

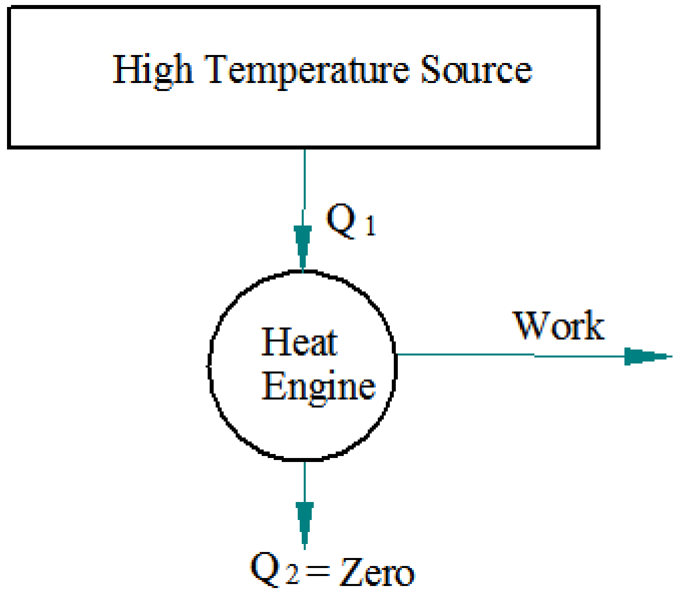


Fig b(Impossible)

- Fig a shows heat engine that obeys the Kelvin-Planck statement of the second law
- Fig b shows heat engine that violates the Kelvin-Planck statement of the second law cannot be built. The above heat engine had Thermal efficiency of 100% which is practically impossible (which cannot be built). This device is called **PMM II**

<u>Second Law of Thermodynamics: Clausius Statement:</u>

- According to Clausius Statement" It is impossible to construct an heat pump *that operates in a cycle,* to transfer heat from a body at a lower temperature to a body at a higher temperature without the assiatnce of external work"
- According to this stamen it clears that It is not at all possible to transfer heat from a cold body to a hot body without the expenditureiof work by an external energy source.

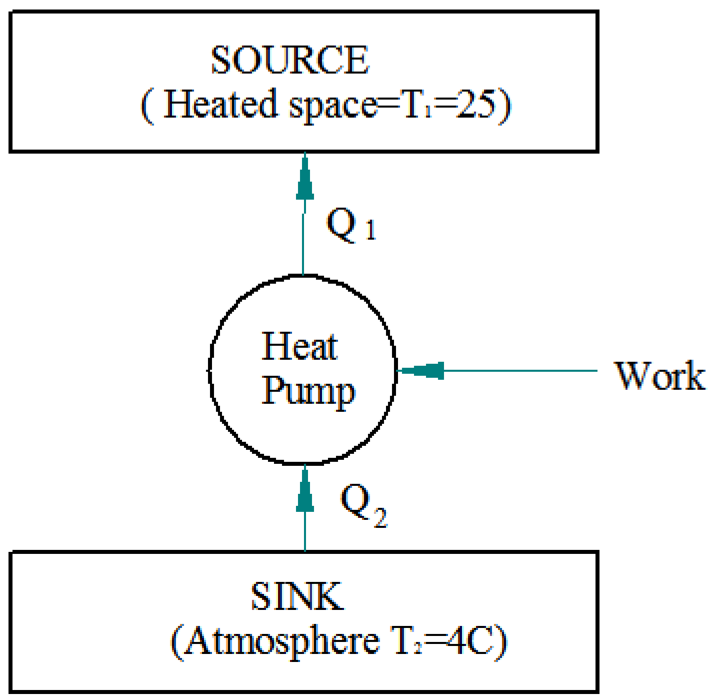


Fig a (Possible)

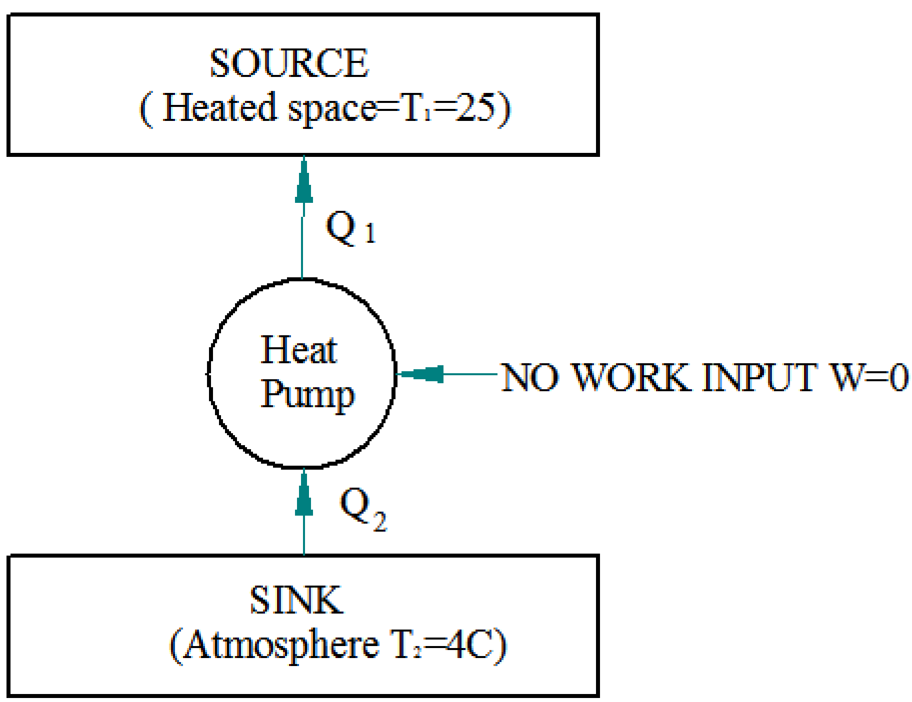


Fig b(Impossible)

- Fig a shows heat engine that obeys Clausius statement of the second law
- Fig b shows heat engine that violates Clausius statement of the second law cannot be built. The above heat which is practically impossible (which cannot be built)

CONCEPT OF WORK AND HEAT:

Mechanics definition of work :

According to Mechanics, Work is defined as the product of force(F) and the distance moved(S) in the direction of force

Mathematically, $W = F \times d$

Where:

W = work (J)

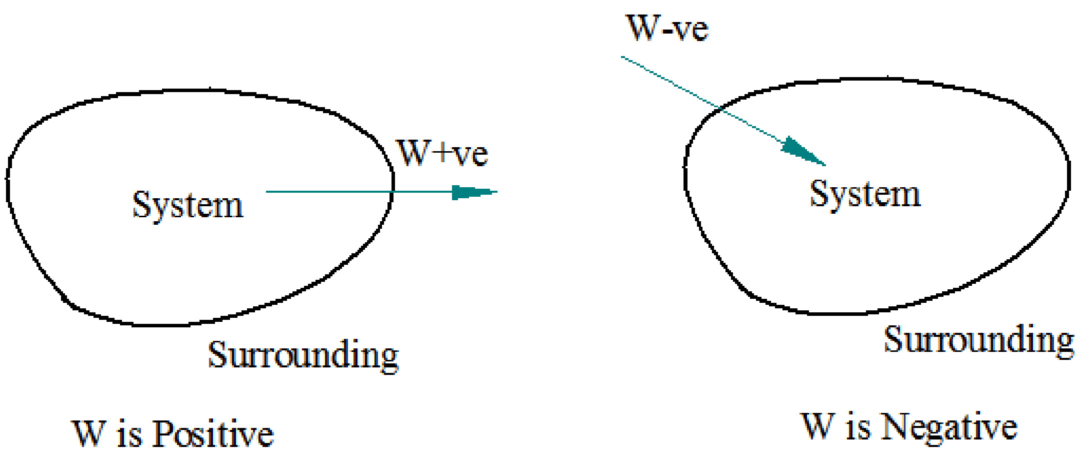
F = force (N)

d = displacement (m)

Thermodynamic definition of work:

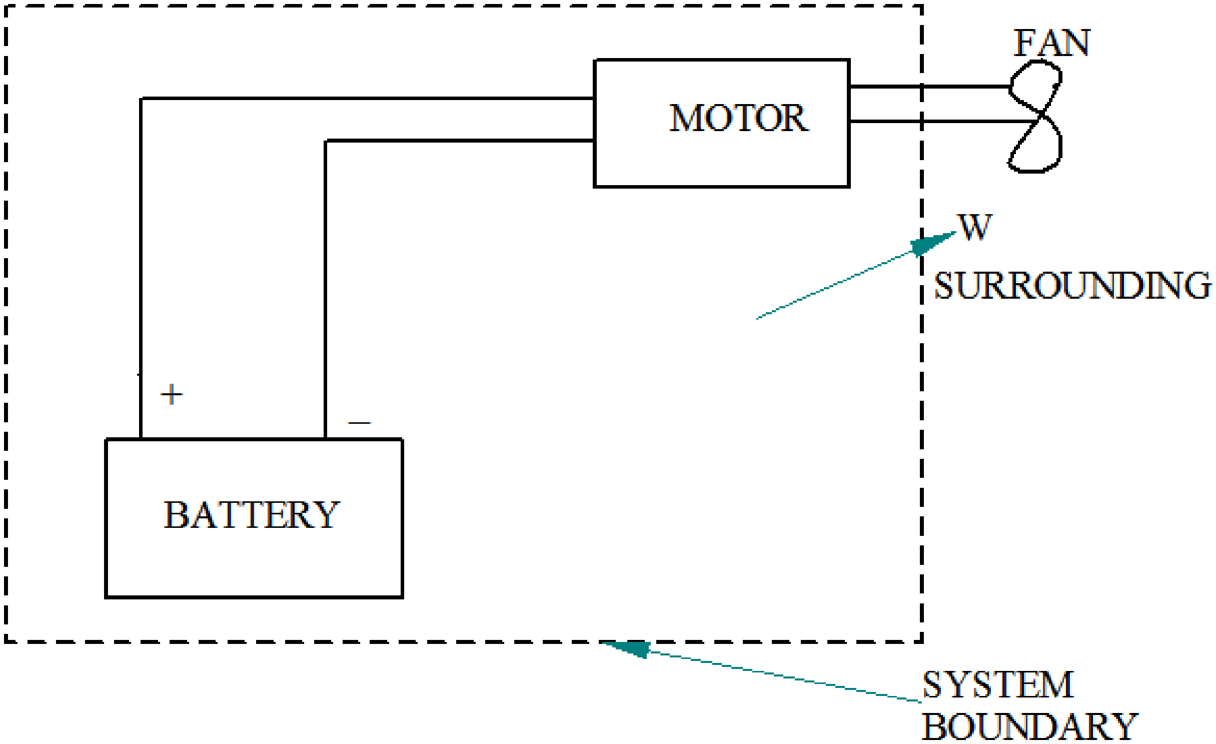
- Work is said to be done by a system , if the sole effect external to the system can be reduced to the raising of a weight.
- Work is said to be done by the system if the total effect outside the system is equivalent to the raising of weight
- The weight may not actually be raised, but the effect external to the system would be reduced to the raising of a weight
- The word 'could be reduced to' indicates that it is not necessary that weights should actually be raised in order to say that there is work interaction between the system and the surroundings.
- The system just sufficient to have an effect which is equivalent to the raising of weight.

Sign Convention:



- The work done by a system is considered as positive
- The work done on a system is considered negative

Example of Work:



- Consider a system consist of storage battery and motor
- Battery supplies electrical energy to motor which runs fan(surroundings)
- This clearly shows that the system(battery) has interaction with surroundings
- This the system is doing work on the surroundings(fan)
- But according to mechanics, there is no work done by the system since there is no force is acting through a distance

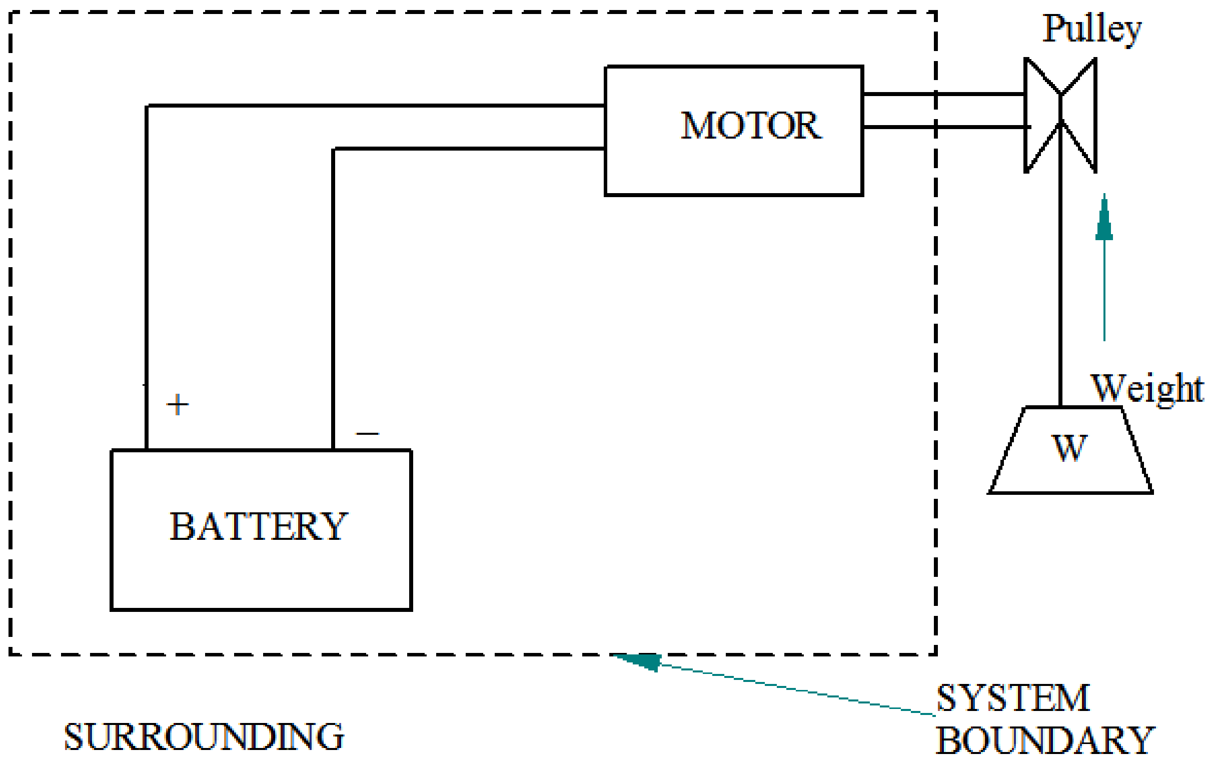


Fig: Thermodynamics definition of work

- Let the fan is replaced with a pulley and weight arrangement as shown in the fig
- According to thermodynamics definition , the work is said done by the system because the motor turns the pulley which raises the weight
- Thus, the sole effect external to the system can be reduced to raising of a weight
- Hence, thermodynamic work is done by the system

<u>Expression for Work/Displacement Work:</u>

- Consider a piston cylinder arrangement as given in the Figure 2.4.
- If the pressure of the fluid is greater than that of the surroundings, there will be an unbalanced force on the face of the piston.
- Hence, the piston will move towards right.

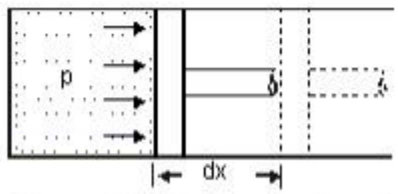


Figure 2.4 Displacement work

Let: F= Force acting on the piston

dX= Distance moved by the piston under the action of gas pressure

Force acting on the piston = Pressure×Area

W K T Work done =Force ×distance

Work done = P×A×dx

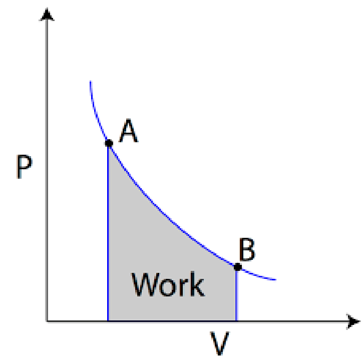
We know that area x length = volume A.dx=dV

Work done = P×dV

Where dV - change in volume.

- This work is known as displacement work or pdV work corresponding to the elemental displacement dx.
- To obtain the total work done in a process, this elemental work must be added from the initial state to the final state. Mathematically,
- That is

$$ {}_1W_2 = \int_1^2 p\,dV $$



- The, area under the P V curve representing the work done in the process

CONCEPT OF HEAT:

Thermodynamic Definition of Heat:

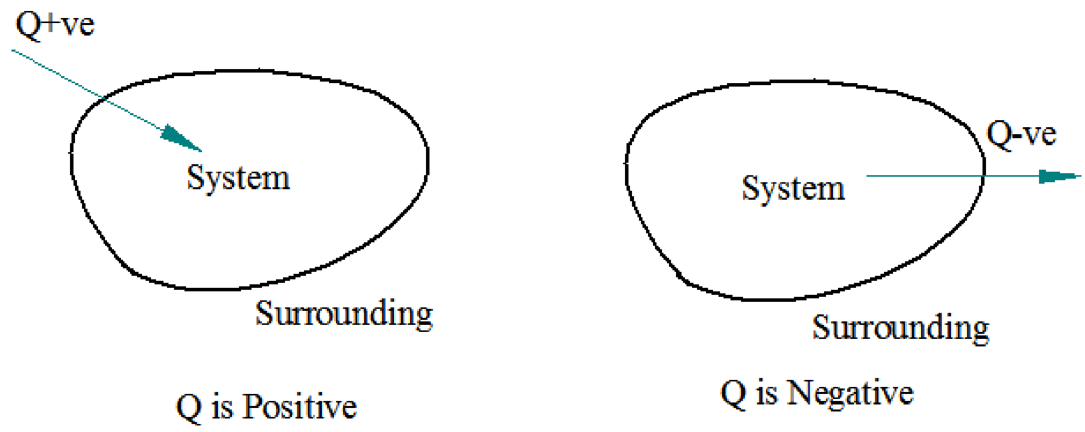
- It is the energy transfer from one system to another system by virtue(reason) of temperature difference
- It is represented by Q and it is expressed in joule(J) or kilo-joule(kJ 10^3J) MJ(10^6J)

Direction of Heat Transfer:

- Direction of heat transfer is from the high temperature to the lower temperature
- The driving force for heat transfer is temperature difference

Sign Convention:

- The symbol Q is used to represent heat transfer
- As a convention of sign, heat transferred to a system is considered as positive and heat transferred from a system is considered as negative



Relationship between Heat and Work

- Heat and work are related. Work can be completely converted into heat, but the reverse is not true: heat energy cannot be wholly transformed into work energy.
- For a closed system, the change in internal energy (ΔU) is related to heat (Q) and work (W) as follows: $\Delta U = Q + W$

EXPRESSION FOR HEAT TRANSFER:

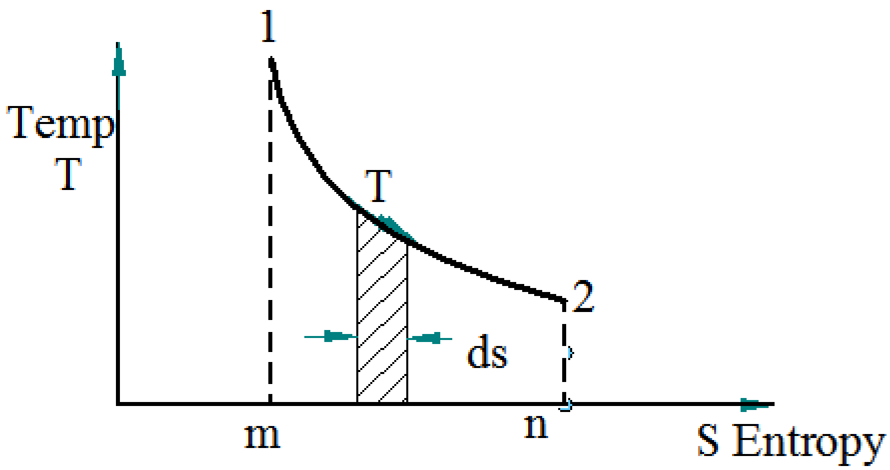


Fig: T-S Diagram

- Fig shows T-S diagram Entropy S is plotted along A axis and Temperature T is plotted along Y axis
- Heat transferred from state 1 to state 2 is calculated as follows

$$_1Q_2 = T.dS = Area = 1\text{-}2\text{-}n\text{-}m\text{-}1$$

COMPARISON BETWEEN WORK AND HEAT:

Similarities:

- Both are path functions
- Both are boundary phenomenon i.e., both are observed at the boundaries of the system as they cross them.
- Both represent transient phenomenon. The systems do not posses heat or work. These energy interactions occur only when a system undergoes change of state
- A system possesses energy, but not work or heat.
- Bothe are not properties of systems

Dissimilarities:

- Heat is energy interaction due to temperature difference only. Work is by reasons other than temperature difference.
- Heat is low grade energy whereas work is high grade energy.
- Heat transferred to a system is considered as positive and heat transferred from a system is considered as negative
- The work done by a system is considered as positive. The work done on a system is considered negative
- In a cyclic process, complete conversion of het to work is impossible but complete conversion of work to heat is possible

Note: Heat is the energy associated with the random motion of particles, while work is the energy of ordered motion in one direction

<u>CONCEPT OF ENTROPY:</u>

- Entropy is defined as the measure of disorder or randomness in a system.
- In general, greater disorder means greater entropy
- Adding heat increases the entropy (and disorder) of the system

  S (gases) > S (liquids) > S (solids)

Change in Entropy is defined as

$\Delta S = Q / T$

Where

Q is the energy transferred as heat to or from the system during the process,

T is the temperature of the system in kelvins

PRINCIPLE OF INCREASE OF ENTROPY:

The entropy of the universe increases because energy never flows uphill spontaneously.

Explanation:

Energy always flows downhill, and this causes an increase of entropy.

Consider the total energy q that is transferred from a hot region at temperature T1 to a cold region at temperature T2.

The entropy S_1 of the hot region is defined as

$$S_1 = \frac{q}{T_1}$$

The entropy S_2 of the cold region is

$$S_2 = \frac{q}{T_2}$$

Therefore, during the energy transfer, the change in entropy is

$$\Delta S = S_2 - S_1 = \frac{q}{T_2} - \frac{q}{T_1} = q\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Since $T_2 < T_1$, $\frac{1}{T_2} > \frac{1}{T_1}$, and ΔS is positive.

The total entropy of the system increases.

The total entropy of the universe is always increasing.

Note: In our solar system heat is generated everywhere including solar fusion and radiated heat from planets. dQ is therefore always a positive number. This is the reason that in our known universe, entropy s is always positive

SPECIFIC HEATS

The amount of heat required to raise the temperature of its unit mass through one degree. Solid and liquid have only one specific heat. Gas has mainly two types of specific heat:

a) **Specific heat at constant pressure (C_p)**

The amount of heat required to raise the temperature of its unit mass through one degree, when its pressure is kept constant.

$Q = mC_pdT$

b) **Specific heat at constant volume (C_v)**

The amount of heat required to raise the temperature of its unit mass through one degree, when its volume is kept constant.

$Q = mC_vdT$

c) Specific Index

It is the ratio of specific heat at constant pressure to specific heat at constant volume is known as specific heat index. It is denoted by γ.

$$\gamma = C_p/C_v$$

DERIVATION OF SPECIFIC HEATS WITH CHARISTICS GAS CONSTANT/ RELATIONSHIP BETWEEN C_P, C_V AND R

Let us consider m kg of a gas enclosed in a container and is being heated at constant pressure.

Let T_1 = Initial temperature of the gas,

T_2 = Final temperature of the gas,

V_1= Initial volume of gas,

V_2 = Final volume of gas,

C_p = Specific heat at constant pressure,

C_v = Specific heat at constant volume,

P = Absolute constant pressure.

We know that heat supplied to the gas at constant pressure,

$Q = mC_p (T_2 - T_1)$.............................. (i)

We also know that a part of this heat is utilisec in doing external work, while the remaining part of heat is used in increasing the internal energy of gas.

i.e. $Q = W + dU$ .... (ii)

now heat utilised for external work,

$W = P(V_2 - V_1)$.............................. (iii)

And increase in internal energy

$dU = mC_v (T_2 - T_1)$ .... (iv)

Putting the values of W and dU in equation (ii)

$Q = P(V_2 - V_1) + mC_v(T_2 - T_1)$................................... (v)

Using characteristic gas equation, we have

$PV_1 = mRT_1$ (For initial condition)

$PV_2 = mRT_2$ (For final condition)

$$P (V_2 - V_1) = mR (T_2 - T_1)$$

Putting the value of P (V2 – V1) from equation (vi) in equation (v), we get

$Q = mR(T_2 - T_1) + mC_v(T_2 - T_1)$

Now putting the value of Q from equation (i) in above equation, we get

$mC_p (T_2 - T_1) = mR(T_2 - T_1) + mC_v(T_2 - T_1)$

or $C_p = R + C_v$

or $C_p - C_v = R$

The equation may be written as

$$C_V \left[\frac{Cp}{Cv} - 1\right] = R$$

$C_v(\gamma - 1) = R$

$$C_v = \frac{R}{\gamma - 1}$$

The value of r in S.I. unit is taken as 287 J/kg K

The equation may also be written as

$C_p = C_v + R$

Dividing both sides by C_v , we get

$$\frac{Cp}{Cv} = 1 + \frac{R}{Cv}$$

$$\gamma = 1 + \frac{R}{Cv}$$

THERMODYNAMIC PROCESSES

INTRODUCTION

When the system changes from one thermodynamic state to the final thermodynamic state due to change in pressure, temperature, volume etc, the system is said to have undergone thermodynamic process. The various types of thermodynamic processes are: isothermal process, adiabatic process, isochoric process, isobaric process and reversible process.

TYPES OF THERMODYNAMIC PROCESSES

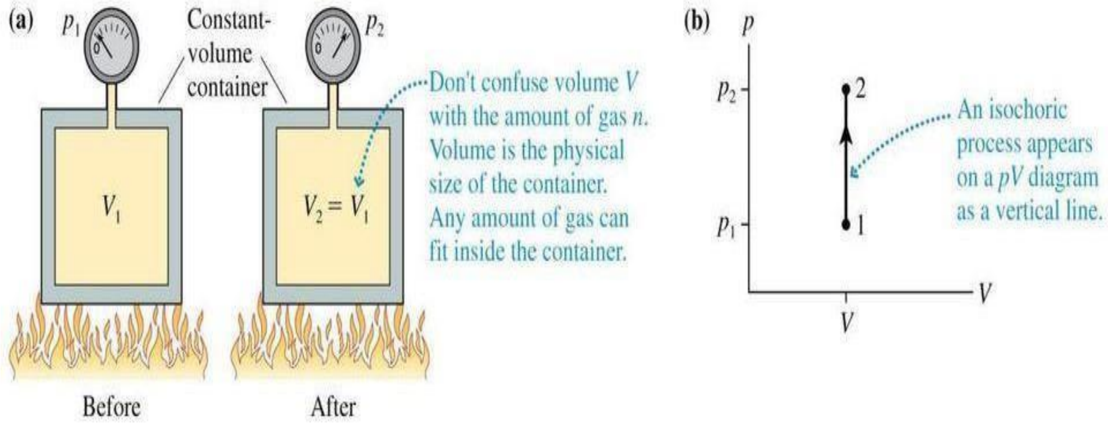
The important thermodynamic processes are:

A. Reversible non-flow processes

1. Isochoric process (Constant volume process)
2. Isobaric process (Constant pressure process)
3. Isothermal process (Constant temperature process)
4. Adiabatic process
5. Hyperbolic process
6. Polytropic process
7. Throttling process

Isochoric process (Constant volume process)

In this process the volume of system remains constant. The main characteristic of this process is that the displacement work is eliminated. An example of this process is the heating or cooling of a gas stored in a rigid cylinder. Since the volume of the gas does not change, no external work is done, and work transferred W is zero.



Therefore from 1st law of thermodynamics for a constant volume process:

$$Q_{1\text{-}2} - W_{1\text{-}2} = U_2 - U_1$$

But, $W_{1\text{-}2} = \int_1^2 PdV = U_2 - U_1$ .... (dV = 0)

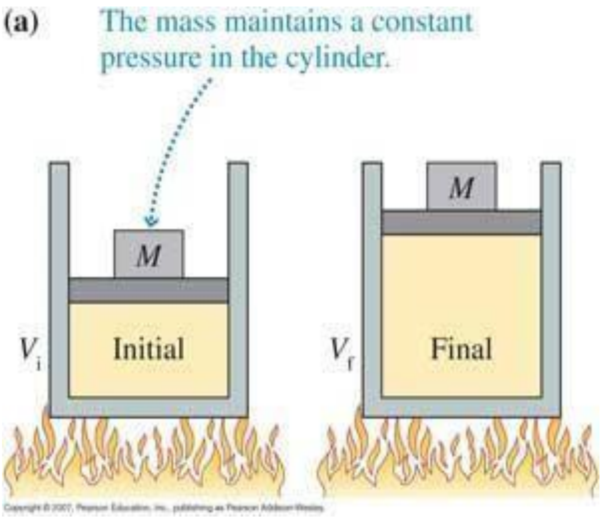
$$Q_{1\text{-}2} = U_2 - U_1$$

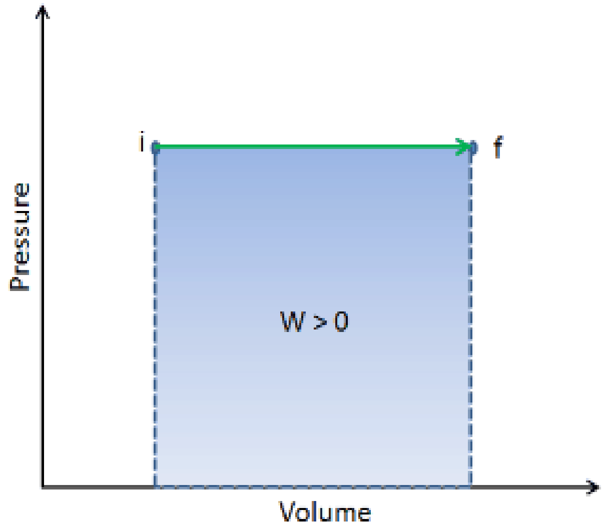
$$Q_{1\text{-}2} = mC_v (T_2 - T_1)$$

Thus, during a constant volume process, the heat transfer equals the change in internal energy of the system.

Isobaric process (Constant pressure process)

The process, during which the pressure of the system remains constant, is called as isobaric process. If the temperature of a gas is increased by the addition of heat while the gas is allowed to expand so that its pressure is kept constant, the volume of the gas will be increase in accordance with Charles law. Since the volume of the gas increases during the process, work is done by the gas at the same time that its internal energy also changes. Therefore for constant pressure process, assuming constant specific heats and ideal gas behaviour,





If the work is carried out quasi-statically,

$$\int_1^2 \delta W = \int_1^2 P\,dV$$

Then, from first law of thermodynamics,

$$\int_1^2 \delta Q - \int_1^2 \delta W = \int_1^2 dU$$

Or

$$\int_1^2 \delta Q = \int_1^2 \delta W + \int_1^2 dU$$

$$= \int_1^2 P\,dV + \int_1^2 dU$$

$$= \int_1^2 d(U + PV)$$

$$\int_1^2 \delta Q = \int_1^2 dH$$

Also $$\int_1^2 \delta Q = \int_1^2 mC_p dT$$

Or $$Q_{1-2} = mC_P (T_2 - T_1)$$

Thus, the heat supplied at constant pressure is equal to change in enthalpy of the system.

Isothermal process (Constant temperature process)

According to Boyle's law, when a gas is compressed or expanded at constant temperature, the pressure will vary inversely with the volume. Since the gas does work as it expands, if the temperature is to remain constant, energy to do the work must be supplied from an external source. When a gas is compressed, work is done on the gas and if the gas is not cooled during the process the internal energy of the gas will increase by an amount equal to the work of compression. Therefore if the temperature of the gas is to remain constant during the process gas must reject heat to the surroundings. Since there is no temperature increase in the system change in internal energy becomes zero. And the amount of work done will be the amount of heat supplied.

From first law of thermodynamics,

$$\delta Q - \delta W = dU$$

But $$dU = mC_V dT$$

Now as $$dT = 0$$

$$dU = 0$$

$$\delta Q - \delta W = 0$$

Or $$\delta Q = \delta W$$

For quasi-static process, $\int_1^2 \delta W = \int_1^2 PdV$

Or $W_{1-2} = \int_1^2 PdV = \int_1^2 \frac{PVdV}{V}$

Or $Q_{1-2} = PV \log_e\left(\frac{V_2}{V_1}\right)$

Or $Q_{1-2} = P_1V_1 \log_e\left(\frac{V_2}{V_1}\right)$

Or $Q_{1-2} = mRT_1 \log_e\left(\frac{V_2}{V_1}\right)$

Hence, the heat supplied during isothermal process is equivalent to non-flow work during the process.

Adiabatic process

The process during which work is done and no heat is transferred across the system boundary is known as adiabatic process.

Heat transferred, $Q_{1-2} = 0$

From first law of thermodynamics,

$Q_{1-2} – W_{1-2} = U_1 – U_2$

Or $Q_{1-2} – W_{1-2} = \Delta U$ .... $Q_{1-2} = 0$

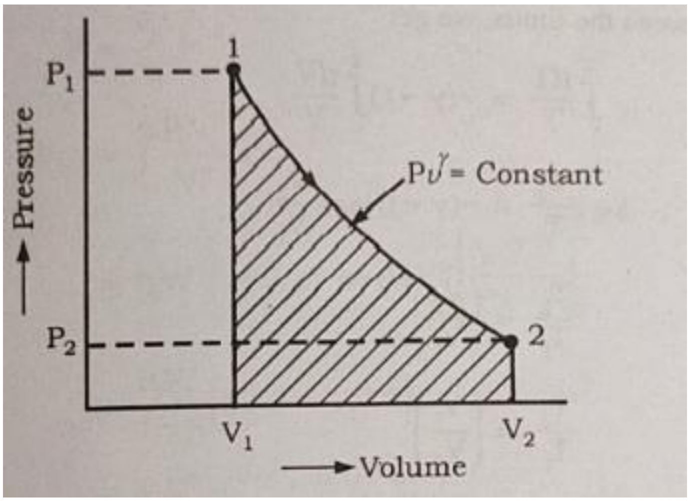
Or $– W_{1-2} = \Delta U$ .... (i)

Work done = Change in internal energy

For perfect gases, we know that

$\Delta U = m \times C_v \times (T_2 – T_1)$ .... (ii)

Also $W_{1-2} = \int_1^2 PdV$ ....(iii)



Putting the values of ΔU and W1-2 from equations (ii) and (iii) in equation (i), we get

$$-\int_1^2 PdV = m.C_V (T_2 - T_1)$$

Or $PdV = -m.\ C_V\ dT$ ………. (iv)

But $PV = mRT$

Or $P = \frac{mRT}{V}$ ……….. (v)

Putting the value of P from equation (v) in equation (iv), we get

$$\frac{mRT}{V}.dV = -m.C_V.dT$$

Or $\frac{dT}{T} = \frac{-R}{C_V} \times \frac{dV}{V}$ ……. (vi)

Now $R = C_P - C_V$

$$\frac{R}{C_V} = \frac{C_P - C_V}{C_V}$$

$$= \frac{C_P}{C_V} - 1$$

$$= \gamma - 1 \qquad \ldots\ldots\ldots (vii)$$

Putting the value of R/C_v from (vii) in equation (vi), we get

$$\frac{dT}{T} = -(\gamma - 1).\frac{dV}{V}$$

Integrating between the limits, we get

$$\int_1^2 \frac{dT}{T} = -(\gamma - 1)\int_1^2 \frac{dV}{V}$$

$$\log e\frac{T_2}{T_1} = -(\gamma - 1)\log e\frac{V_2}{V_1}$$

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

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

$$TV^{\gamma-1} = \text{Constant}$$

$$\frac{V_1}{V_2} = \frac{P_2T_1}{P_1T_2}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \times \frac{T_1}{T_2}\right)^{(\gamma-1)}$$

$$\frac{T_2}{T_1} \times \left(\frac{T_2}{T_1}\right)^{\gamma-1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1}$$

$$\left(\frac{T_2}{T_1}\right)^{\gamma} = \left(\frac{P_2}{P_1}\right)^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$PV^{\gamma} = \text{Constant}$$

$$W_{1\text{-}2} = \int_1^2 P\,dV$$

$$PV^{\gamma} = P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

$$P = \frac{P_1V_1^{\gamma}}{V^{\gamma}}$$

$$W_{1\text{-}2} = \int_1^2 \frac{P_1V_1^{\gamma}}{V^{\gamma}}\,dV$$

$$= P_1V_1^{\gamma}\int_1^2 V^{-\gamma}.dV = P_1V_1^{\gamma}\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_1^2$$

$$= \frac{P_1V_1^{\gamma}}{1-\gamma}\left[V_2^{1-\gamma} - V_1^{1-\gamma}\right]$$

$$= \frac{P_1V_1^{\gamma}.V_2^{1-\gamma} - P_1V_1^{\gamma}.V_1^{1-\gamma}}{1-\gamma}$$

$$= \frac{P_2V_2 - P_1V_1}{1-\gamma} \qquad \left(\because\ P_1V_1^{\gamma} = P_2V_2^{\gamma}\right)$$

$$= \frac{P_1V_1 - P_2V_2}{\gamma-1}$$

$$W_{1\text{-}2} = \frac{mR(T_1 - T_2)}{\gamma-1}$$

It should be noted that during reversible adiabatic process, entropy remains constant, so the process is also known as isentropic process.

Condition for isentropic process:

1. The process should be frictionless.
2. No heat should be transferred.
3. Work should be done by the gas or on the gas.
4. In real practice, isentropic process is not possible.

Isentropic Process

If an adiabatic process is reversible then it is called Isentropic process i.e., reversible adiabatic process is known as isentropic process. For an adiabatic process to qualify as isentropic process, then it should be frictionless. All the other properties of this process are same as that of adiabatic process.

Polytropic process

It is found that in actual practice many processes approximate to a reversible process of the PV^n = Constant, where n is called polytropic index. Both vapours and perfect gases follow this type of process closely. Work done during the process from state 1 to state 2 by system,

$$\int_1^2 \delta W = \int_1^2 P\,dV = \int_1^2 \frac{P_1V_1^n}{V^n}\,dV$$

$$W_{1-2} = P_1V_1^n\left[\frac{V_2^{-n+1} - V_1^{-n+1}}{-n+1}\right]$$

$$W_{1-2} = \frac{P_1V_1^nV_2^{-n+1} - P_1V_1^n\,V_1^{-n+1}}{-n+1}$$

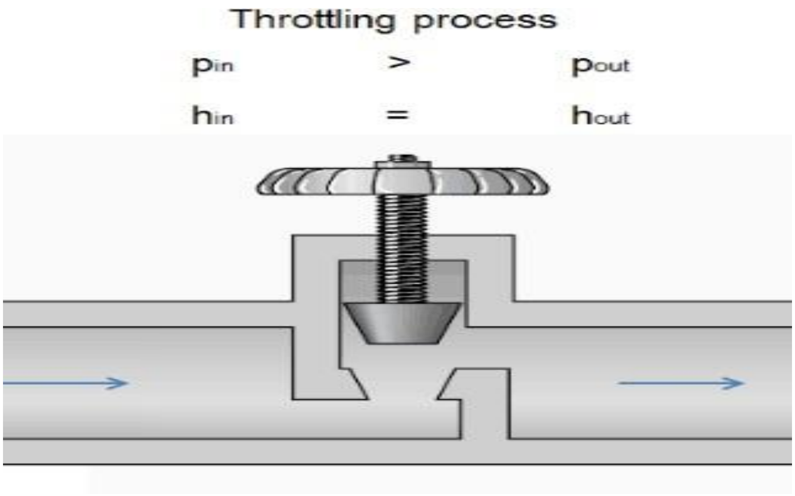
$$W_{1-2} = \frac{P_2V_2^nV_2^{-n+1} - P_1V_1^n \cdot V_1^{-n+1}}{-n+1} \qquad \left(\because P_1V_1^n = P_2V_2^n\right)$$

$$W_{1-2} = \frac{P_2V_2 - P_1V_1}{-n+1}$$

$$W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}$$

Throttling process

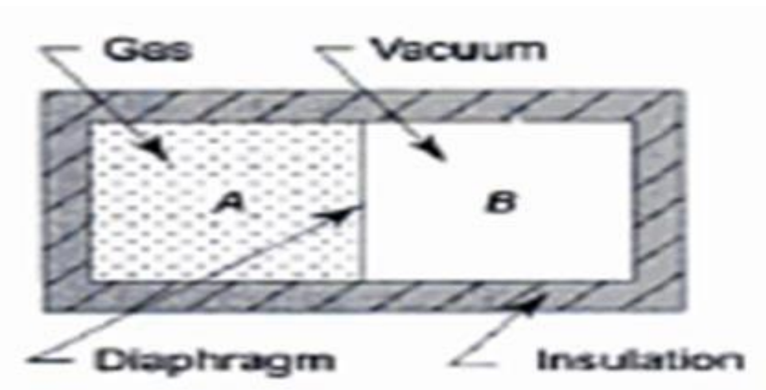
The throttling process is an irreversible steady flow expansion process in which a perfect gas is expanded through an orifice of minute dimensions such as a narrow throat or as lightly opened valve.



Due to fall in pressure during expansion, the gas should come out with a large velocity, but due to high frictional resistance between the gas and the walls of the aperture, there is no considerable change in velocity. The kinetic energy of the gas is converted into heat which is utilized in warming the gas to its initial temperature. Since no heat is supplied or rejected during the throttling process and also no work is done. There is no change in enthalpy from one state to another, $h_1 = h_2$; no work is done, $W = 0$; and the process is adiabatic, $Q = 0$.

Free expansion process

The expansion of gas in perfect vacuum is called free expansion. Consider a properly insulated cylinder with a partition and stopper. Now place some gas on one side and evacuate other side. When stopper is removed the gas expands freely to the other side of cylinder. This process is called free expansion or irreversible isothermal process.



Since it is properly insulated no heats enters or leave the cylinder (adiabatic) and temperature of gas remains constant i.e., isothermal. The matter inside cylinder does not cross the system boundaries (walls of cylinder) hence work done is 0. Since temperature is constant, there is no change in internal energy of system.

$$\delta Q - \delta W = dU$$

Since, $dU = 0$, Thus, internal energy of system remains constant.

$$H = U + PV$$

STEAM BOILERS

A steam generator or a boiler is defined as a closed vessel in which water is converted into steam by burning of fuel in presence of air at desired temperature, pressure and at desired mass flow rate.

Function of a boiler

The steam generated is employed for the following purposes

- Used in steam turbines to develop electrical energy
- Used to run steam engines
- In the textile industries, sugar mills or in chemical industries as a cogeneration plant
- Heating the buildings in cold weather
- Producing hot water for hot water supply

Classification of Boilers

The different ways to classify the boilers are as follows

1. According to location of boiler shell axis

a) Horizontal
b) vertical
c) Inclined boilers.

When the axis of the boiler shell is horizontal the boiler is called **horizontal boiler.**

Example: Lancashire boiler, Locomotive boiler, Babcock and Wilcox boiler etc.

If the axis is vertical, the boiler is called **vertical boiler**

Example: Cochran boiler.

If the axis of the boiler is inclined, it is known as **inclined boiler**.

2. According to the flow medium inside the tubes

a) Fire tube
b) Water tube boilers.

The boiler in which hot flue gases are inside the tubes and water is surrounding the

tubes are called **fire tube boilers**.

Example: Lancashire, locomotive, Cochran and Cornish boilers

When water is inside the tubes and the hot gases are outside, the boiler is called **water tube boiler.**

Example: Simple vertical boiler, Babcock and Wilcox boiler.

3. According to Boiler Pressure

According to pressure of the steam raised the boilers are classified as follows;

a) Low pressure (3.5 - 10 bar)
b) Medium pressure (10-25 bar)
c) High pressure boilers(> 25 bar)

Examples

Low pressure: Cochran and Cornish boiler

Medium pressure: Lancashire and Locomotive boiler

High pressure: Babcock and Wilcox boiler.

4. According to the draft used

a) Natural draft
b) Artificial draft boilers

Boilers need supply of air for combustion of fuel. If the circulation of air is provided with the help of a chimney, the boiler is known as **natural draft boiler**. When either a forced draft fan or an induced draft fan or both are used to provide the flow of air the boiler is called **artificial draft boiler**.

Examples

Natural draft boiler: Simple vertical boiler, Lancashire boiler.

Artificial draft boiler: Babcock and Wilcox boiler, Locomotive boiler.

5. According to Method of water circulation

a) Natural circulation
b) Forced circulation

If the circulation of water takes place due to difference in density caused by temperature of water, the boiler is called **natural circulation boiler**. When the circulation is done with the help of a pump the boiler is known as **forced circulation boiler**.

Examples

Natural circulation: Babcock & Wilcox boiler, Lancashire boiler

Forced circulation: Velox boiler, Lamont boiler, Loffler boiler

6. According to Furnace position

a) Internally fired
b) Externally fired boilers

When the furnace of the boiler is inside its drum or shell, the boiler is called **internally fired boiler.** If the furnace is outside the drum the boiler is called **externally fired boiler.**

Examples

Internally fired boiler: Simple vertical boiler Lancashire boiler, Cochran boiler

Externally fired boiler: Babcock and Wilcox boiler

7. According to type of fuel used

a) Solid
b) Liquid
c) Gaseous
d) Electrical
e) Nuclear energy fuel boilers

The boiler in which heat energy is obtained by the combustion of solid fuel like coal or lignite is known as **solid fuel boiler**. A boiler using liquid or gaseous fuel for burning is known as **liquid or gaseous fuel boiler**. Boilers in which electrical or nuclear energy is used for generation of heat are respectively called as **electrical energy headed boilers** and **nuclear energy heated boiler.**

8. According to number of Tubes

a) Single-tube
b) Multi-tube boiler

A boiler having only one fire tube or water tube is called a **single tube boiler**. The boiler having two or more, fire or water tubes is called **multi tube boiler**.

Examples

Single tube boiler: Cornish boiler, Vertical boiler.

Multi-tube boiler: Lancashire boiler, Locomotive boiler, Babcock and Wilcox boiler.

9. According to Boiler Mobility

a) Stationary
b) Portable
c) Marine boilers

When the boiler is fixed at one location and cannot be transported easily it is known as **stationary boiler.** If the boiler can be moved from one location to another it is known as a **portable or mobile boiler**. The boilers which can work on the surface of water are called **marine boilers**.

Examples

Stationary: Lancashire, Babcock and Wilcox boiler, vertical boiler

Portable: Locomotive boiler.

Marine: Marine boilers

Specification of a Boiler

- ❖ Size of drum (Diameter and length)
- ❖ Rate of steam generation(kg/hr)
- ❖ Heating surface (Square meters)
- ❖ Working pressure (bar)
- ❖ No. of tubes / drum

- Type of boiler
- Manufacturer of boiler
- Initial cost
- Quality of steam
- Repair and inspection facility

Comparison between water-tube and fire tube boilers

S no.	Particulars	Fire tube boilers	Water tube boilers
1.	Mode of firing	Internally fired	Externally fired
2.	Rate of steam production	lower	Higher
3.	construction	Difficult	Simple
4.	transportation	Difficult	Simple
5.	Treatment of water	Not so necessary	More necessary
6.	Operating pressure	Limited to 16 bar	Under high pressure as 100 bar
7.	Floor area	More floor area	Less floor area
8.	Shell diameter	Large for same power	Small same power
9.	explosion	Less	More
10.	Risk of bursting	lesser	More risk

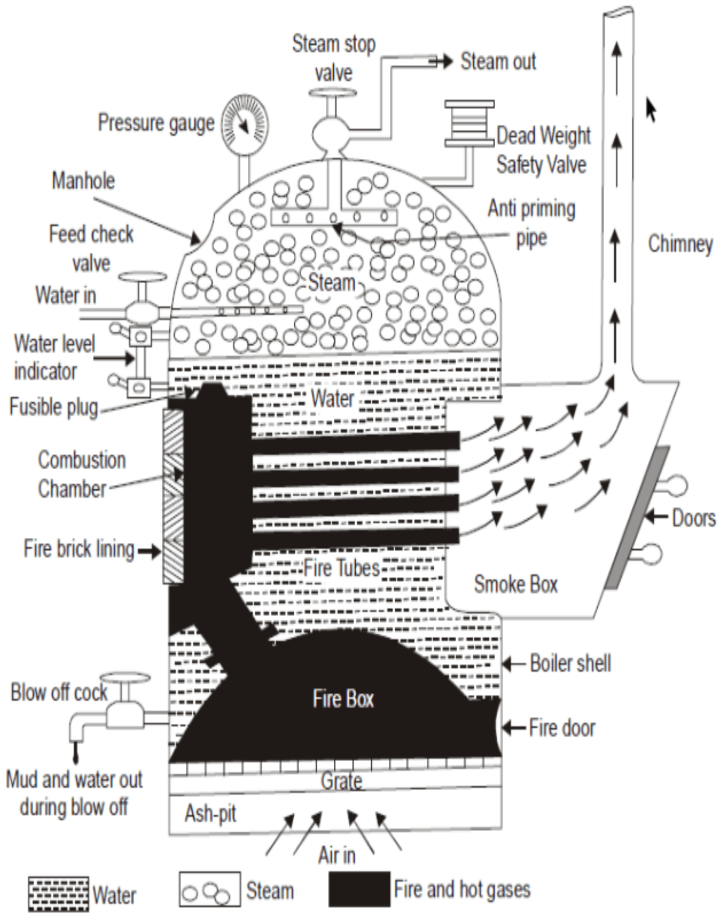
COCHRAN BOILER

It is a Vertical drum axis, natural circulation, natural draft, multi tubular, low pressure, solid fuel fired fire tube boiler with internally located furnace.

Constructional details: It consists of ;

- *Shell:* It is hemispherical on the top, where space is provided for steam.
- *Crate*: It is placed at the bottom of the furnace where coal is burnt.
- *Fire box:* It is also dome-shaped like the shell so that the gases can be deflected back till they are passed out through the flue pipe to the combustion chamber.
- *Flue pipe:* It is a short passage connecting the fire box with the combustion chamber.
- *Fire tubes*: A number of horizontal fire tubes are provided
- *Combustion chamber*: It is lined with fire bricks on the side of the shell to prevent overheating of the boiler. Hot gases enter the fire tubes from the flue pipe through the combustion chamber.
- *Chimney*: It is provided for the exit of the flue gases to the atmosphere from the smoke box.
- *Man-hole*: It is provided for inspection and repair of the interior of the boiler shell.

Normal size of a Cochran boiler is given by;
Shell diameter – 2.75 meters and Height of the shell – 6 meters.



Working of the Cochran boiler: Coal is fed into the grate through the fire hole and burnt. Ash formed during burning is collected in the ash pit provided just below the grate and then it is removed manually. The host gases from the grate pass through the flue pipe to the combustion chamber. The hot gases from the combustion chamber flow through the horizontal fire tubes and transfer the heat to the water by convection. The flue gases coming out of fire tubes pass through the smoke box and are exhausted to the atmosphere through the chimney. Smoke box is provided with a door for cleaning the fire tubes and smoke box.

Advantages of Cochran Boiler

- Low initial installation cost.
- It requires less floor area.
- Easy to operate and handle.
- Transportation of Cochran boiler is easy.
- It can use all types of fuel.

Disadvantages of Cochran Boiler

- Low rate of steam generation.
- Inspection and maintenance is difficult.

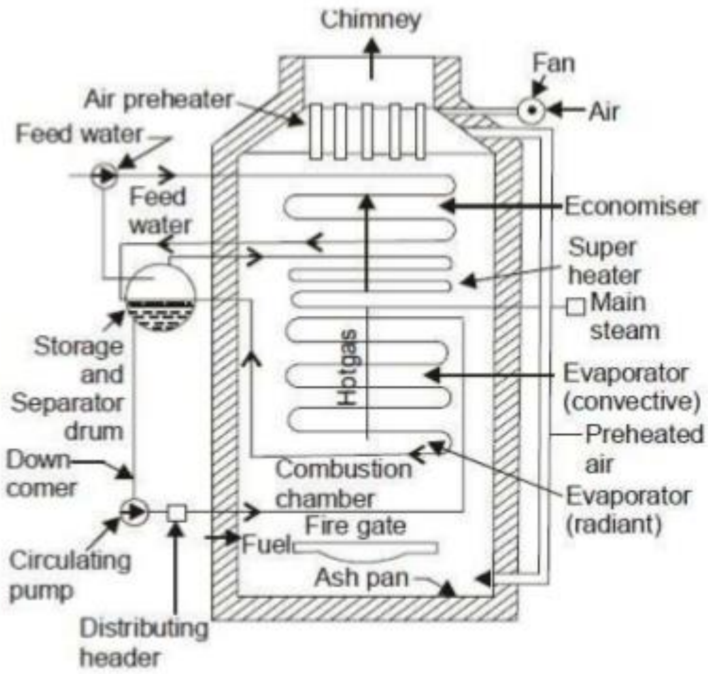
- High room head is required for its installation due to the vertical design.
- It has limited pressure range.

Applications of Cochran Boiler

- Variety of process applications in industries
- Chemical processing divisions
- Pulp and Paper manufacturing plants
- Refining units

LA MONT BOILER

La Mont boiler is a high pressure, forced circulation, water tube boiler with internally fired furnace. An external pump is used to circulate the water within small diameter water tubes of the boiler.



This boiler works on basic principle of forced convection. If the water is circulating by a pump inside the tube, the heat transfer rate from gas to the water is increases. It is the basic principle of it.

Working

- In Lamont boiler, the feed pump circulates the water in the economiser of the boiler. The economiser heats the water to some degree. From economiser, water enters into steam separating drum.

- From steam separating drum the mixture of water and steam is forced circulated through the radiant evaporator by an external centrifugal pump. In forced circulation, the pressure of circulation of water through the tubes is more as compared with the natural circulation.

- Radiant evaporator heats the water and changes it into steam. Form radiant evaporator the water-steam mixture passes through the convective evaporator. Here the temperature of the fluid increase and most the water gets converted into saturated steam. And after that the saturated steam enters into the steam separator drum.
- The steam separator drum as names indicates separates the steam from water. The steam gets collected at the upper portion of the drum. From steam separator drum, steam passes through the super heater. The super heater increases the temperature of the steam to the desired level. And finally the superheated steam is either transfer to the steam collecting drum or made to strike on the blades of the turbine.
- The working pressure, temperature and capacity of this boiler is 170 bar, 773 K and 50 tonnes/hour.

Advantages:

1. It is a high pressure boiler.

2. It is flexible in design.

3. This boiler can be reassembled into natural circulation boiler.

4. It can be easily started.

5. It has high steam generation capacity of about 50 tonnes/ hour.

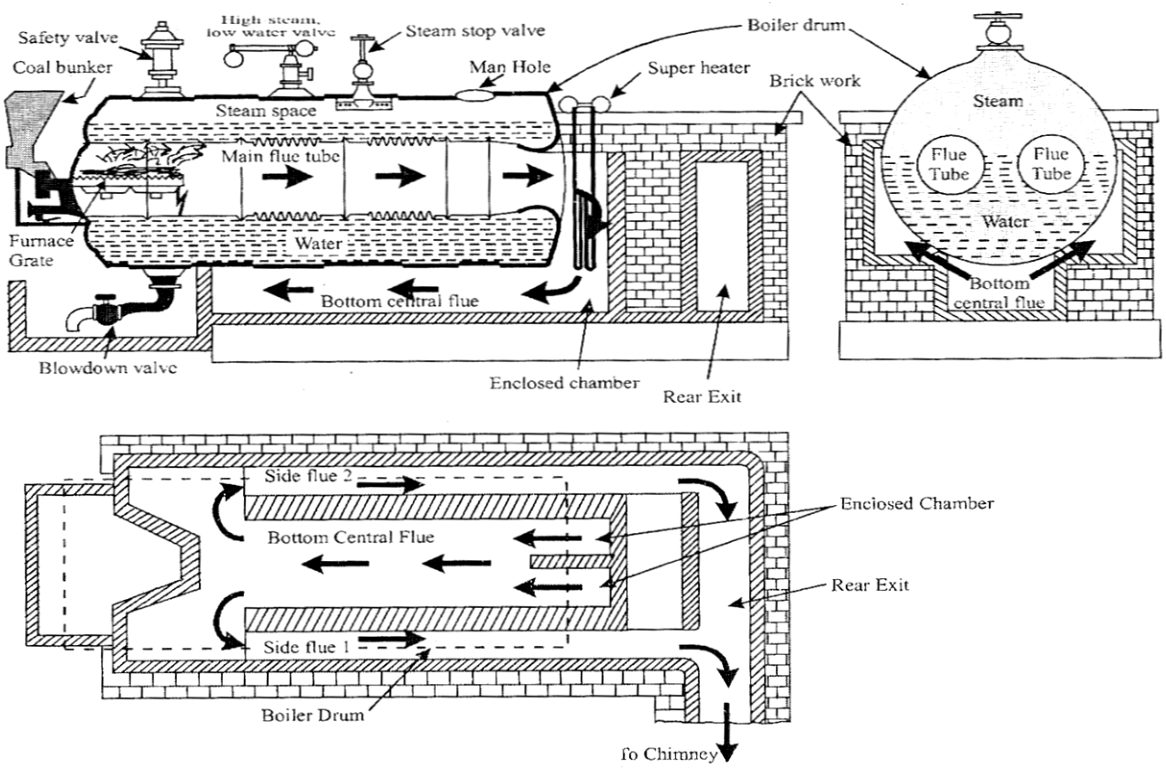
6. This boiler has higher heat transfer rate.

Disadvantages:

There is a bubble formation at surfaces of the tubes in this boiler. This reduces the heat transfer rate to the steam.

Lancashire boiler:

Lancashire boiler is a stationary, fire tube boiler which is constructed for normal working pressure up to 15 bar and 8500 kg of steam per hour. This boiler is widely used in sugar mills and chemical industries.



Construction:

The cylindrical shell is placed horizontally over brickwork and partly (3/4th) filled with water. The water level inside the boiler should be above the furnace tube which is constructed inside the drum as in figure

Two large tubes called furnace or flue tubes extend throughout the length of boiler drum. In each flue tubes two furnace greats are provided inside for burning fuel with ash pit at their rear end. The diameter of these flue tubes are made about 0.3 to 04 times of the boiler, in order to get in grates of sufficient area for burning. The brick work setting provides enclosed chamber for each of the flue tubes at the rear end of the boiler shell, which in turn connected to side channels

1 & 2 at their front end. The two side channels are connected to their rear end to a common rear passage which is connected to chimney.

Working:

The fuel is charged on grates and burned with a large quantity of air to produce hot gases. Initially the **first run** of hot gas passes inside the drum and from front end to rear end. During this heat transfer takes place from hot gas to water along the walls of the flue tubes.The hot gasses then emerge to rear enclosed chamber in the rear end, then pass downwards and unite. Now in **second run** hot gases pass from bottom portion of the boiler shell to bottom central channel. After second run hot gases divide at the front end of boiler shell and enters side channel 1 & 2 for third run. During the third run hot gasses pass through side channels to rear end of boiler and make their exit to chimney. During **third run** heat transfer takes place between hot gas and water through a portion of boiler shell exposed to side channel. Finally, steam accumulates in the boiler shell and can be taken out through stop valve.The boiler is mounted with essential mountings and accessories like stop valve, safety valve, blow off valve, pressure gauge, water gauge etc with **super heater** if required.

Babcock and Wilcox boiler:

Babcock and Wilcox boiler is a stationary, water tube, natural circulation boiler. It has a capacity to produce steam up to 40 bar and 4000 kg / hour. This type of boiler is used in thermal power plants, etc.

Construction and working:

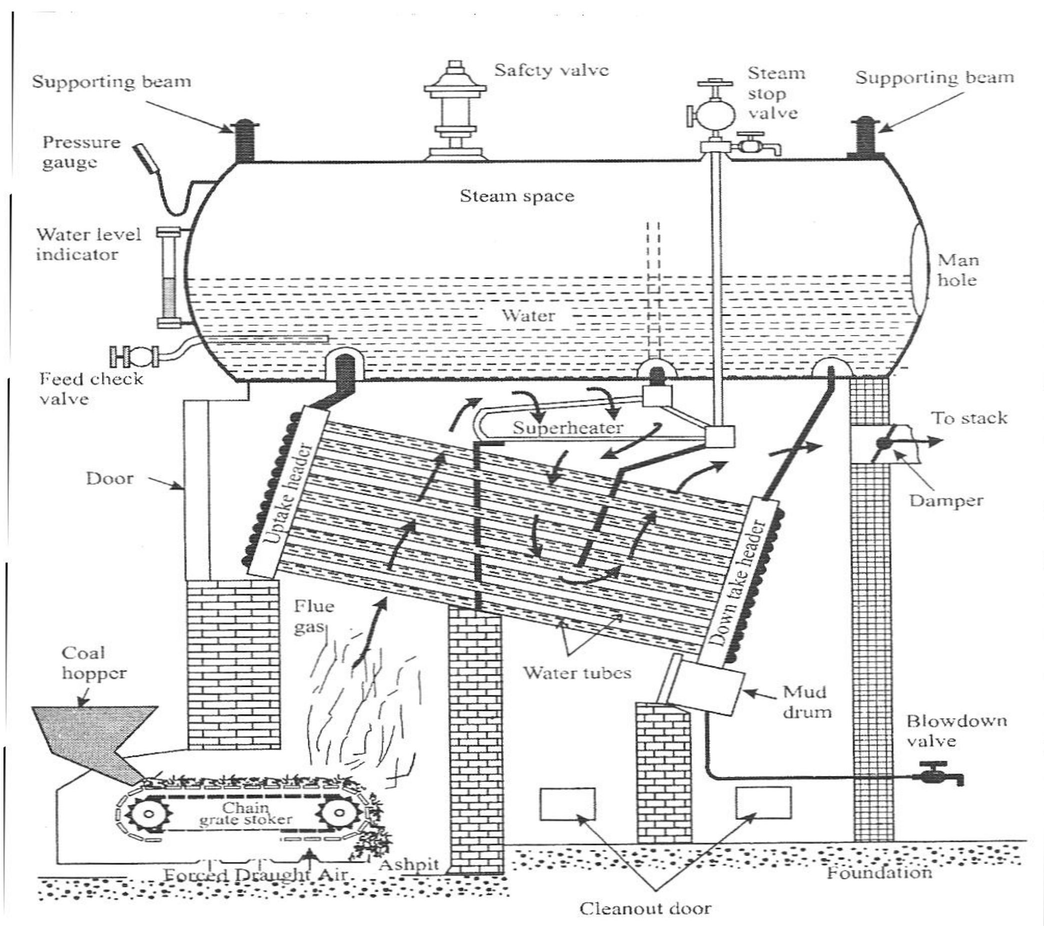
This boiler mainly consists of,

- Water tubes
- Water and steam drum
- Chain grate stoker
- Super heater
- Mud box

Water tubes: Water tubes are placed between the furnace at an inclined position which connect uptake and down take. The drum is connected at the front end to uptake and at backend to down take. The fire brick baffles make the hot gases to move in the upward direction then downward and again upward before leaving through chimney.

Water and steam drum: A horizontal drum is placed above the water tubes and is half filled with water and steam remains on other half. The portion of water tubes which is just above the furnace is heated more compared to others, the water density increases and rises to drum through the uptake where steam particles separate from water and collect over water surface. The water from drum comes down through down take into water tubes and move up again to drum through uptake, by this circulation of become continues.

Chain grate stoker: - The high capacity boilers are generally provided with chain grate stoker. It has slowly moving endless chain of grate bars and coal is feed at the front end of grate and burnt while moving on grate in furnace and residual ash will falls at other end.



Boiler draught

- Difference in gas pressure at any point in a flow passage and the ambient (same elevation) atmospheric pressure.
- Draught is achieved by a small pressure difference which causes the flow of air or gas to take place.
- It is measured in millimetre (mm) or water.
- To move the air through the fuel bed and to produce a flow of hot gases through the boiler economiser, preheater and chimney require a difference of pressure.
- Draught can be achieved by the use of chimney, fan, steam or air jet or a combination of these.

Purpose of Boiler Draught

1. To provide an adequate supply of air for fuel combustion.

2. For throw out the exhaust gases of combustion from the combustion chamber.

3. To discharge these gases to the atmosphere through the chimney.

Types of Draught

1. Natural Draught

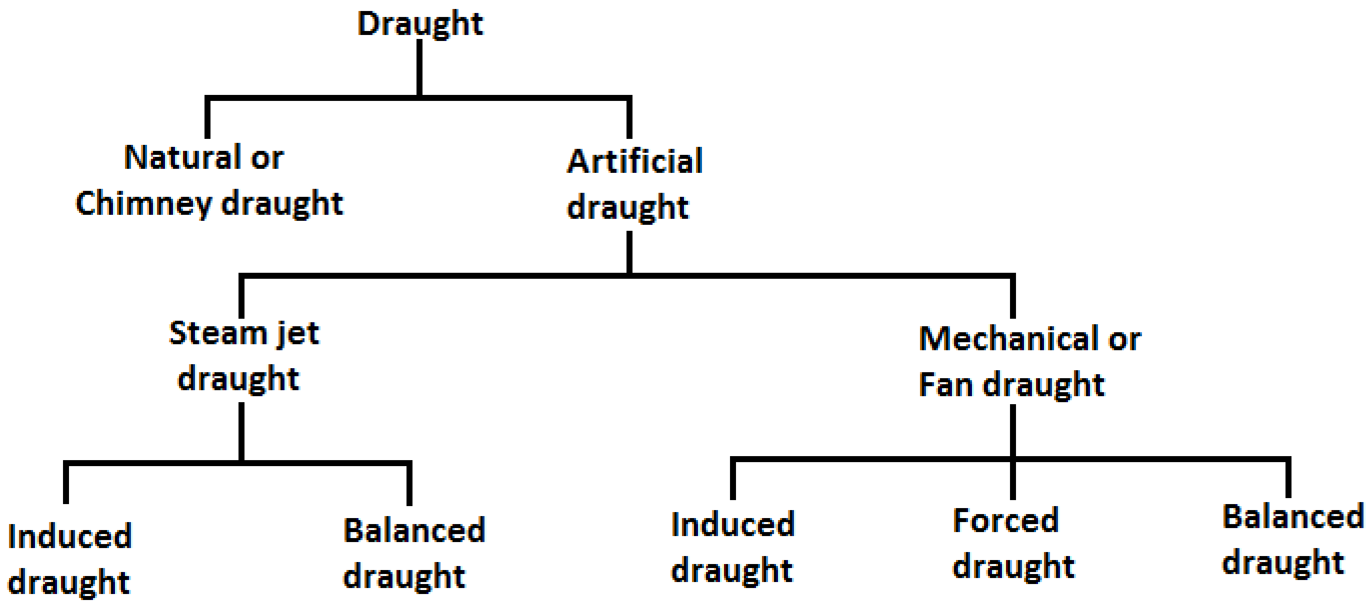
2. Artificial Draught

Measurement of Draught

The amount of draught produce depends upon:

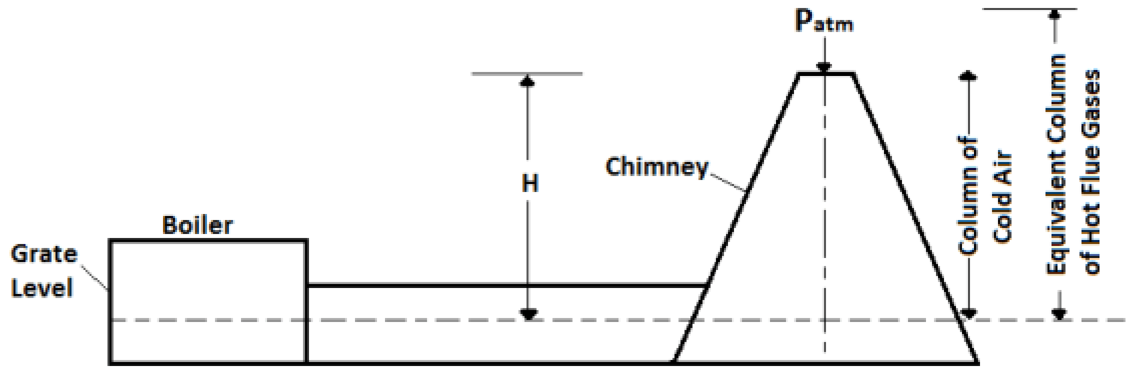
1. The nature and depth of fuel at the furnace.
2. Design of combustion chamber or firebox.
3. The rate of combustion required.
4. Resistance is allowed in the system due to baffles, tubes, superheaters, economizers, air pre-heaters etc.

Classification of Boiler Draught



Natural Draught

Natural draught system employs a tall chimney as shown in the figure. The chimney is a vertical tubular masonry structure or reinforced concrete. It is formed for enclosing a column of flue gases to produce the draught.



Natural Draught

It removes the gases high enough to prevent air pollution. The draught is produced by this tall chimney due to the temperature difference of hot gases in the chimney and cold external air outside the chimney.

Advantages of Natural Draught

1. No external power requires.
2. Less capacity investment
3. The maintenance cost is low as there is no mechanical part.
4. Chimney keeps the flue gases at a high place in the atmosphere which prevents the contamination of the atmosphere.
5. it has a long life.

Disadvantages of Natural Draught

1. The maximum pressure available for producing natural draught by the chimney is hardly 10 to 20 mm of water under the normal atmospheric and flue gas temperatures.
2. The available draught reduces with increases in outside air temperature and for generating enough draught, the exhaust gases have to be discharged at relatively high temperatures resulting in the loss of overall plant efficiency. Thus maximum utilization of Heat is not possible.

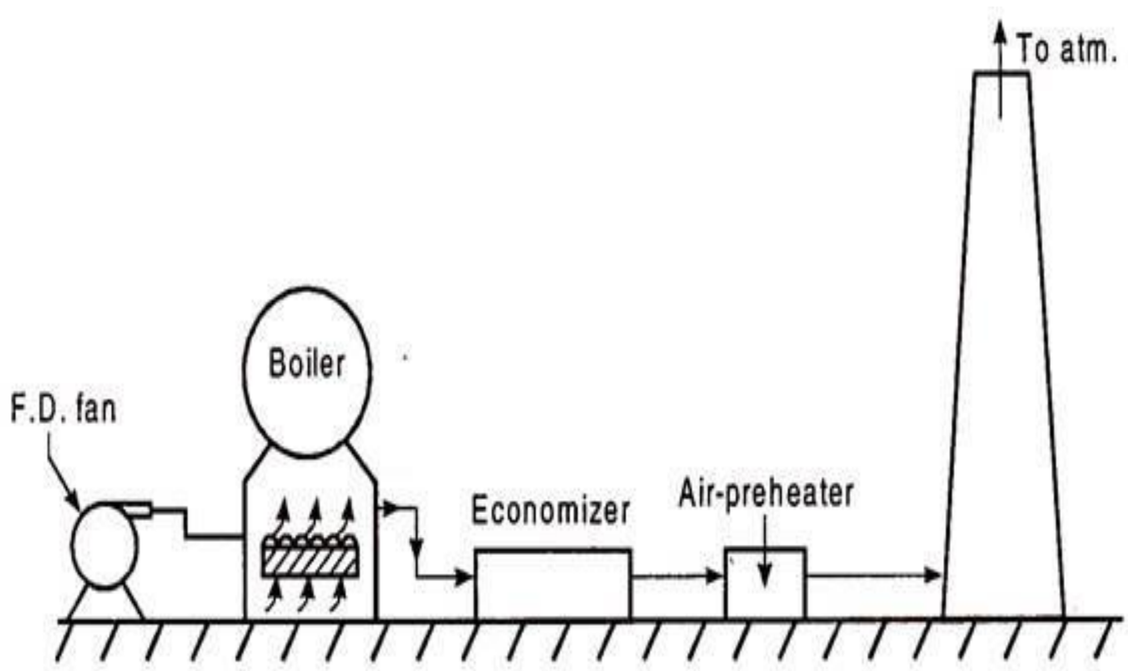
Artificial Draught:

In bigger power plants, the draught of the order of 25-350 mm of H_2O column is required. Far producing this much draught, the chimney height has to be increased considerably, which is neither convenient nor economical. Also, since the draught depends upon the climatic conditions, some mechanical equipments are used for producing the required draught and the draught so produced is called as the artificial draught.

1. **Forced Draught:**

In a Forced draught system, a Fan or Blower is provided is shown in figure which forces the air in the combustion chamber. In the combustion chamber combustion of air and fuel takes place and hot gases generated. These gases are forced to pass through the flues, economiser, air pre-heater and then they are exhausted after recovering heat of flue gases. This draught system is known positive draught system, since the pressure of gases throughout the system is above atmospheric pressure.

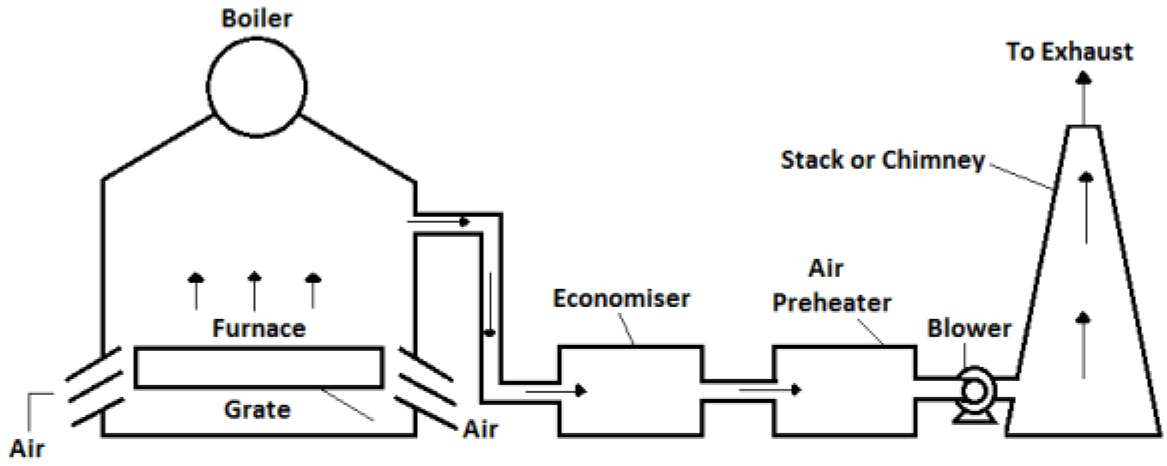
It is to be noted that, the function of chimney use is to discharge the gases high in the atmosphere to reduce air pollution and it is not much significant for producing draught.



ii. Induced Draught:

In this system, the Blower or Induced Draught fan is located near the base of chimney. The air is sucked in the system, by reducing the pressure through the system below atmosphere. The flue gases, generated after combustion are drawn through the system and after recovering heat in the economiser, air-preheater, they are exhausted through the chimney to the atmosphere.

Here it is to be noted that the draught produced is independent of the temperature of hot gases, so the gases may be discharged as cold as possible after recovering as much heat as possible.



Induced Draught System

Advantages of Forced Draught (F.D.) over Induced Draught (I.D.):

i. The size and power required by I.D. fan is more because this fan handles more gases.

ii. Since the I.D. fan handles hot gases, water cooled or air cooled bearings are to be used.

iii. F.D. fan consumes less power and normal bearing can be used.

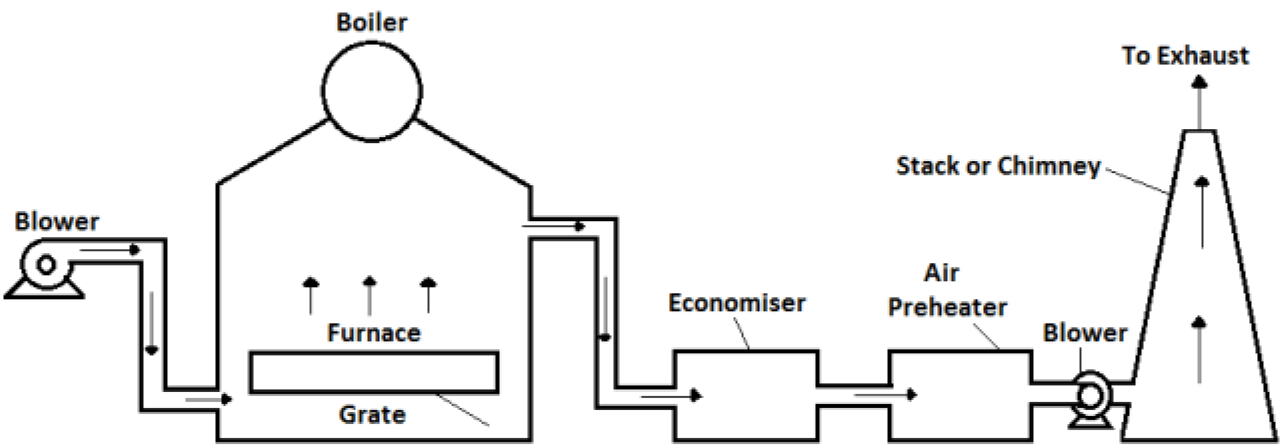
iii. Balanced Draught:

It is always preferable to use combinations of I.D. and F.D. instead of Forced or Induced draught alone.

If Forced Draught alone is used then the furnace cannot be opened for firing or for inspection. Because the high pressure air/gases inside the furnace will try to blow out, and there is every chance of blowing out of the fire completely and the furnace may stop.

If Induced Draught fan alone is used, then also furnace cannot be opened either for firing or for inspection. Because the cold air will try to rush into the furnace, which reduces the effective draught.

To overcome both these difficulties Balanced Draught is used. In this case I.D. fan and F.D. fan are provided as shown.



Balanced Draught System

Steam Jet Draught

It is a very simple and easy method of producing artificial draught without the need for an electric motor. It may be forced or induced depending on where the steam jet is installed. Steam under pressure is available in the boiler.

When a small position of steam is passed through a jet or nozzle, pressure energy converts to kinetic energy and steam comes out with a high velocity. This high-velocity steam carries, along with it, a large mass of air or flue gases and makes it flow through the boiler. Thus steam jet can be used to produce draught and it is a simple and cheap method.

Actually the steam jet is directed towards a fix direction and carries all its energy in kinetic form. It creates some vacuum in it's surrounding and attracts the air of flue gases either by carrying along with it. Thus it has the capacity to make the flow of the flue gases either by carrying or including towards chimney. It depends on the position of the steam jet.

Types of Steam Jet Draught

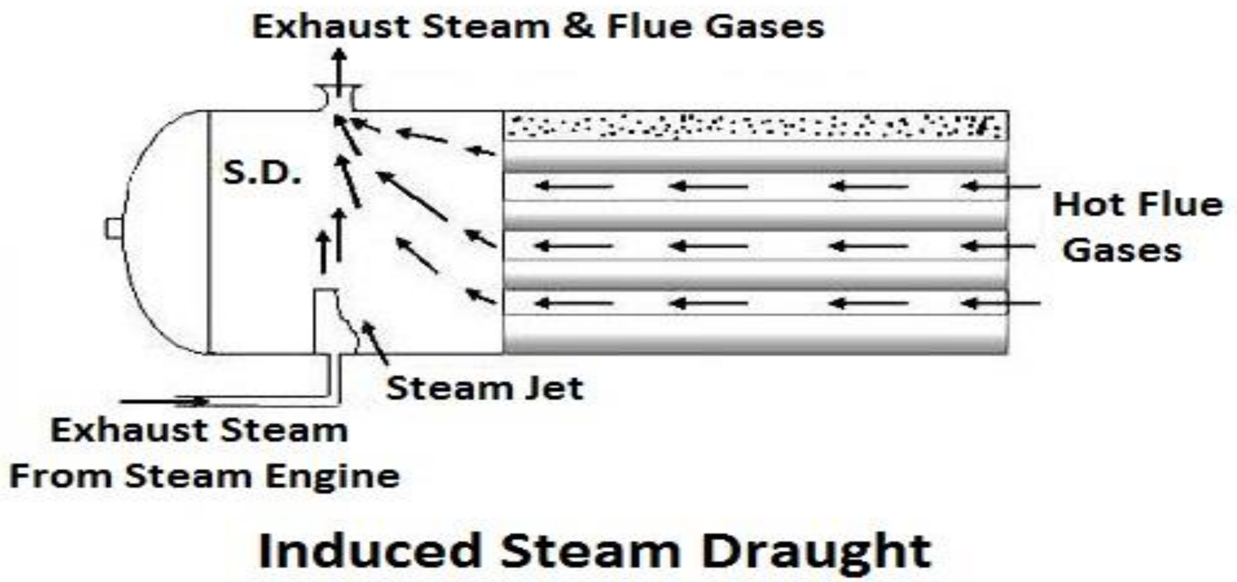
The following are the main two types of steam jet draught:

1. Induced steam jet draught.
2. Forced steam jet draught.

If the steam jet is directed into the smoke box, near, the chimney, the air is sucked through the system, into the smoke box. If the jet is Located before grate, air is forced through the system. Induced type is favoured as forced draught increases heat losses.

1. **Induced Steam Jet Draught**

The jet of steam is turned into a smoke box or chimney. The kinetic head of the steam is high but static head is low i.e., it produces a partial vacuum which brings the air through the grate, ash pit, flues and then to motor box and chimney.



Induced draught is produced by steam jet in case of Locomotive boiler. When the Locomotive in stationary, steam from the boiler may be supplied to the smoke box through the nozzle to create draught. While locomotive is running, due to motion, the air flows to the furnace.

2. **Forced Steam Jet Draught**

Steam from the boiler after having been throttled to a gauge pressure of 1.5 to 2 bar is supplied to the jet or nozzle installed in the ash pit. The steam rising out of nozzles with a great velocity drags air by the fuel bed, furnace, flue passage and then to the chimney. Here the steam jet is pushing or forcing the air and flue gases to flow through boiler hence it is forced steam jet draught.

Advantages of Induced Steam Jet Draught

1. It is quite simple and cheap.
2. The induced steam jet draught has the capability of using low-grade fuels.
3. It occupies very less space.
4. It is quite simple and cheap.
5. The initial cost is low.
6. Maintenance cost is low.
7. Exhaust steam from the steam engine or turbine can be used easily in the steam jet draught.

Disadvantages of Steam Jet Draught

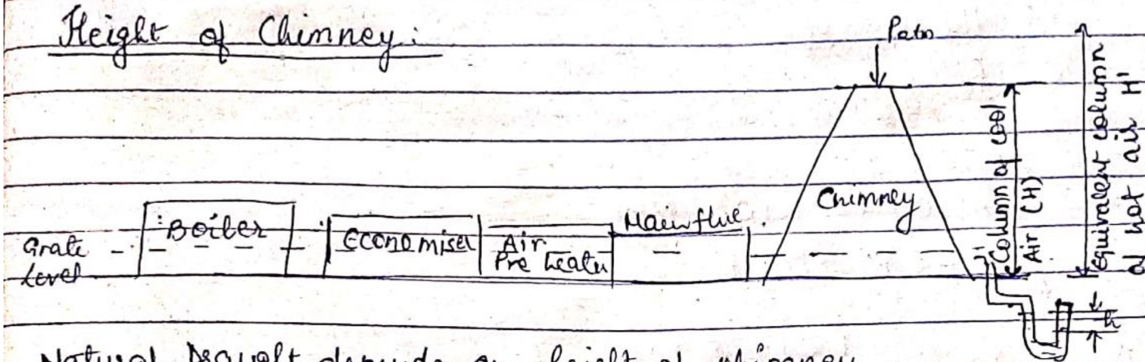
1. It can operate only when some steam is generated.
2. Draught produced very low.

Comparison Between Forced Draught and Induced Draught

Forced Draught	Induced Draught
Fan or blower is placed before the grate	Fan or blower is placed after the grate
The pressure inside the flue gases is slightly more than atmospheric pressure	The pressure inside the flue gases is slightly less than atmospheric pressure
Fan requires less power	Fan requires more power
The flow of the flue gases through the boiler is more uniform	The flow of the flue gases through the boiler is less uniform
The danger of fire in case pf leakage of flue gases.	No danger of fire in case of leakage of flue gases.

Height of Chimney :

Height of Chimney:



Natural Draught depends on height of chimney.

Let,

m_a = Mass of air supplied in kg/kg of fuel.

m_a+1 = Mass of chimney gases (kg/kg of fuel)

T_a = Absolute temperature of atmosphere

T_g = Average absolute temperature of chimney gases

P_a = Atmospheric pressure (N/m^2)

H = Height of chimney (m)

ρ_a = Mass density of air outside chimney

ρ_g' = Avg. Mass density of hot gases

∵ Static ~~Pressure~~ draught : Difference of pressure causing the flow of gases. Its value is small & generally measured by a water manometer.

$\Delta P < 12$ mm of H_2O.

Static Draught = Pressure at grate on open side (P_2) − Pressure at chimney side (P_1)

We have,

$P_1 = P_a + \rho_g' \cdot g \cdot H$ [$\rho_g' \cdot g H$ = Pressure exerted by column of hot gases of height 'H' mete

$P_2 = P_a + \rho_a g H$ [$\rho_a \cdot g H$ = Pressure due to column of cold air out side chimney of height 'H' m.

So,

$$\Delta P = P_2 - P_1 = (\rho_a - \rho_g') g H \quad (A)$$

Specific volume of air at N.T.P.

$$v_0 = \frac{R T_0}{P_0}$$

$$= \frac{0.287 \text{ kJ/kg/K} \times 273 \text{ K}}{101.325 \text{ kPa}}$$

$$= 0.7732 \text{ m}^3/\text{kg}$$

∵ The volume of ~~flued gases~~ is negligible as compared to volume of air supplied per kg of fuel

∴ Volume of flue gases can be taken equal to volume of air

From Charles Law: ($V \propto T$)

$$\frac{V_a}{T_a} = \frac{V_0}{T_0} = \frac{m_a v_0}{T_0}$$

$$V_a = \frac{m_a \times 0.7732}{273} T_a$$

So,

$$\rho_a = \frac{m_a}{V_a} = \frac{273}{0.7732} \times \frac{1}{T_a} = \frac{353}{T_a}$$

~~Similarly volume of~~

As per Avagadro's Law, the flue gas at NTP occupies same volume as air used at NTP

Similarly value of flue gases inside chimney :-

$$\frac{V_g}{T_g} = \frac{V_o}{T_o} \Rightarrow V_g = \frac{0.7732}{273} m_a T_g$$

So,
$$\rho_g = \frac{m_g}{V_g} = \frac{m_a+1}{V_g} = \frac{m_a+1}{0.7732 m_a} \times \frac{273}{T_g}$$
$$= \frac{353}{T_g}\left(\frac{m_a+1}{m_a}\right)$$

So, From eq^n (A) (B) & (C)

$$\Delta P = \left[\frac{353}{T_a} - \frac{353}{T_g}\left(\frac{m_a+1}{m_a}\right)\right] g H$$

$$\boxed{\Delta P = 353 g H \left[\frac{1}{T_a} - \left(\frac{m_a+1}{m_a}\right)\frac{1}{T_g}\right]} \; N/m^2 \quad \text{(D)}$$

In terms of water column (mm of H_2O column)

$$\Delta P = (\rho g h)_w \quad \text{where } \rho_w = 1000 \; kg/m^3$$

$$h_w = h \text{ (mm of water)} = \frac{h}{1000} \text{ meter}$$

$$\Rightarrow \Delta P = 1000 \; kg/m^3 \times g \times \frac{h}{1000} \; m$$

$$\Delta P \Rightarrow ~~1000~~ g h ~~kg/m^2~~ \quad \text{(5)}$$

So from eq^n (D) & (5)

we have

~~1000 g h =~~

$$g h = 353 g H \left[\frac{1}{T_a} - \left(\frac{m_a+1}{m_a}\right)\frac{1}{T_g}\right]$$

$$\boxed{h = 353 H \left[\frac{1}{T_a} - \left(\frac{m_a+1}{m_a}\right)\frac{1}{T_g}\right]}$$

Now assuming draught ΔP produced is equivalent to H_1 meters of burnt gases, we have

$$\Delta P = \rho_g g H_1 = 353 \left(\frac{m_a+1}{m_a}\right) \frac{1}{T_g} g H_1 \quad \text{—— (6)}$$

From eqⁿ (D) & (6)

$$\cancel{353}\left(\frac{m_a+1}{m_a}\right) H_1 \cancel{g} \frac{1}{T_g} = \cancel{353}\cancel{g} H \left[\frac{1}{T_a} - \left(\frac{m_a+1}{m_a}\right)\frac{1}{T_g}\right]$$

$$\Rightarrow \quad H_1 = H \left(\frac{m_a}{m_a+1}\right) T_g \left[\frac{1}{T_a} - \left(\frac{m_a+1}{m_a}\right)\frac{1}{T_g}\right]$$

$$\boxed{H_1 = H \left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]}$$

Now

Diameter of Chimney :

∵ The theoretical velocity of hot flue gases flows through chimney

$$C_g = \sqrt{2gH_1}$$

Consider h_f = frictional losses in column of hot flue gases
then

$$C_g = \sqrt{2g(H_1 - h_f)}$$

$$C_g = 4.43\sqrt{H_1 - h_f} \Rightarrow \sout{C_g = 4.43\sqrt{H_1} \times \sqrt{1 - \frac{h_f}{H_1}}}$$

$$C_g = 4.43\sqrt{H_1} \times \sqrt{\left(1 - \frac{h_f}{H_1}\right)}$$

$C_g = K\sqrt{H_1}$ where, $K = 4.43\sqrt{1 - \frac{h_f}{H_1}}$

Experimentally —

$K = 0.825$ for brick chimney

$= 1.1$ (steel chimney)

Mass of flue gases flowing through chimney

$$\dot{m}_g = \rho_g A C_g \quad (kg/s)$$

$$= \rho_g \left(\frac{\pi}{4} D^2\right) C_g$$

$$D^2 = \frac{4\,\dot{m}_g}{\pi \rho_g C_g}$$

$$D = 1.128 \sqrt{\frac{\dot{m}_g}{\rho_g C_g}}$$

Condition for maximum discharge through chimney

$C_g = \sqrt{2gH'}$ where $h_f = 0$

$$C_g = \sqrt{2gH\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]}$$

$$\dot{m}_g = \rho_g A C_g \quad ~~= A C_g \rho_g~~$$

$$= A\, C_g\, \rho_g$$

$$= A\left[\sqrt{2gH\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]}\right]\left[\frac{P}{RT_g}\right]$$

For maximum discharge $\frac{d\dot{m}_g}{dT_g} = 0$

Final Result ✓

$$\boxed{\frac{T_g}{T_a} = 2\,\frac{m_a+1}{m_a}}$$

⇒ $(H_1)_{max} = H$ | $(h_w)_{max} = \frac{176.5}{T_a} H$ mm of water

Unit- V

Steam Engines

In **steam engines**, the steam is utilised as the working substance. Those engines operate on the principle of the first law of thermodynamics, i.e., heat and work are mutually convertible.

In a reciprocating steam engine, as the heat energy in the steam is converted into mechanical work by the reciprocating (to and fro) motion of the piston it is also called a **reciprocating steam engine.** Moreover, as the combustion of the fuel takes place outside the engine cylinder, it is also called an external combustion engine.

Parts of Steam Engines

All the parts of a steam engine may be broadly divided into two groups i.e., stationary parts and moving parts. Although a steam engine consists of many parts, both stationary and moving.

The following are important parts of a steam engine:

1. Frame
2. Cylinder
3. Steam Chest
4. D-Slide Valve
5. Inlet and Exhaust Parts
6. Piston
7. Piston Rod
8. Cross-head
9. Connecting Rod
10. Crankshaft
11. Eccentric
12. Eccentric Rod and Valve Rod
13. Flywheel
14. Governor

1. Frame

It is a heavy cast iron part, which supports all the s as well as moving parts and holds them in a proper position. It, generally, rests on engine foundations.

2. Cylinder

It is a cast-iron cylindrical hollow vessel, in which the piston moves back and forth under steam pressure. Both ends of the cylinder are sealed and made steam tight. In small steam engines, the cylinder forms an integral part of the frame.

3. Steam Chest

It is cast as an integral part of the cylinder. It supplies steam to the cylinder with the movement of the D-slide valve.

4. D-slide Valve

D-slide valve moves in the steam chest with simple harmonic motion. Its function is to throwout the exhaust steam from the cylinder at the proper moment.

5. Inlet and Exhaust Parts

Inlet and exhaust are holes provided in the body of a cylinder for the movement of steam. The steam is admitted from the steam chest alternately to either side of the cylinder through the inlet ports. After doing its work in the cylinder, the steam is exhausted through the exhaust port.

6. Piston

It is a cylindrical disc, moving back and forth, in the cylinder because of the steam pressure. A piston working is to convert the heat energy of steam into mechanical work. Piston rings are made up of cast iron and are fitted in the grooves in the piston. Their purpose is to prevent the leakage of steam.

7. Piston Rod

It is a circular rod, which is connected to the piston on one side and crosshead to the other. Its function is to transfer motion from a piston to the cross head.

8. Cross-head

It is a link between the piston rod and the connecting rod. Its function is to control the motion of the piston rod and to prevent it from bending.

9. Connecting rod

It is made of forged steel, whose one end is connected to the crosshead and the other to the crank. Its function is to convert the reciprocating motion of the piston (or crosshead) into rotary motion of the crank.

10. Crankshaft

It is the shaft of the engine that has a crank. The crank operates on the lever principle and produces rotary motion of the shaft. The crankshaft is held on main bearings of the engine.

11. Eccentric

It is generally made of cast iron and is fitted to the crankshaft. Its working is to produce reciprocating motion to the slide valve.

12. Eccentric Rod and Valve Rod

The eccentric rod is made up of forged steel; one end is fixed to the eccentric and other to the valve rod. Its function is to convert the rotary motion of the crankshaft into to and fro motion of the valve rod. The valve rod attaches the eccentric rod and the D-slide valve. Its function is to provide a simple harmonic motion to the D-slide valve.

13. Flywheel

The flywheel is a heavy cast iron wheel, attached on the crankshaft. Its function is to prevent the fluctuation of the engine. It also prevents the jerks from the crankshaft.

14. Governor

Governor is a device which keeps the engine speed, more or less, uniform at load conditions. This is done by either controlling the amount of pressure of steam supplied to the engine.

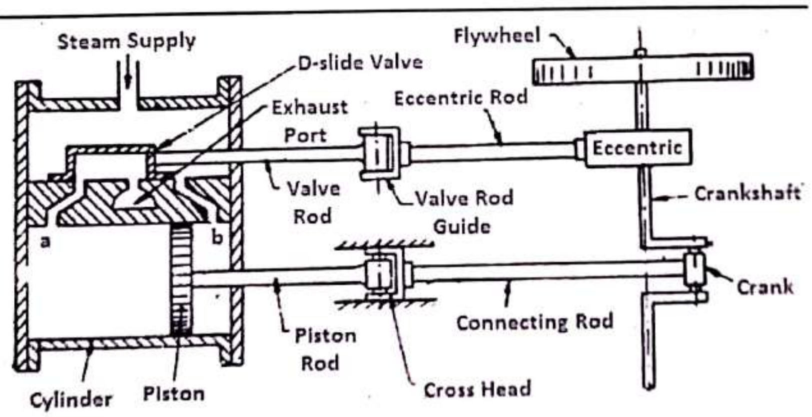
Working Principle:

Working principle of a single cylinder double acting horizontal reciprocating steam engine:

The principal parts of a single-cylinder, double-acting horizontal reciprocating steam engine are shown in the figure.

The superheated steam at high pressure (about 20 atmospheres) from the boiler is led into the steam chest. After that, the steam makes its way into the cylinder through any of the ports 'a' or 'b' depending upon the position of the D-slide valve.

When port 'a' is open, the steam rushes to the left side of the piston and forces it to the right. At this stage, the slide valve covers the exhaust port and the other steam port as shown in the figure. Since the pressure of steam is greater on the left side than that on the right side, the piston moves to the right.



Single Cylinder Double Acting Horizontal Reciprocating Steam Engine

When the piston reaches near the end of the cylinder, it closes the steam port 'a' and exhausts port. The port 'b' is now open, and the steam passes to the right side of the piston.

This forces the piston to the left and at the same time the exhaust steam goes out through the exhaust pipe, and thus completes the cycle of operation. The same process is repeated in other cycles of operation, and as such the engine works.

IC ENGINES

Internal combustion engines can be classified on the following basis.
(a) Based on number of strokes : Number of strokes involved in a cycle of IC engine can be two strokes or four strokes. Such engine can be;
(i) Two stroke engines
(ii) Four stroke engines
(b) Based on thermodynamic cycle : Depending upon thermodynamic cycle used in the internal combustion engines these can be classified as:
(i) Engines based on Otto cycle ('Spark-Ignition engine')
(ii) Engines based on Diesel or Dual cycle ('Compression-Ignition engine')
(c) Based on mechanism of ignition: Internal combustion engines have combustion as the basic process. Combustion process may be initiated using externally assisted ignition (spark ignition) or it may get initiated on its' own due to excessive compression (compression ignition). Such engines are called:
(i) Spark ignition engines
(ii) Compression ignition engines.
The spark ignition engines may have "magneto ignition system" or "battery ignition system" for creating necessary electric potential for producing spark.
(d) Based on type of fuel used: IC engines may be classified depending upon the type of fuel being used. These can be:
(i) Petrol engines (petrol being used as fuel)
(ii) Gas engines (gaseous fuel being used)
(iii) Diesel engines (diesel being used as fuel)
(iv) Multi-fuel engines (more than one fuel being used)
(e) Based on fuel admission: IC engines can be of different types depending upon arrangement used for fuel admission:
(i) Carburettor type engines (use carburettor fuel metering)
(ii) Injection type engines (use fuel injector and injection system)
(f) Based on type of cooling: IC engines have inherent requirement of continuous cooling of engine.
Based on type of cooling these can be classified as:
(i) Air cooled engines (Generally used in small sized engines)
(ii) Water cooled engines (Generally used in large sized engines)
(g) Based on type of motion: IC engines may have reciprocating motion of piston or it may also have rotary motion. Such engines can be:
(i) Reciprocating engines
(ii) Rotary engines
Reciprocating engines may have different cylinder arrangements such as:
(i) Opposed cylinder engines
(ii) Inclined cylinder engines
(iii) V-shaped cylinder arrangement.
Rotary engines may be further classified as single rotor engines or multirotor engines i.e. (i) Single rotor engine
(ii) Multi rotor engine

ENGINE: Engine is a device which converts one form of Energy into another form

− **HEAT ENGINE:** Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine.

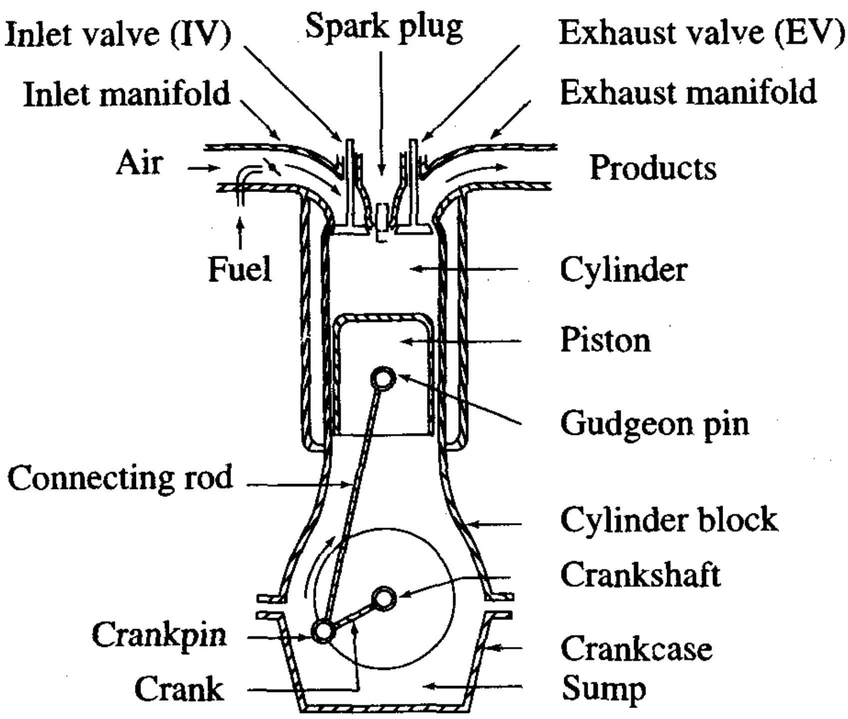
− Heat engines can be broadly classified into two categories:

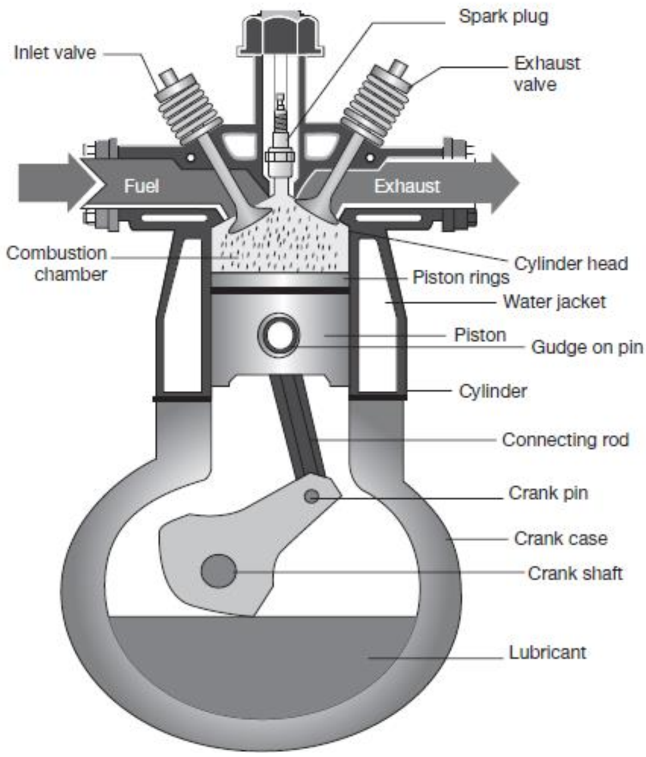
a) Internal Combustion Engines (IC Engines)

b) External Combustion Engines (EC Engines)

Engine Components

− A cross section of a single cylinder spark-ignition engine with overhead valves is shown in Fig. The major components of the engine and their functions are briefly described below.





a) Cylinder block

− The cylinder block is the main supporting structure for the various components. The cylinder of a multicylinder engine are cast as a single unit, called cylinder block. The cylinder head is mounted on the cylinder block. The cylinder head and cylinder block are provided with water jackets in the case of water cooling or with cooling fins in the case of air cooling.

b) Cylinder

− As the name implies it is a cylindrical vessel or space in which the piston makes a reciprocating motion. The varying volume created in the cylinder during the operation of the engine is filled with the working fluid and subjected to different thermodynamic processes. The cylinder is supported in the cylinder block.

c) Piston

− It is a cylindrical component fitted into the cylinder forming the moving boundary of the combustion system. It fits perfectly (snugly) into the cylinder providing a gas-tight space with the piston rings and the lubricant. It forms the first link in transmitting the gas forces to the output shaft.

d) Combustion chamber

− The space enclosed in the upper part of the cylinder, by the cylinder head and the piston top during the combustion process, is called the combustion chamber. The combustion of fuel and the consequent release of thermal energy results in the building up of pressure in this part of the cylinder.

e) Inlet manifold

− The pipe which connects the intake system to the inlet valve of the engine and through which air or air-fuel mixture is drawn into the cylinder is called the inlet manifold.

f) Exhaust manifold

− The pipe which connects the exhaust system to the exhaust valve of the engine and through which the products of combustion escape into the atmosphere is called the exhaust manifold.

g) Inlet and Exhaust valves

− Valves are commonly mushroom shaped poppet type. They are provided either on the cylinder head or on the side of the cylinder for regulating the charge coming into the cylinder (inlet valve) and for discharging the products of combustion (exhaust valve) from the cylinder.

h) Spark Plug

− It is a component to initiate the combustion process in Spark- Ignition (SI) engines and is usually located on the cylinder head.

i) Connecting Rod

− It interconnects the piston and the crankshaft and transmits the gas forces from the piston to the crankshaft. The two ends of the connecting rod are called as small end and the big end (Fig.). Small end is connected to the piston by gudgeon pin and the big end is connected to the crankshaft by crankpin.

j) Crankshaft − It converts the reciprocating motion of the piston into useful rotary motion of the output shaft. In the crankshaft of a single cylinder engine there are a pair of crank arms

and balance weights. The balance weights are provided for static and dynamic balancing of the rotating system. The crankshaft is enclosed in a crankcase.

k) Piston rings

− Piston rings, fitted into the slots around the piston, provide a tight seal between the piston and the cylinder wall thus preventing leakage of combustion gases.

l) Gudgeon pin

− It links the small end of the connecting rod and the piston.

m) Camshaft

− The camshaft (not shown in the figure) and its associated parts control the opening and closing of the two valves. The associated parts are push rods, rocker arms, valve springs and tappets. This shaft also provides the drive to the ignition system. The camshaft is driven by the crankshaft through timing gears.

n) Cams

− These are made as integral parts of the camshaft and are so designed to open the valves at the correct timing and to keep them open for the necessary duration.

o) Flywheel

− The net torque imparted to the crankshaft during one complete cycle of operation of the engine fluctuates causing a change in the angular velocity of the shaft. In order to achieve a uniform torque an inertia mass in the form of a wheel is attached to the output shaft and this wheel is called the flywheel.

p) Carburetor

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

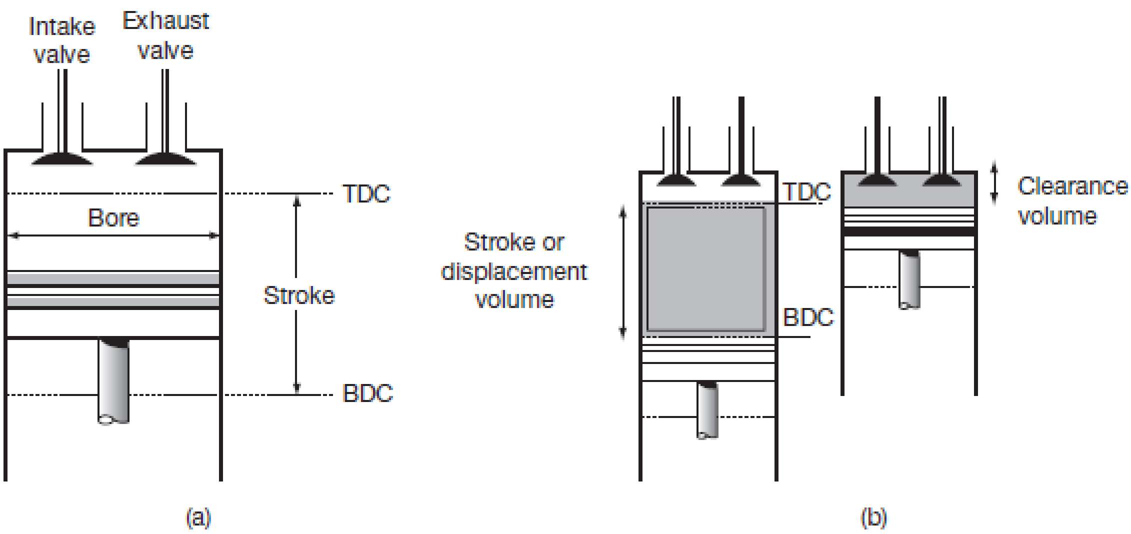
q) Fuel pump

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

r) Fuel injector

− Fuel injector is used to inject diesel fuel in the form of fine atomized spray under pressure at the end of compression stroke.

Terminologies used in IC engine



− Cylinder Bore (d): The nominal inner diameter of the working cylinder is called the cylinder bore and is designated by the letter d and is usually expressed in millimeter (mm).

− Piston Area (A): The area of a circle of diameter equal to the cylinder bore is called the piston area and is designated by the letter A and is usually expressed in square centimeter (cm^2).

− Stroke (L): It is the linear distance travelled by the piston when it moves from one end of the cylinder to the other end. It is equal to twice the radius of the crank. It is designated by the letter L and is expressed usually in millimeter (mm).

IC Engine nomenclature

− Stroke to Bore Ratio (L/d): L / d ratio is an important parameter in classifying the size of the engine.

− Dead Centre:

In the vertical engines, top most position of the piston is called Top Dead Centre (TDC). When the piston is at bottom most position, it is called Bottom Dead Centre (BDC).

In horizontal engine, the extreme position of the piston near to cylinder head is called Inner Dead Centre (IDC.) and the extreme position of the piston near the crank is called Outer Dead Centre (O.D.C.).

− **Displacement or Swept Volume (Vs):** The volume displaced by the piston in one stroke is known as stroke volume or swept volume. It is expressed in terms of cubic centimeter (cc) and given by

$$V_s = A \times L = (\pi/4)\, d^2 L$$

− **Cubic Capacity or Engine Capacity:** The displacement volume of a cylinder multiplied by number of cylinders in an engine will give the cubic capacity or the engine capacity. For example, if there are K cylinders in an engine, then

$$\text{Cubic capacity} = V_s \times K$$

− **Clearance Volume (Vc):** It is the volume contained between the piston top and cylinder head when the piston is at top or inner dead center.

− **Compression Ratio (r):** The ratio of total cylinder volume to clearance volume is called the compression ratio (r) of the engine.

$r = Total\ cylinder\ volume\ Clearance\ volume$

$\therefore r = (Vc + Vs)/Vc$

For petrol engine r varies from 6 to 10 and for Diesel engine r varies from 14 to 20.

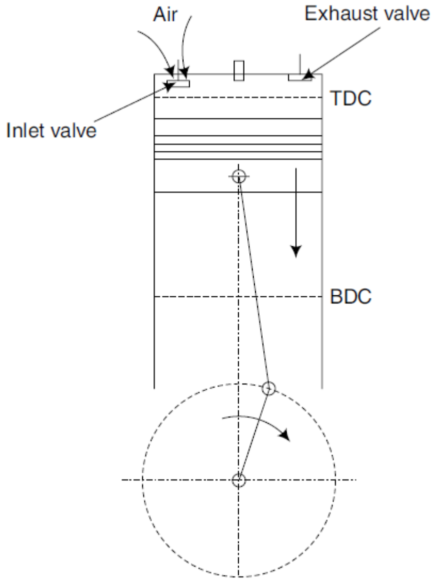
Four Stroke Spark Ignition Engine

Petrol engines are also known as spark-ignition (S.I.) engines. Petrol engines take in a flammable mixture of air and petrol which is ignited by a timed spark when the charge is compressed. The first four stroke spark-ignition (S.I.) engine was built in 1876 by Nicolaus August Otto.

In a four-stroke engine, the cycle of operations is completed in four strokes of the piston or two revolutions of the crankshaft.

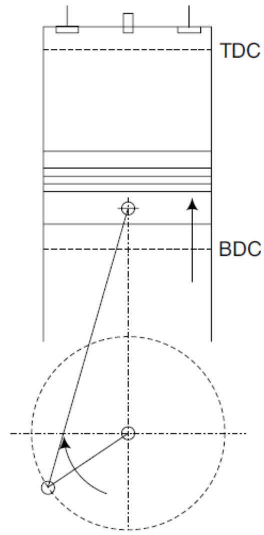
− During the four strokes, there are five events to be completed, viz., suction, compression, combustion, expansion and exhaust. Each stroke consists of 180° of crankshaft rotation and hence a four-stroke cycle is completed through 720° of crank rotation.

− The cycle of operation for an ideal four-stroke SI engine consists of the following four strokes: (i) suction or intake stroke; (ii) compression stroke; (iii) expansion or power stroke and (iv) exhaust stroke.



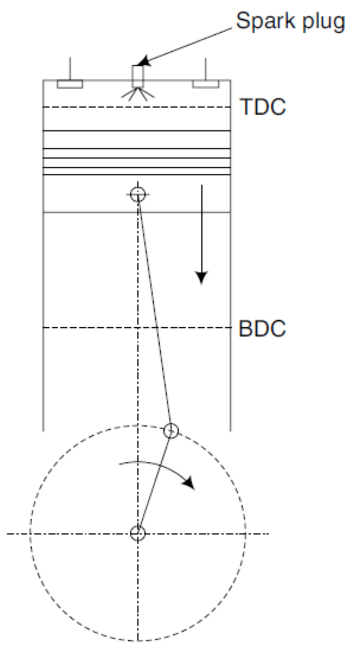
Inlet valve : OPENED
Exhaust valve : CLOSED

(a) Suction stroke



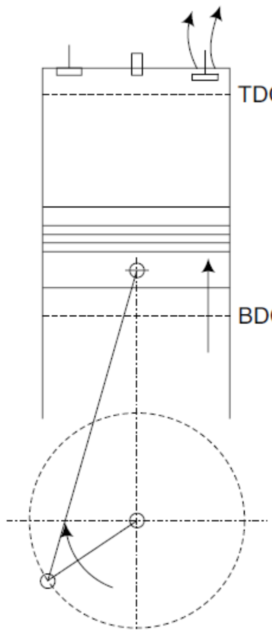
Inlet valve : CLOSED
Exhaust valve : CLOSED

(b) Compression stroke



Inlet valve : CLOSED
Exhaust valve : CLOSED

(c) Power stroke



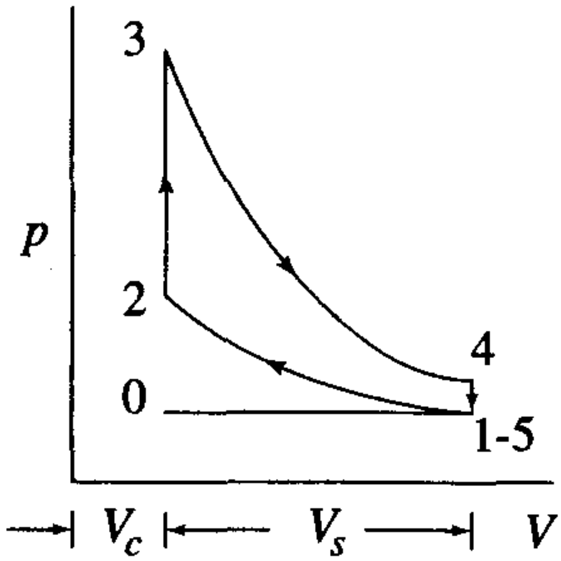
Inlet valve : CLOSED
Exhaust valve : OPENED

(d) Exhaust stroke

a) Suction or Intake Stroke:

Suction stroke $0 \rightarrow 1$ (Fig.) starts when the piston is at the top dead centre and about to move downwards. The inlet valve is assumed to open instantaneously and at this time the exhaust valve is in the closed position (a).

− Due to the suction created by the motion of the piston towards the bottom dead centre, the charge consisting of fuel-air mixture is drawn into the cylinder. When the piston reaches the bottom dead centre the suction stroke ends and the inlet valve closes instantaneously.



b) Compression Stroke: The charge taken into the cylinder during the suction stroke is compressed by the return stroke of the piston 1→2,. During this stroke both inlet and exhaust valves are in closed position, Fig. (b).

− The mixture which fills the entire cylinder volume is now compressed into the clearance volume. At the end of the compression stroke the mixture is ignited with the help of a spark plug located on the cylinder head.

− In ideal engines it is assumed that burning takes place instantaneously when the piston is at the top dead centre and hence the burning process can be approximated as heat addition at constant volume.

− During the burning process the chemical energy of the fuel is converted into heat energy producing a temperature rise of about 2000 °C (process 2→3), . The pressure at the end of the combustion process is considerably increased due to the heat release from the fuel.

c) Expansion or Power Stroke: The high pressure of the burnt gases forces the piston towards the BDC, (stroke 3→4). Both the valves are in closed position, Fig. (c). Of the four-strokes only during this stroke power is produced. Both pressure and temperature decrease during expansion.

d) Exhaust Stroke: At the end of the expansion stroke the exhaust valve opens instantaneously and the inlet valve remains closed, Fig. (d). The pressure falls to atmospheric level a part of the burnt gases escape. The piston starts moving from the bottom dead centre to top dead centre (stroke 5→0), and sweeps the burnt gases out from the cylinder almost at atmospheric pressure. The exhaust valve closes when the piston reaches TDC.

− At the end of the exhaust stroke and some residual gases trapped in the clearance volume remain in the cylinder. These residual gases mix with the fresh charge coming in during the following cycle, forming its working fluid.

− Each cylinder of a four-stroke engine completes the above four operations in two engine revolutions, first revolution of the crankshaft occurs during the suction and compression strokes and the second revolution during the power and exhaust strokes.

− Thus for one complete cycle there is only one power stroke while the crankshaft makes two revolutions. For getting higher output from the engine the heat addition (process 2→3) should be as high as possible and the heat rejection (process 3→4) should be as small as possible. Hence, one should be careful in drawing the ideal p - V diagram , which should represent the processes correctly.

Working of Four Stroke Compression-Ignition Engine

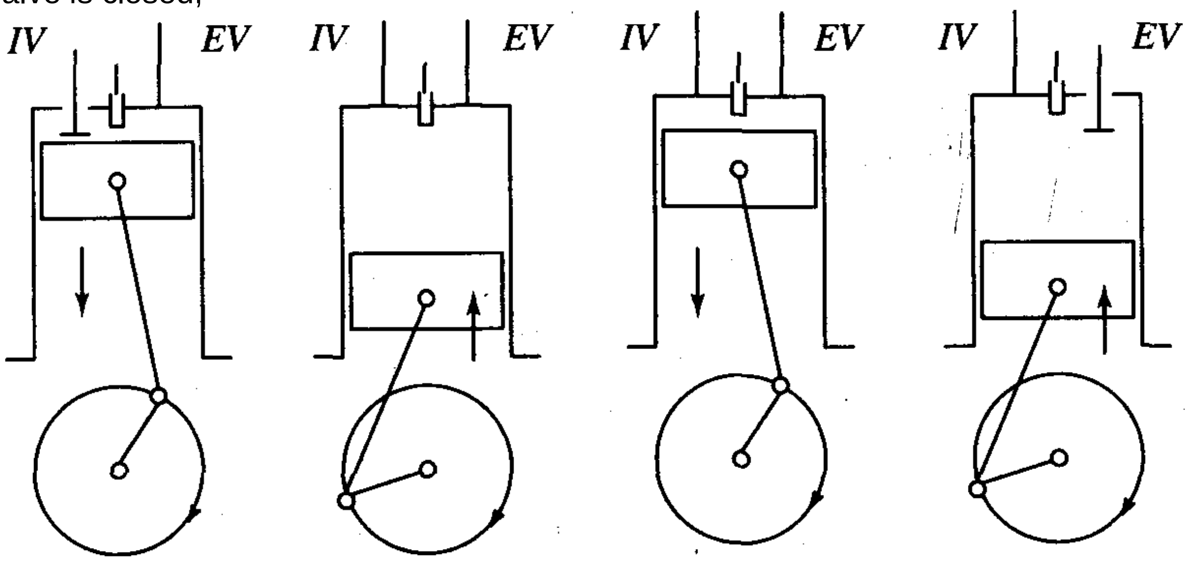
− The four-stroke Cl engine is similar to the four-stroke SI engine but it operates at a much higher compression ratio. The compression ratio of an SI engine is between 6 and 10 while for a Cl engine it is from 16 to 20.

− In the Cl engine during suction stroke, air, instead of a fuel-air mixture, is inducted. Due to higher compression ratios employed, the temperature at the end of the compression stroke is sufficiently high to self-ignite the fuel which is injected into the combustion chamber.

− In Cl engines, a high pressure fuel pump and an injector are provided to inject the fuel into the combustion chamber. The carburetor and ignition system necessary in the SI engine are not required in the Cl engine.

− The ideal sequence of operations for the four-stroke Cl engine as shown in Fig. 1.6 is as follows:

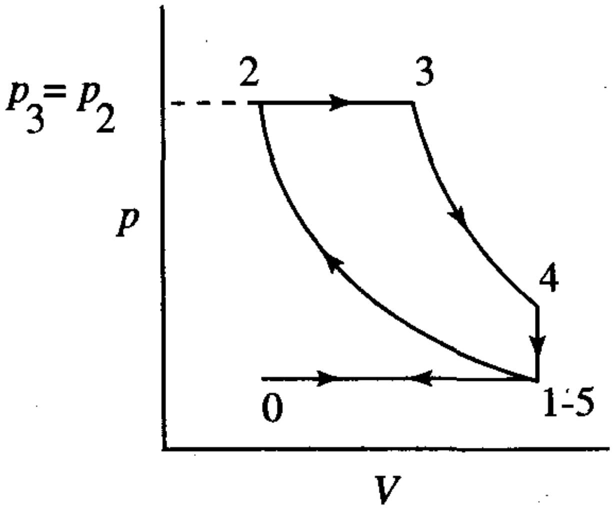
a) Suction Stroke: In the suction stroke piston moves from TDC to BDC. Air alone is inducted during the suction stroke. During this stroke inlet valve is open and exhaust valve is closed,



(a) Suction (b) Compression (c) Expansion (d) Exhaust

b) Compression Stroke: In this stroke piston moves from BDC to TDC. Air inducted during the suction stroke is compressed into the clearance volume. Both valves remain closed during this stroke, (b).

c) Expansion Stroke: Fuel injection starts nearly at the end of the compression stroke. The rate of injection is such that combustion maintains the pressure constant in spite of the piston movement on its expansion stroke increasing the volume. Heat is assumed to have been added at constant pressure. After the injection of fuel is completed (i.e. after cut-off) the products of combustion expand. Both the valves remain closed during the expansion stroke, Fig. (c).



d) Exhaust Stroke: The piston travelling from BDC to TDC pushes out the products of combustion. The exhaust valve is open and the intake valve is closed during this stroke, Fig (d).

− Due to higher pressures in the cycle of operations the CI engine has to be sturdier than a SI engine for the same output. This results in a CI engine being heavier than the SI engine. However, it has a higher thermal efficiency on account of the high compression ratio (of about 18 as against about 8 in SI engines) used.

Comparision SI AND CI Engines.

S.I. Engines	C.I. Engines
1. It is based on Otto cycle or constant volume heat addition and rejection cycle.	1. It is based on a Diesel cycle or constant pressure heat addition and constant volume heat rejection cycle.
2. A high volatile and high self-ignition temperature fuel, i.e., gasoline is used.	2. Comparatively low volatile and low self-ignition temperature fuel, i.e., diesel is used.
3. A gaseous mixture of fuel and air is inducted during the suction stroke. A carburetor is necessary to provide the mixture.	3. Fuel is injected at high pressure at the end of compression stroke. A fuel pump and injector units are used.
4. Throttle controls the quantity of fuel-air mixture introduced.	4. The quantity of fuel is regulated in the pump. Air quantity is not controlled. There is quality control.
5. For combustion of the charge, it requires an ignition system with a spark plug in the combustion chamber.	5. Autoignition occurs due to the high-temperature of air resulting from high-compression.
6. Compression ratio ranges from 6 to 10.	6. Compression ratio ranges from 16 to 20.
7. Due to light weight and homogeneous combustion, they are high-speed engines.	7. Due to heavy weight and heterogeneous combustion, they are comparatively low-speed engines.
8. It has a lower thermal efficiency due to lower compression ratio but delivers more power for same compression ratio.	8. It has a higher thermal efficiency due to high-compression ratio and delivers lesser power for the same compression ratio.

Comparision 4 stroke and 2 stroke Engines.

	4-stroke engine	2-stroke engine
1.	One working stroke for every 4 strokes or 2 revolutions.	One working stroke for every 2 strokes or one revolution.
2.	As the number of cycles is less, power output is less for the same cylinder size.	Power is more for the same cylinder size. More suitable for a diesel power plant.
3.	The weight of the engine is more for the same output power.	The weight of the engine is considerably less. So, it is more suitable for a marine engine.
4.	Operating temperature is less. So, less consumption of lubricating oil.	Operating temperature is more. So, more consumption of lubricating oil. Special piston cooling is necessary in large engines.
5.	Variation of torque is more. So, heavier flywheel is necessary.	Smaller flywheel is enough as the torque is more uniform.
6.	Noise is less.	Noise is more due to frequent exhaust.
7.	Higher thermal efficiency.	Thermal efficiency is less due to possible wastage of fuel–air mixture through the exhaust port.
8.	Due to the valve mechanism, the design and manufacture of the engine is difficult and cost is more.	Easier in design and the manufacturing cost is less.
9.	Straight piston is used.	Deflector piston is used.

Working of a two-stroke petrol engine

In a four-stroke S.I. engine, there is one power stroke in two revolutions of the crankshaft and two strokes, viz., suction and exhausts are nonproductive. If these two non-productive strokes could be served by an alternative arrangement, especially without movement of the piston then there will be one power stroke for each revolution of the crankshaft.

In such an engine, the power output can be doubled, theoretically, for the same speed compared to four-stroke engine. Based on this concept, D. Clark (1878) developed the two-stroke engine.

In two-stroke engines the cycle is completed in one revolution of the crankshaft. The main difference between two-stroke and four-stroke engines is in the method of filling the fresh charge and removing the burnt gases from the cylinder.

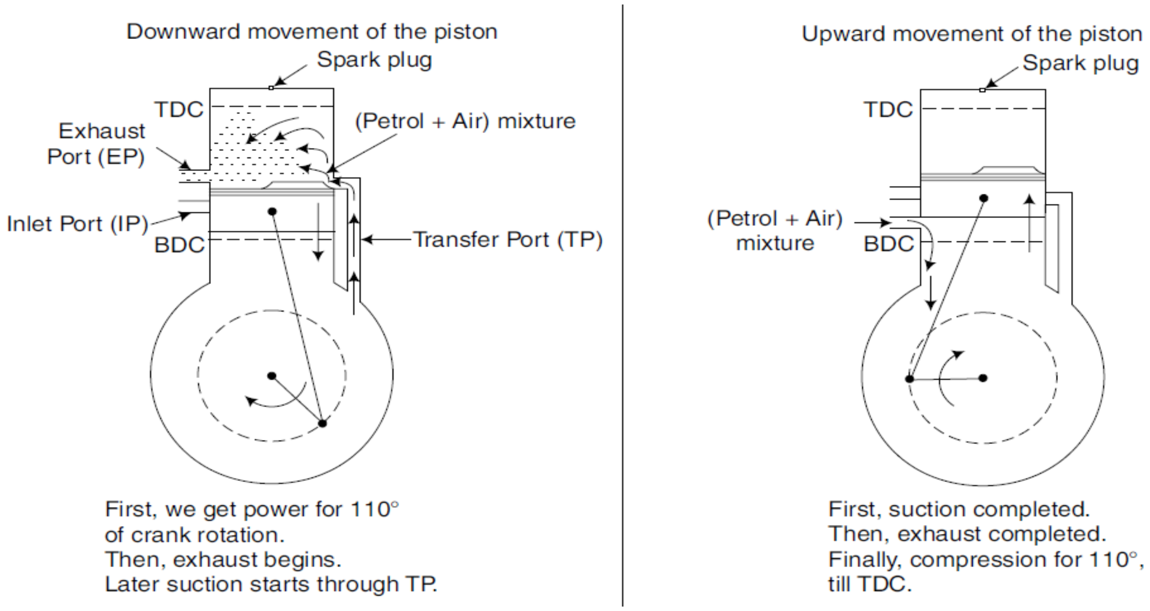
− In the four-stroke engine these operations are performed by the engine piston during the suction and exhaust strokes respectively.

− In a two- stroke engine, the filling process is accomplished by the charge compressed in crankcase or by a blower. The induction of the compressed charge moves out the product of combustion through exhaust ports. Therefore, no separate piston strokes are required for these two operations.

− Two strokes are sufficient to complete the cycle, one for compressing the fresh charge and the other for expansion or power stroke. It is to be noted that the effective stroke is reduced.

− The air-fuel charge is inducted into the crankcase through the spring loaded inlet valve when the pressure in the crankcase is reduced due to upward motion of the piston during compression stroke. After the compression and ignition, expansion takes place in the usual way.

− During the expansion stroke the charge in the crankcase is compressed. Near the end of the expansion stroke, the piston uncovers the exhaust ports and the cylinder pressure drops to atmospheric pressure as the combustion products leave the cylinder.

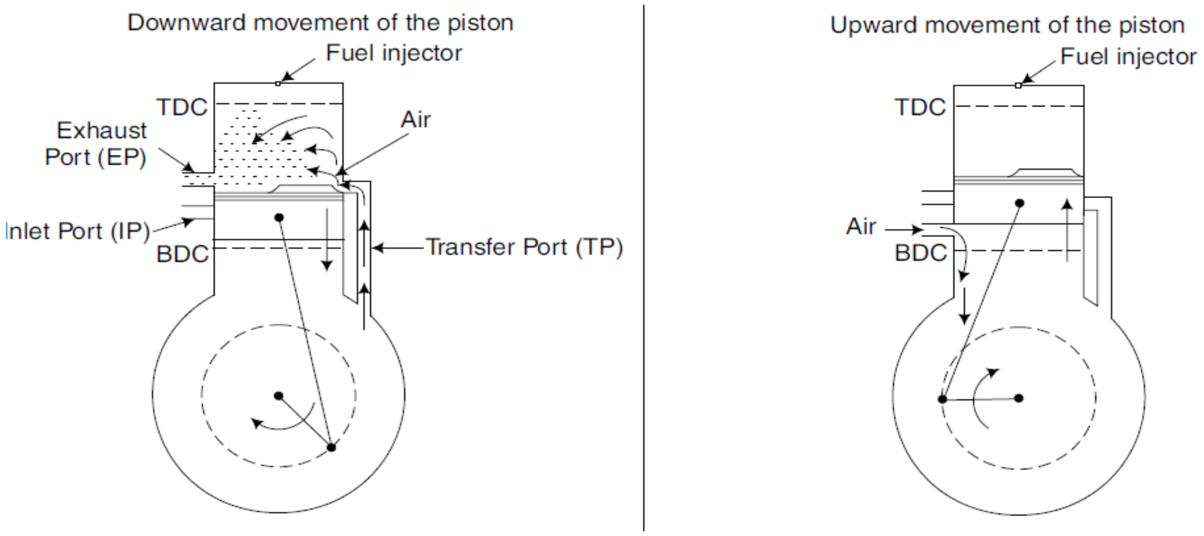


The piston top usually has a projection to deflect the fresh charge towards the top of the cylinder preventing the flow through the exhaust ports. This serves the double purpose of scavenging the combustion products from the upper part of the cylinder and preventing the fresh charge from flowing out directly through the exhaust ports.

− The same objective can be achieved without piston deflector by proper shaping of the transfer port. During the upward motion of the piston from B D C the transfer ports close first and then the exhaust ports, thereby the effective compression of the charge begins and the cycle is repeated.

Working of a two-stroke diesel engine

It is very similar to the operation of a 2-stroke petrol engine. In a 2-stroke diesel engine, the cylinder is provided with the inlet port, the transfer port and the exhaust port. The ports are opened and closed by the movement of the piston itself. The exhaust port is slightly above the transfer port.

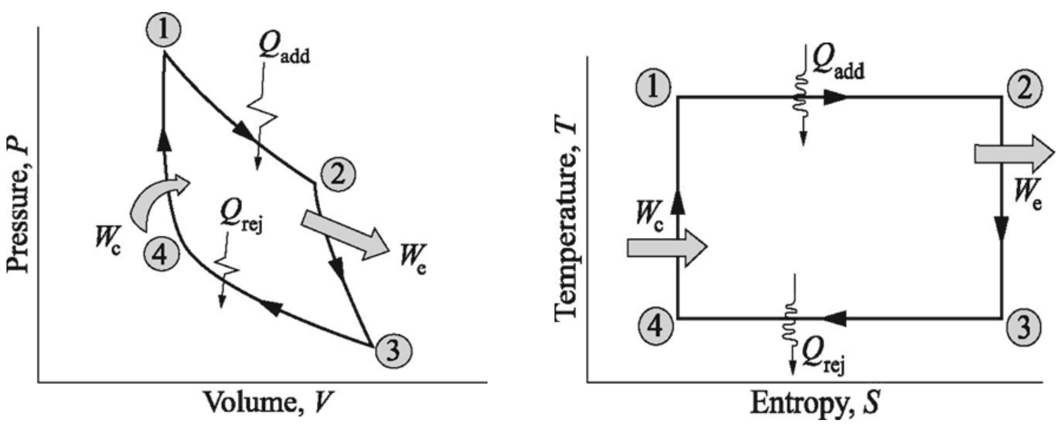


Let us study the condition when the piston is at TDC. In this position, only the inlet port is kept open and other two ports are closed. The air from the atmosphere is drawn into the crank case due to the vacuum produced by the upward movement of the piston. The air above the piston is compressed to a high temperature. The compression ratio for a diesel engine varies from 15 – 20. Diesel oil at a high pressure is injected in an atomised form into the hot compressed air. Combustion starts and the piston is pushed down due to the pressure created. During this downward motion, the inlet port is also closed due to which the air will get compressed inside the crank case. At about 70° from BDC the exhaust port is opened and the gases are sent to the atmosphere. At about 60° from BDC, the transfer port is opened due to which the air from the crank case enters the cylinder.

Because of the special shape of the piston crown, the air is deflected and is prevented from going out directly through the exhaust port. Also, the deflected air helps in pushing the exhaust gases out. Thus, during the downward motion of the piston, the operations of power, exhaust and suction are obtained.

Carnot Cycle: Carnot cycle is a reversible cycle that is composed of four reversible processes, two isothermal and two adiabatic.

- **Process 1 - 2 (Reversible Isothermal Heat Addition)**
- **Process 2 – 3 (Reversible Adiabatic Expansion)**
- **Process 3 – 4 (Reversible Isothermal Heat Rejection)**
- **Process 4 – 1 (Revesible Adiabatic Compression)**



$$\Sigma(Q_{net})_{cycle} = \Sigma(W_{net})_{cycle}$$

$$Q_{add} - Q_{rej} = W_e - W_c$$

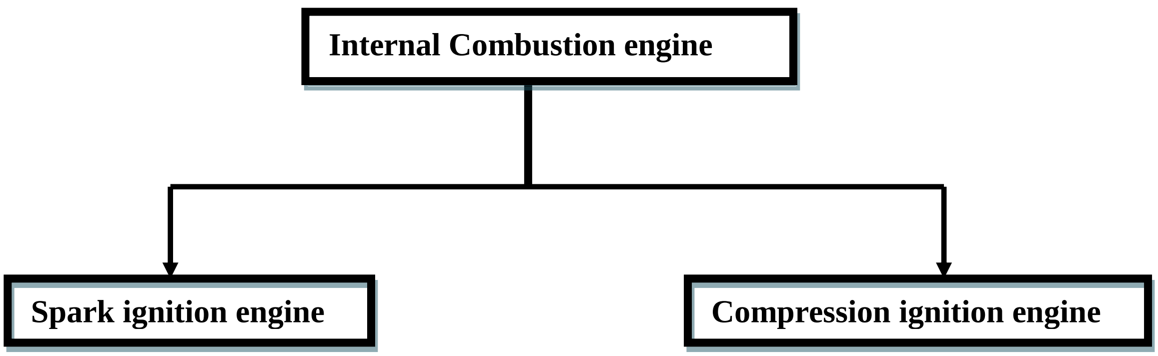
$$\eta = \frac{W_{net}}{Q_{add}} = \frac{Q_{add} - Q_{rej}}{Q_{add}}$$

$$\boxed{\eta = 1 - \frac{Q_{rej}}{Q_{add}}}$$

From T-S diagram

$$\eta = 1 - \frac{T_2\,(\Delta S)}{T_1\,(\Delta S)}$$

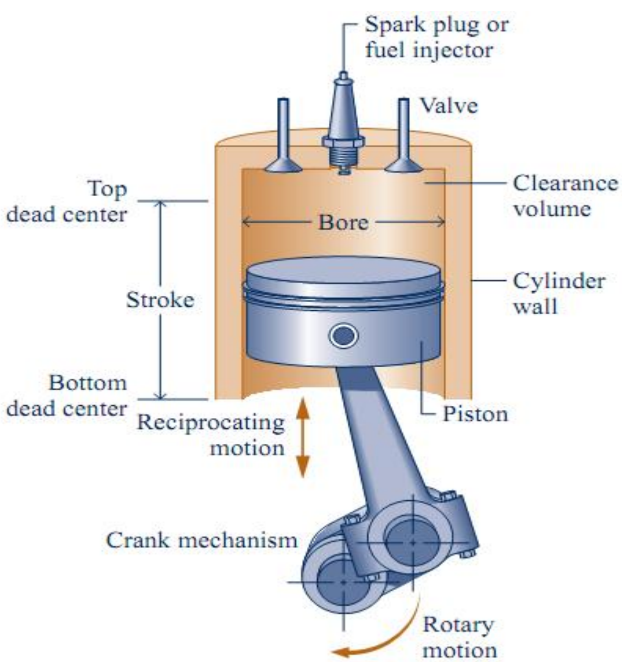
$$\boxed{\eta = 1 - \frac{T_2}{T_1}}$$



These engines are petrol engine and they work on Otto cycle

These engines are diesel engine and they work on Diesel cycle

Basic components of IC engine



Engine Terminology:

1.Top Dead Center (TDC): Position of the piston when it stops at the furthest point away from the crankshaft.

– Top because this position is at the top of the engines (not always), and dead because the piston stops as this point.

– When the piston is at TDC, the volume in the cylinder is a minimum called the clearance volume.

2. Bottom Dead Center (BDC): Position of the piston when it stops at the point closest to the crankshaft. Volume of the cylinder is maximum.

3. Stroke : Distance traveled by the piston from one extreme position to the other : TDC to BDC or BDC to TDC.

4. Bore : It is defined as cylinder diameter or piston face diameter; piston face diameter is same as cylinder diameter(minus small clearance).

5. Swept volume/Displacement volume : Volume displaced by the piston as it travels through one stroke.

– Swept volume is defined as stroke times bore.

– Displacement can be given for one cylinder or entire engine (one cylinder times number of cylinders).

Clearance volume : It is the minimum volume of the cylinder available for the charge (air or air fuel mixture) when the piston reaches at its outermost point (top dead center or outer dead center) during compression stroke of the cycle.

– Minimum volume of combustion chamber with piston at TDC.

Compression ratio : The ratio of total volume to clearance volume of the cylinder is the compression ratio of the engine.

– Typically compression ratio for SI engines varies form 8 to 12 and for CI engines it varies from 12 to 24

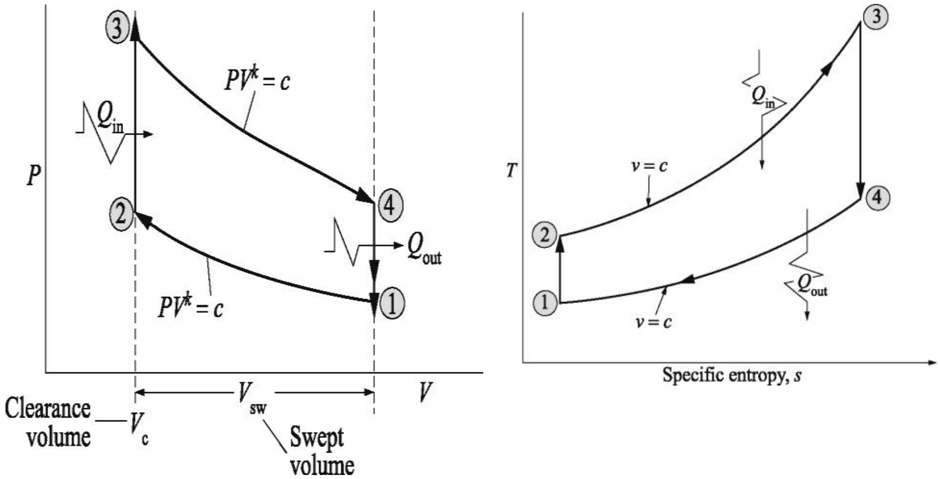
Otto cycle:

The processes in Otto cycle are

- ❖ **(1 – 2)** Isentropic Compression
- ❖ **(2 – 3)** Constant volume heat addition.

❖ **(3 – 4)** Isentropic Expansion.

❖ **(4 – 1)** Constant volume heat rejection.



Efficiency of Otto Cycle

$$\eta_{Otto} = \frac{W_{net}}{Heat\ Supplied}$$

$$Wnet = W_{3-4} - W_{2-1}$$

$$W_{3-4} = C_v (T_3 - T_4) = C_v\ T_3 \left(1 - \frac{1}{r_k^{\gamma-1}}\right)$$

$$W_{2-1} = C_v\ (T_2 - T_1) = C_v\ T_1 (1 - r_k^{\gamma-1})$$

$$W_{net} = C_p \left(1 - \frac{1}{r_k^{\gamma-1}}\right) T_3 - T_1\ r_k^{\gamma-1}$$

$$\boxed{\eta_{otto} = \left[1 - \frac{1}{r_k^{\gamma-1}}\right]}$$

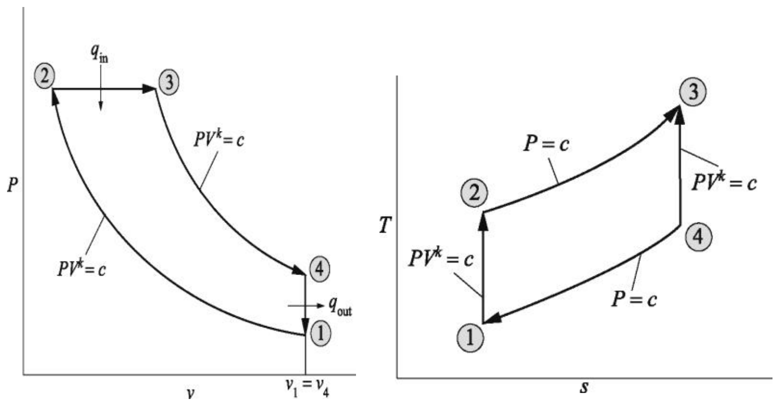
$$\text{Work ratio} = \frac{W_{net}}{W_{turbine}} = 1 - \left[\frac{T_1}{T_3}\right] r_k^{(\gamma-1)}$$

Diesel cycle

The processes in Diesel cycle are:

- ❖ **(1 – 2)** Isentropic Compression
- ❖ **(2 – 3)** Constant pressure heat addition.
- ❖ **(3 – 4)** Isentropic Expansion.

❖ **(4 – 1)** Constant volume heat rejection.



Efficiency of Diesel cycle

$$\eta_{Diesel} = \frac{W_{net}}{Heat\ Supplied} = \frac{q_{in} - q_{out}}{q_{in}}$$

Now $q_{in} = c_p(T_3 - T_2)$ and $q_{out} = c_v(T_4 - T_1)$

Hence $\eta_{th} = \dfrac{c_p(T_3 - T_2) - c_v(T_4 - T_1)}{c_p(T_3 - T_2)}$

$$= 1 - \frac{(T_4 - T_1)}{\gamma((T_3 - T_2))} = 1 - \frac{T_1\left[\dfrac{T_4}{T_1} - 1\right]}{\gamma T_2\left[\dfrac{T_3}{T_2} - 1\right]}$$

Now $\dfrac{T_1}{T_2} = \left(\dfrac{v_2}{v_1}\right)^{\gamma-1} = \left(\dfrac{1}{r_c}\right)^{\gamma-1}$

Also since $p_3 = p_2$, hence $\dfrac{T_3}{T_2} = \dfrac{v_3}{v_2} = \rho$

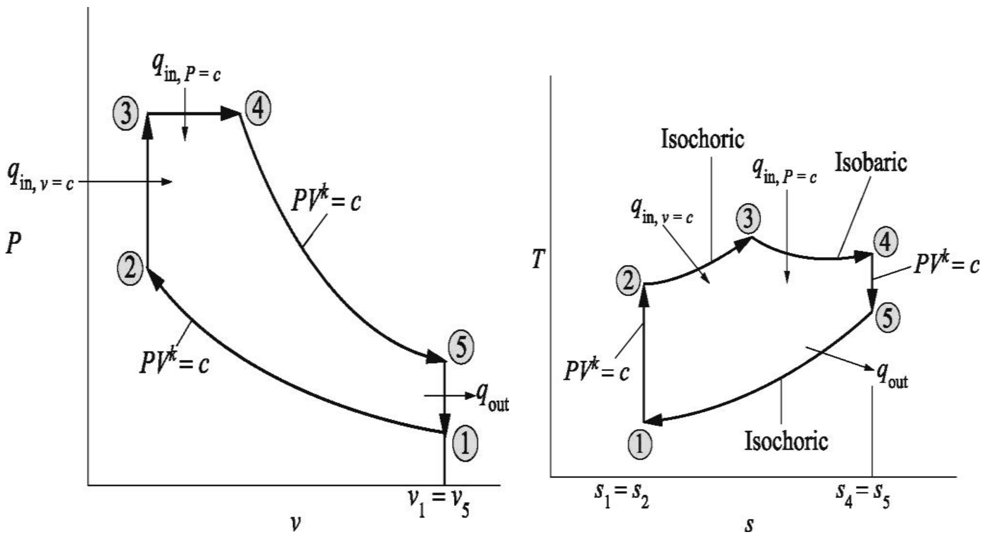
where ρ is the cut-off ratio.

Again since $v_4 = v_1$, $\dfrac{T_4}{T_1} = \dfrac{p_4}{p_1} = \rho^{\gamma}$

Substituting the values of $\dfrac{T_1}{T_2}$, $\dfrac{T_3}{T_2}$, and $\dfrac{T_4}{T_1}$, the value of thermal efficiency

$$\eta_{th} = 1 - \left(\frac{1}{r_c}\right)^{\gamma-1}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right]$$

Dual cycle:



Processes in Dual cycle:

1. (1-2) Isentropic compression

2. (2-3) Constant volume heat addition

3. (3-4) Constant pressure heat addition

4. (4-1) Isentropic expansion

5. (5-1) Constant volume heat rejection.

Efficiency of Dual cycle

$$\eta_{dual} = \frac{q_{in} - q_{out}}{q_{in}}$$

$$= \frac{c_v(T_3 - T_2) + c_p(T_4 - T_3) - c_v(T_5 - T_1)}{c_v(T_3 - T_2) + c_p(T_4 - T_3)}$$

$$\eta_{dual} = 1 - \left[\frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)}\right]$$

Efficiency,

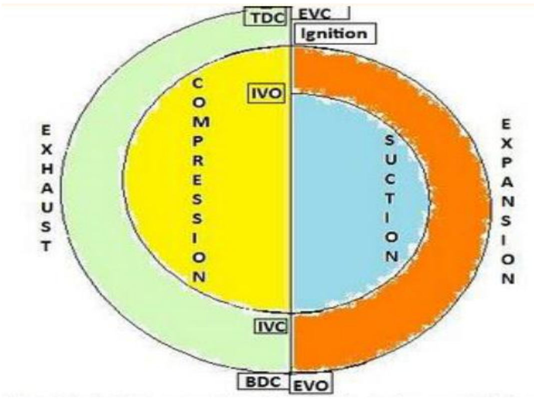
$$\boxed{\eta_{Dual} = 1 - \left[\frac{1}{r_c^{\gamma-1}}\right]\left[\frac{r_p\rho^{\gamma} - 1}{(r_p - 1) + \gamma r_p(\rho - 1)}\right]}$$

Comparision between SI engine and CI engine

SI engine	CI engine
Working cycle is Otto cycle.	Working cycle is diesel cycle.
Petrol or gasoline or high octane fuel is used.	Diesel or high cetane fuel is used.
High self-ignition temperature.	Low self-ignition temperature.
Fuel and air introduced as a gaseous mixture in the suction stroke.	Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke.
Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced.	Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump.
Use of spark plug for ignition system	Self-ignition by the compression of air which increased the temperature required for combustion
Compression ratio is 6 to 10.5	Compression ratio is 14 to 22
Higher maximum RPM due to lower weight	Lower maximum RPM
Maximum efficiency lower due to lower compression ratio	Higher maximum efficiency due to higher compression ratio
Lighter	Heavier due to higher pressures

Valve timing diagram

The exact moment at which the inlet and outlet valve opens and closes with reference to the position of the piston and crank shown diagrammatically is known as valve timing diagram. It is expressed in terms of degree crank angle. The theoretical valve timing diagram is shown in Fig.



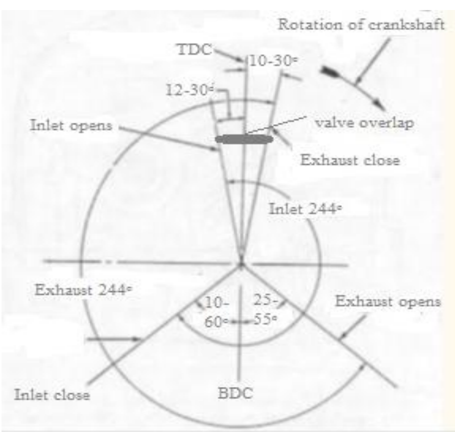
But actual valve timing diagram is different from theoretical due to two factors-mechanical and dynamic factors. Figure 4 shows the actual valve timing diagram for four stroke low speed or high speed engine.

Opening and closing of inlet valve

➢ Inlet valve opens 12 to 30□ CA before TDCto facilitate silent operation of the engine under high speed. It increases the volumetric efficiency.

➢ Inlet valve closes 10-60□ CA after TDC due to inertia movement of fresh charge into cylinder i.e. ram effect.

Figure represents the actual valve timing diagram for low and high speed engine.



Opening and closing of exhaust valve

Exhaust valve opens 25 to 55□ CA before BDC to reduce the work required to expel out the burnt gases from the cylinder. At the end of expansion stroke, the pressure inside the chamber is high, hence work to expel out the gases increases.

Exhaust valve closes 10 to 30° CA after TDC to avoid the compression of burnt gases in next cycle. Kinetic energy of the burnt gas can assist maximum exhausting of the gas. It also increases the volumetric efficiency.

Valve overlap

During this time both the intake and exhaust valves are open. The intake valve is opened before the exhaust gases have completely left the cylinder, and their considerable velocity assists in drawing in the fresh charge. Engine designers aim to close the exhaust valve just as the fresh charge from the intake valve reaches it, to prevent either loss of fresh charge or unscavenged exhaust gas.