

UNIT-I

Tensile Test on Materials

①

- Tensile testing is one of the most widely used and simplest mechanical test for materials.
- It is a test in which a sample is subjected to a controlled tension until failure occurs.
- It is method by which one can see the behaviour of a material under tensile load variation.
- The various properties measured by this test are :-
 - Elastic Limit of materials
 - Ultimate tensile strength
 - Breaking tensile strength
 - Maximum elongation
 - Reduction in Area.
- These evaluated material properties allow design engineer to predict how material will behave in actual applications.
- It is simple, inexpensive and fully standardized and fundamental material test.
- It is done by pulling the Standard Test Specimen (made of the material to be tested) until it breaks.

WHY PERFORM TENSILE TEST (Benefits of Tensile Testing)

The test is very important for design engineers because of the following reasons:-

- It shows, how the material reacts with the forces being applied in tension,
- To draw stress-strain curve, which shows the behaviour of material under varying tensile load.
- To determine the Elastic limit of material.

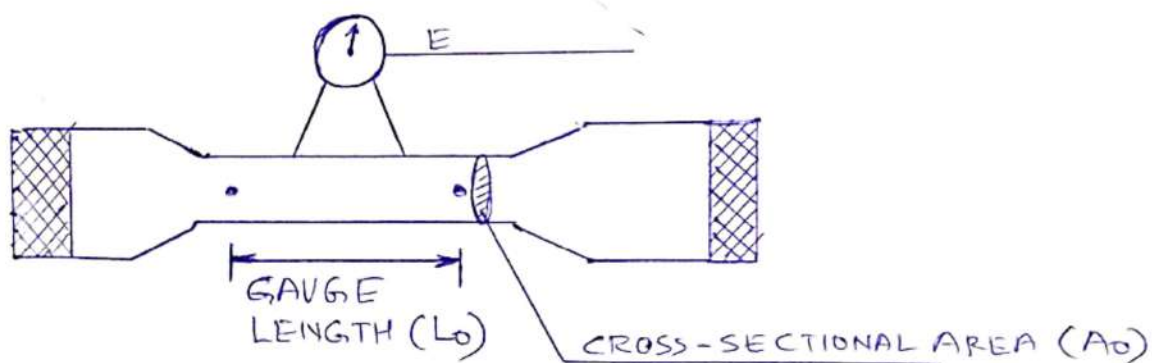
- To determine the material's tensile strength.
- To determine the Ultimate tensile strength i.e. maximum stress that can be withstand.
- To determine the breaking tensile strength.
- To determine the maximum elongation of the material.
- To determine the reduction in area.
- It provides data for safety of components
- To provides the best suitable material for specific application.
- To ensure compliance with standards set.

TENSILE TEST EXPERIMENT (PROCEDURE STEPS)

~~For~~ This test is perform on a machine which is called UNIVERSAL TESTING MACHINE (UTM) or Tensile testing Machine.

- The test process involves applying an increasing load/force on a standard test specimen till it fractures. Specimen is made by mild steel or any ductile material.

~~STANDARD~~ STANDARD SPECIMEN



TYPE OF SPECIMEN	ASTM	BRITISH Std.
SHEET ($\frac{L_0}{\sqrt{A_0}}$)	4.5	5.65
ROD ($\frac{L_0}{A_0}$)	4.0	5.0

STEP 1: Preparation of Specimen

A standard Test specimen of the material to be tested, has been constructed as per standards. It has known dimension, i.e. length and cross-sectional area.

STEP-2: Holding Specimen to VTM

STEP-3: Apply Gradual Load

STEP-4: Make Observations

STEP-5: Make Calculations

STEP-6: Draw Stress-Strain Curve

The applied force (Stress) and displacement (strain) are plotted on a stress-strain curve. The entire process has been recorded by stress/strain curve. This graph shows the condition of material under varying load. The data by this curve are used to determine the mechanical properties of material.

The following data measured -

- Ultimate Tensile Strength - It is the maximum tensile stress carried by the material before failure.
- YIELD STRENGTH - It is the stress at which plastic deformation or yielding observed to begin.
- ELONGATION : It is required for ductility measurements and strain measurements.

STEP 7: Final Calculations

Various measurements (Ultimate Tensile Strength, Yield strength and Elongation) are calculated after the test specimen has broken.

Step 8: Find Elongation : The specimen is put back together to measure the final length, then this measured length is compared to the original length (pre-test length) to find elongation.

STEP 9: Find Reduction Area

The original cross-section (pre-test specimen) is also compared with the final cross-section (post test specimen) to obtain reduction in area.

APPLICATIONS OF TENSILE TESTING

Tensile testing used to assurance the quality of materials used for finished products.

The applications are

- (1) Aerospace Industry
- (2) Automotive Industry
- (3) Beverage Industry
- (4) Construction Industry
- (5) Electrical & Electronics Industry
- (6) Pharmaceuticals Industry
- (7) Safety, Health, Fitness and Textiles Industry

STRESS- STRAIN DIAGRAM FOR DUCTILE MATERIALS

The stress-strain relation of any material is obtained by conducting tension test on standard specimen. Different materials behave differently and their behaviour in tension and in compression differ slightly.

Fig shows STRESS vs STRAIN Diagram for the typical mild steel or ductile material.

STRESS

Load divided by original cross-sectional area is called as nominal stress or simply as stress. If load is P in Newton and A is cross sectional area in mm^2 .

Then

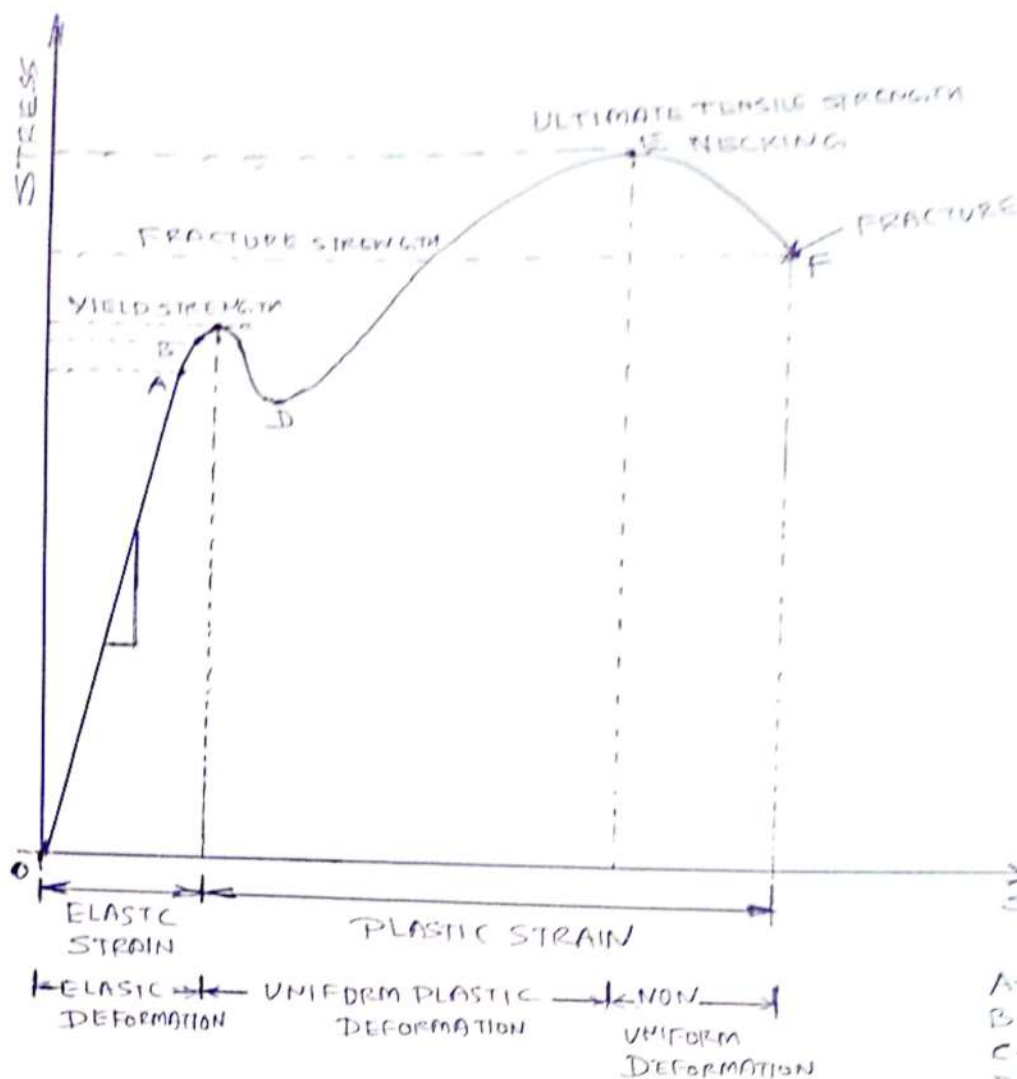
$$\text{STRESS}(\sigma) = \frac{P}{A} \quad \text{N/mm}^2$$

STRAIN: The change in length per unit length is known as linear strain.

$$\text{Linear Strain} = \frac{\text{Change in length}}{\text{Original length.}}$$

$$\text{Strain}(\epsilon) = \frac{\Delta l}{l}$$

Strain is obtained by dividing extensometer reading by gauge length of extensometer (L_1) and by dividing scale reading by grip to grip length of the specimen (L_2)



The following important points are observed on stress-strain curve:

- (a) LIMIT OF PROPORTIONALITY (A) :- It is the limiting value of the stress up to which stress is proportional to strain. At this point when the load removed, the deformation disappears. It is the point after straight line starts bending. The slope of this straight line is known as the Modulus of Elasticity or Young's Modulus. (which shows the stiffness of material.)
- (b) Elastic Limit B This is the limiting value of stress up to which if the material is stressed and then released (unloaded) strain disappears completely and the original length is regained. This point is slightly beyond the limit of proportionality.

(c) UPPER YIELD POINT (C) -

This is the stress at which, the load starts reducing and extension increases. This phenomenon is called yielding of material. At this stage strain is about 0.125 percent. After this point the curve is no longer a straight line. After this point the material undergoes more rapid deformation. This point gives the yield strength of the material.

(d) Lower Yield Point (D)

At this stage the stress remains same but strain increases for some time. It is the point after which material try to regain its strength.

(e) Ultimate Stress or Ultimate Strength Point (E) :

This is the maximum stress ~~resist~~ the material can resist. At this stage cross-sectional area at a particular section starts reducing very fast. This called neck formation. After this stage load resisted and ~~then~~ then the stress developed starts reducing. This point is important for design engineers. This ~~point~~ is ultimate tensile strength is referred as the tensile strength of the material. The shear strength of a material is generally about 50% of its tensile strength and the torsional strength about 75%.

(f) Breaking Point (F) -

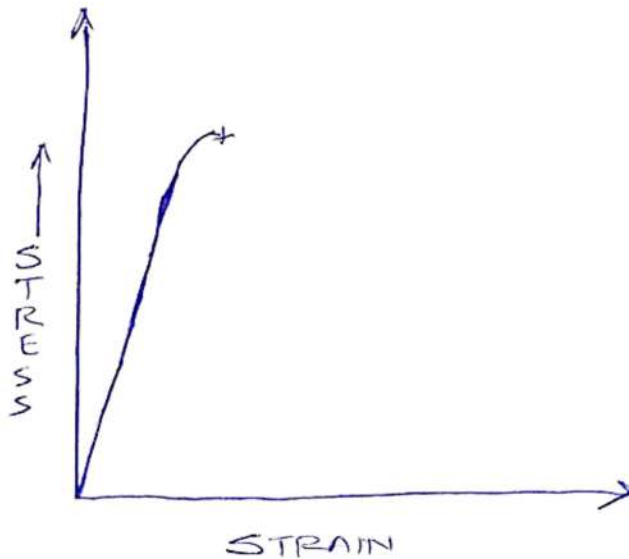
The stress at which finally the specimen fails is called breaking point. At this ^{point} strain is 20 to 25 percent. It is the point occurred after maximum deformation. At this point the specimen breaks into pieces.
(or fracture point)

~~(A) Stress-strain diagram for brittle materials~~

Main

STRESS - STRAIN DIAGRAM FOR BRITTLE MATERIALS

Fig shows a stress-strain curve drawn for brittle material (CAST IRON). Generally brittle metals don't show the yield point (elongation) in the stress-strain curve as found in ductile material or mild steel. A perfect brittle material would fracture nearly at the elastic limit. There is no yield point and no necking takes place. Ultimate point and breaking point are one and the same. The strain at failure is very small.



Mainta Calculations

(9)

$$(1) \text{ Stress} = \frac{\text{Resisting Force}}{\text{Cross-Sectional Area}} = \frac{P}{A} \text{ N/mm}^2$$

$$(2) \text{ STRAIN} = \frac{\text{Change in length}}{\text{Original length}} = \frac{\Delta l}{l}$$

(3) Percentage Elongation :

It is defined as the ratio of the final extension at fracture to original length expressed as percentage.

$$\text{Percentage Elongation} = \frac{L' - L}{L} \times 100$$

where L' - length at fracture, L is original length.

(For ductile material it is about 20 to 25 percentage elongation)

(4) Percentage Reduction in Area -

It is defined as the ratio of maximum changes in the cross-sectional area to original cross-sectional area, expressed as percentage.

$$\text{Percentage Reduction in Area} = \frac{A - A'}{A} \times 100$$

where A - Original cross sectional Area

A' - Minimum cross-sectional area,

NOMINAL STRESS AND TRUE STRESS

The direct stress is based on the value obtained by dividing the load by original cross-sectional area.

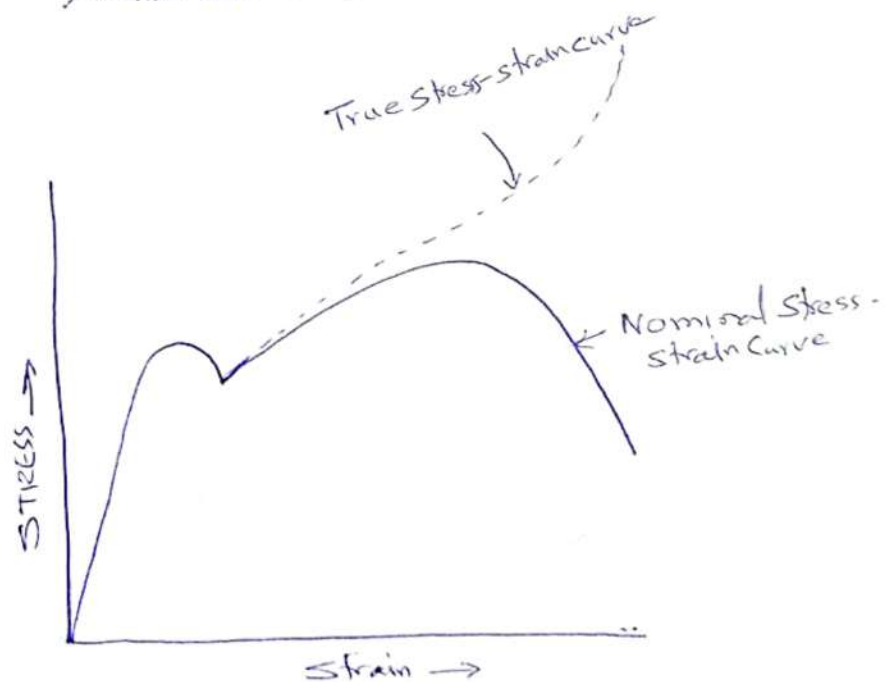
This is the reason why the value of stress started dropping after neck is formed in mild steel or ductile material.

But ^{actually} material is stressed its cross-sectional area changes. We should divide load by the actual cross-sectional area to get true stress in the material.

To ~~dist~~ difference between the two values we introduce the term nominal stress and true stress and define them as:

$$\text{Nominal Stress} = \frac{\text{Load}}{\text{Original Cross-sectional Area}}$$

$$\text{True Stress} = \frac{\text{Load}}{\text{Actual cross-sectional Area}}$$



$$\text{Factor of Safety} = \frac{\text{Ultimate Stress}}{\text{Working Stress}}$$

For steel - 1.85, concrete - 3, timber - 4 to 6

HOOKE'S LAW

Robert Hooke, an English mathematician, conducted several experiments and concluded that;

Stress is proportional to strain up to elastic limit. This is called Hooke's Law. Hooke's Law is up to elastic limit.

$$\sigma \propto \epsilon$$

Where σ is stress and ϵ is strain

$$\sigma = E \epsilon$$

Where E is proportionality constant of the material and it is known as Modulus of Elasticity or Young's Modulus.

$$\text{Modulus of elasticity } E = \frac{\sigma}{\epsilon}$$

$$E = \frac{P/A}{\Delta L/L} = \frac{PL}{A\Delta L}$$

Q A circular rod of diameter 16 mm and 500 mm long is subjected to a tensile force 40 kN. The modulus of elasticity for steel may be taken as 200 kN/mm². Find stress, strain and elongation of the bar due to applied load.

Solution

$$\text{Given that, Load } P = 40 \text{ kN} = 40 \times 1000 \text{ N}$$

$$E = 200 \text{ kN/mm}^2 = 200 \times 1000 \text{ N/mm}^2$$

$$L = 500 \text{ mm}$$

$$\text{Dia. of the rod } d = 16 \text{ mm}$$

$$\therefore \text{Sectional Area (A)} = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (16)^2 = 201.06 \text{ mm}^2$$

$$\text{Stress } (\sigma) = \frac{P}{A} = \frac{40 \times 1000}{201.06} = 198.94 \text{ N/mm}^2$$

$$\text{Strain } (\epsilon) = \frac{P}{E} = \frac{198.94}{200 \times 10^3} = 0.0009947$$

$$\text{Elongation } \Delta L = \frac{PL}{AE} = \frac{40 \times 1000 \times 500}{201.06 \times 200 \times 10^3} = 0.497 \text{ mm}$$

Q. A specimen of steel 20 mm diameter with gauge length 200 mm is tested to destruction. It has an extension of 0.25 mm under a load 80 kN and the load at elastic limit is 102 kN. The maximum load is 130 kN.

The total extension at fracture is 56 mm and diameter at neck is 15 mm. Find.

- (1) The stress at elastic limit.
- (2) Young's Modulus
- (3) Percentage elongation
- (4) Percentage reduction area
- (5) Ultimate tensile stress

Solution

Given that, Diameter of Specimen (d) = 20 mm

$$\therefore \text{Cross Sectional Area (A)} = \frac{\pi}{4} d^2 = \frac{\pi}{4} (20)^2 = 314.16 \text{ mm}^2$$

$$(i) \text{ Stress at elastic limit} = \frac{\text{Load at elastic limit}}{\text{Area}} = \frac{102 \times 10^3}{314.16} = 324.675 \text{ N/mm}^2$$

$$(ii) \text{ Young's Modulus } E = \frac{\text{Stress}}{\text{Strain}} \text{ within elastic limit.} \\ = \frac{P/A}{\Delta L/L} = \frac{80 \times 10^3 / 314.16}{0.25 / 200} = 203718 \text{ N/mm}^2$$

$$(iii) \text{ Percentage Elongation} = \frac{\text{Final Extension}}{\text{Original Length}} = \frac{56}{200} \times 100 = 28$$

$$(iv) \text{ Percentage Reduction in Area} = \frac{\text{Initial Area} - \text{Final Area}}{\text{Initial Area}} \times 100 \\ = \frac{\frac{\pi}{4} (20)^2 - \frac{\pi}{4} (15)^2}{\frac{\pi}{4} \times 20^2} \times 100 \\ = 43.75$$

$$(v) \text{ Ultimate Tensile Stress} = \frac{\text{Ultimate load}}{\text{Area}} \\ = \frac{130 \times 10^3}{314.16} = 413.80 \text{ N/mm}^2$$

Q A rod 150cm long and diameter 2cm is subjected to an axial pull of 20kN. If the modulus of elasticity of the material of rod is $2 \times 10^5 \text{ N/mm}^2$, determine stress, strain and the elongation of the rod. (June 2014)

Sol Given that, $l = 150 \text{ cm} = 1500 \text{ mm}$, $d = 2 \text{ cm} = 20 \text{ mm}$, $P = 20 \text{ kN} = 20 \times 1000 \text{ N}$
 $E = 2 \times 10^5 \text{ N/mm}^2$

- Stress in the rod will be given by,

$$\sigma = \frac{\text{Axial Pull}}{\text{Cross-sectional Area}} = \frac{P}{\frac{\pi}{4} d^2} = \frac{20 \times 10^3}{\frac{\pi}{4} \times (20)^2} = 63.66 \text{ N/mm}^2$$

- Modulus of elasticity of rod (E) = $\frac{\text{Stress}}{\text{Strain}}$

$$2 \times 10^5 = \frac{63.66}{\epsilon}$$

$$\epsilon = \frac{63.66}{2 \times 10^5} = 3.183 \times 10^{-4}$$

Elongation of the rod will be given by,

$$\delta l = \epsilon \times l$$

$$= 3.183 \times 10^{-4} \times 1500 = 0.477 \text{ mm}.$$

Q Find the Young's Modulus of a brass rod of diameter 25 mm and of length 250 mm which is subjected to a tensile load of 50 kN when the extension of the rod is equal to 0.3 mm, (June 22,

Sol Given that, $d = 25 \text{ mm}$, $l = 250 \text{ mm}$, $P = 50 \text{ kN} = 50 \times 1000 \text{ N}$
 $\delta l = 0.3 \text{ mm}.$

- Stress in the rod (σ) = $\frac{P}{\frac{\pi}{4} d^2} = \frac{50 \times 1000}{\frac{\pi}{4} \times (25)^2} = 101.86 \text{ N/mm}^2$

- Strain in the rod (ϵ) = $\frac{\delta l}{l} = \frac{0.3}{250} = 0.0012$

$\therefore$ Young's Modulus = $\frac{\sigma}{\epsilon} = \frac{101.86}{0.0012} = 84.88 \times 10^3 \text{ N/mm}^2$

PROPERTIES RELATED TO AXIAL LOADING -

①

For designing structural elements to resist the applied loads, the following strength properties should be known -

- (a) TENSILE STRENGTH - If an element is subjected to pulling forces, the resistance developed per unit area is termed as tensile stress and the maximum stress the material can resist is termed as tensile strength.

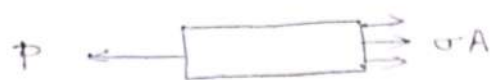


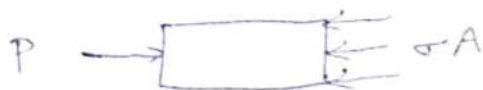
Fig shows a bar under tension and stresses at a cross-section and also an element of bar under tensile stress. In this P is the tensile force applied and σ is the tensile stress (resistance per unit area) and A is the cross-sectional area.

$$P = \sigma A$$

$$\sigma = \frac{P}{A} \left(\frac{N}{m^2} \text{ or Pascal or Pa} \right)$$

(b) COMPRESSIVE STRESS

Instead of Pull, if P is in the direction which pushes the bar ~~shortened~~ and its effect is shorten the bar, the internal ~~stress~~ resistance developed per unit area is called compressive stress.



$$\sigma = \frac{P}{A} \left(\frac{N}{m^2} \text{ or Pa} \right)$$

IMPACT TESTING OF MATERIALS

①

Impact testing is used to determine the material toughness or impact strength at impact/^{test} loading condition.

A notched test specimen is broken by the impact of a heavy pendulum or hammer, falling at a fixed velocity through a fixed distance. It measures the energy absorbed by the fractured specimen.

IMPORTANCE OF IMPACT TESTING -

Impact testing is essential for the materials undergo very rapid loading processes such as in vehicular collisions or accidents.

The ~~purpose of~~ purpose or objective of impact testing is to measure the "material's ability to resist high-rate loading."

Impact strength covers following design criteria:

- The service life of a Part.
- Product reliability
- Component safety.

WHAT IMPACT TEST DETERMINES -

- The amount of energy absorbed by the material during fracture or during a collision.
- To determine the Material Toughness or Impact Strength.
- Acts as a tool to study temperature-dependent brittle-ductile transition.
- To determine whether the material is brittle failure or ductile failure.
- To determine fracture resistance or impact resistance.

TYPES OF IMPACT TESTING -

The three most popular types of impact test are:-

- Charpy (V-notch) Impact test.
- Izod Impact tests.
- Drop - Weight Testing.

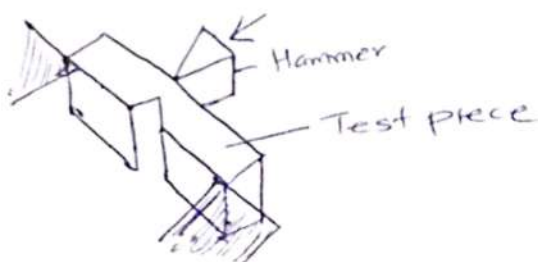
All three tests are determine the same characteristics of the material. They involve a known weight released from a known height. It causes colliding with the specimen fixed in its fixture.

They uses a different orientation of the test specimen, which causes it stressed in different directions.

PROCEDURE OF CHARPY IMPACT TEST -

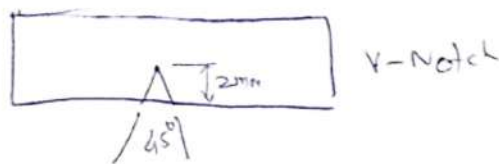
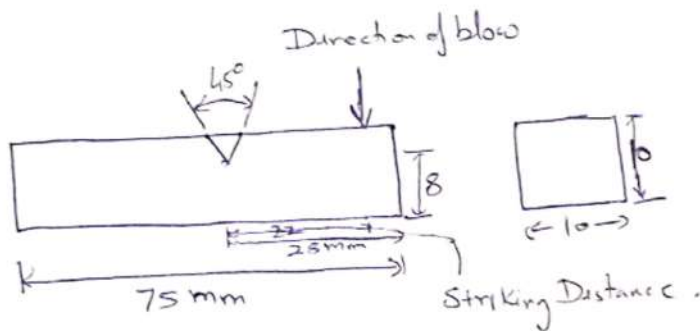
- The Charpy - V-notch test is a standardized high strain-rate test.
- It determines the amount of energy absorbed by material during fracture.
- Test specimen is a $10\text{mm} \times 10\text{mm}$ (full size) cross-section with either V or U notch is taken.
- It is a dynamic test. A test piece V or V-notched is placed in the middle and supported at each end like simple supported beam on the anvil. It is broken by a single blow/impact of a freely swinging pendulum as shown in fig.

The energy absorbed is measured, it is measured of the impact strength of material.

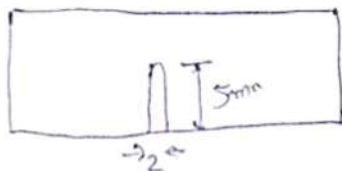


120D IMPACT TEST .

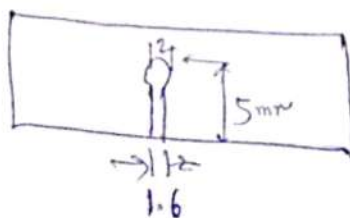
- In this test specimen is a square or round section having either one or two or three notches.
- The specimen is clamped vertically on the anvil with the notch facing the hammer.
- 120D Impact testing can be conducted up to 240 foot-pounds on standard single notch specimen.
- In this test the blow is struck on the same face as the notch and at the fixed height above it.
- The energy absorbed is measured, it is a measure of the impact strength of material.



V-Notch



U-Notch



Keyhole-Notch

Why do we use notch in impact test?

Impact energy is a measure of the work done to fracture a test specimen. When the striker impacts the specimen, the specimen will absorb energy until it yields. The test specimen continues to absorb energy and work hardens at the plastic zone at the notch. When the specimen can absorb no more energy, fracture occurs.

Impact Test

- Impacting testing of material is done for the testing of Toughness of the material.

- Toughness is the ability of a material to absorb strain energy without fracture.

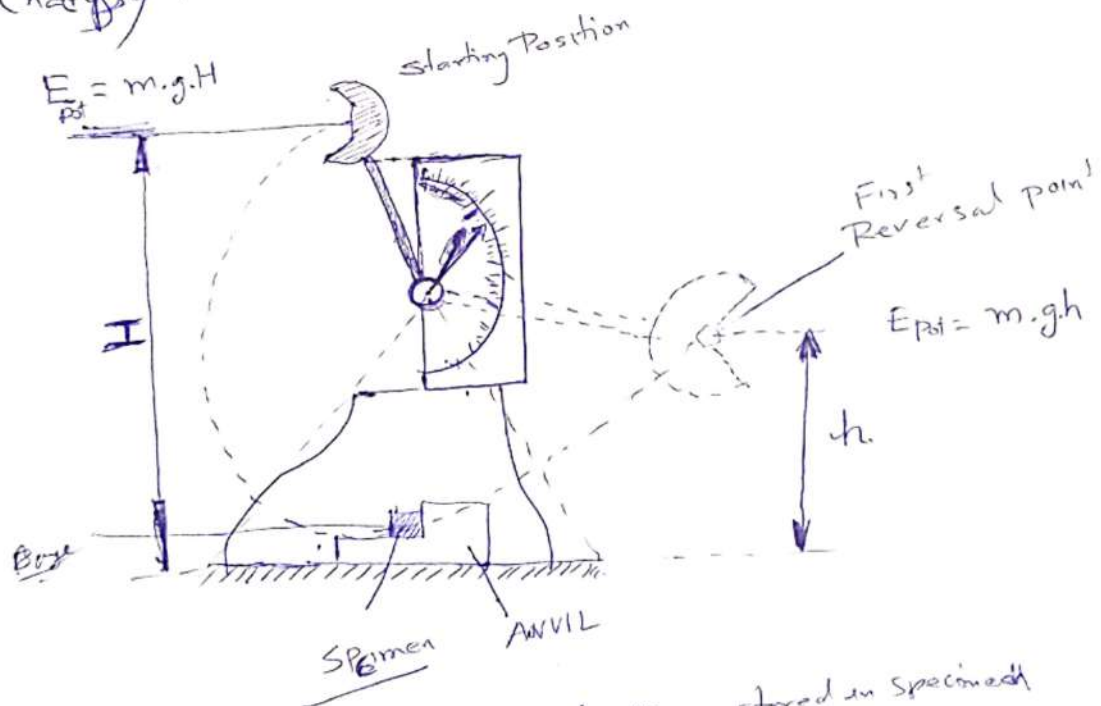
- It is calculated by

$$\text{Modulus of toughness} = \frac{S.E}{\text{Volume}} \text{ upto fracture.}$$

Impact test is done by two methods:

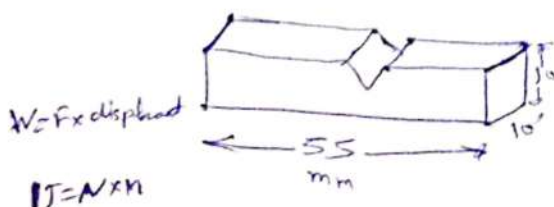
(1) Izod Test

(2) Charpy test.



lost by hammer = Strain Energy stored in Specimen

$$\text{Energy absorbed} = m.g.H - m.g.h = mg(H-h) \text{ Joule.}$$



(1) Izod test - In Izod test ~~when~~ the specimen is used as ~~beam~~ cantilever.

(2) Charpy test - In Charpy test ~~where~~ the position of ~~beam~~ ~~is~~ as ~~cantilever~~ ~~to~~ beam.

HARDNESS TESTING OF MATERIAL

Hardness is a characteristic of a material. It is not fundamental physical property. Hardness can be define as,

Resistance of metal to indentation, scratching, abrasion or cutting. An ability of a material to resist ~~scat~~ scratching wear and tear and indentation.

IMPORTANCE OF HARDNESS TESTING :

Hardness testing plays a vital role in material testing quality control and acceptance or rejection of components. Hardness testing of material before use is very important in following ways:-

- To assess resistance to plastic deformation.
- To determining resistance to penetration.
- To predict the part quality for applications.
- To compare the material with hardness characteristics.
- It indicates how easily a material can be machined.
- It is also important to take coating and treatments decisions.

UNITS OF HARDNESS :

- Brinell Hardness Number (BHN)
- Rockwell Hardness Number (RHN)
- Vickers Pyramid Number (HV)
- Diamond Pyramid Number (DPH)

TYPES OF HARDNESS TESTING -

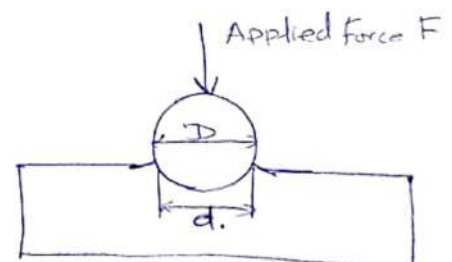
- Brinell Hardness Testing (Ball as indenter)
- Rockwell Hardness testing (Cone as indenter)
- Vickers Hardness Testing (Diamond)
- Moh's hardness Scale (for Minerals)

BRINELL HARDNESS TESTING (BALL)

- The Brinell test uses a hardened steel ball (5 to 10 mm diameter) Indentor
- Sometimes tungsten carbide ball indentor may also use.
- The indentor is applied to the test material below a load of 3000 Kg.
- Force is applied for a specified time usually between 10 to 30 seconds.
- The load time period has to ensure the plastic deformation of the metal ceased.
- The load can be reduced to 1500 Kg or 500 Kg for testing soft materials to avoid excessive indentation.
- The load is applied for 10 to 15 seconds in the case of iron and steel.
- The diameter of the indentation left in the test specimen is measured with the help of a microscope.
- The Brinell Hardness Number (BHN) is obtained by dividing the load Applied by the Surface Area of the Indentation.

$$BHN = \frac{\text{Load applied (F)}}{\text{Surface Area of the Indentation (mm}^2\text{)}}$$

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



D - Indenter diameter
d - Indentation diameter

- It is generally referred as
BHN (Brinell Hardness Number)

APPLICATIONS -

- To test CAST IRON, Steel frameworks.
- Most commonly used to test castings and forgings.
- To test Aluminium and copper alloys (at lower forces)
- Engine castings and large diameter pipes also test by Brinell hardness Test.

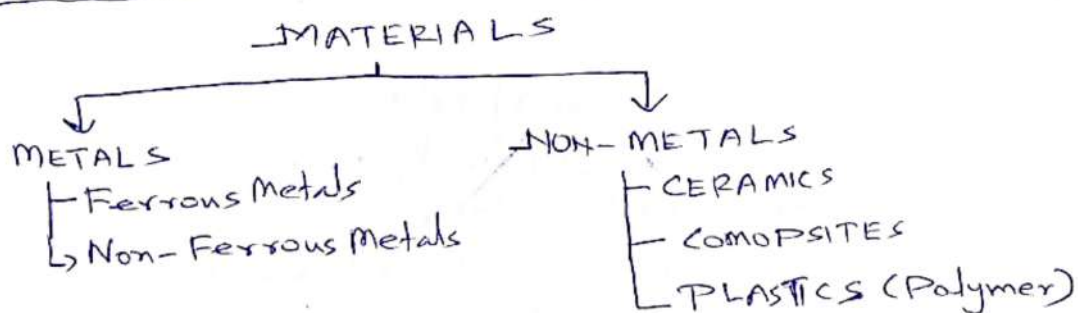
The brief knowledge of manufacturing process has been made compulsory for every engineers so that he can make himself acquainted with basic knowledge of manufacturing process and materials. In the every sphere of human activity, engineering materials are used in one form or the other.

The engineering metals always play an important role in an industry, because the process of all manufacturing starts with the raw materials.

All materials available cannot be considered as engineering materials. Engineering Materials should contains following properties:-

- 1) It should be able to converted into shaped (like cast, forged, formed, machined, sintered etc.
- 2) It should be joined easily with other materials. (like welded, brazed, soldered).
- 3) It should be contained mechanical and electrical properties. (like, strength, hardness, ductility, malleability, heat resisting property, low electrical resistance, high fatigue resistance, dimensional stability, corrosion resistance etc)
- 4) Material selected should provide goods at lower cost to procure give higher profit with all required qualities present in it,

MATERIALS can be Classified as:-



METALS

- Metals are composed of one (Iron, Al, Copper etc) or more (Alloys) metallic ~~met~~ elements.
- There is little amount of ~~in~~ non-metallic objects also present. (like N, carbon, oxygen etc.)
- Atomic arrangement is well arranged.
- Both metals and alloys are possible.
- Compare with ceramic and polymers, metals are denser.
- From mechanical properties point of view metals are strong, good conductor of heat and electricity, opaque to light, stiff, ductile, resistance to fracture etc.
- Metals are used as structural component (static load) and machine component (dynamic load).

Metals are of two types :-

(1) Ferrous Materials (2) Non-Ferrous Materials

(1) Ferrous Materials -

Ferrous metals mostly contain Iron as major constituent. A small amount of other metals/elements added into ferrous metals to give the desired properties. Iron as the base metal i.e. more than 98%.

ex. Mild Steel, Carbon Steel, Stainless Steel, Cast Iron and Wrought Iron.

Properties of Ferrous Metals -

Ferrous metals have following properties:

- They are good conductor of heat and electricity.
- They tend to react chemically with environment with the exception of noble metals.
- They have good tensile strength and durability.
- They are magnetic in nature.
- They have little resistance to corrosion.

b) Non-Ferrous Metals -

The non-ferrous metals are generally inferior in strength but superior in corrosion resistance when compared to ferrous metals. Non-ferrous metals are more costly than ferrous metals.

Ex.: Copper, Aluminium, Zinc, Lead, Alloy like Brass, Bronze, Duralium etc.

(ii) Non-Metallic Materials -

~~Materials which contain animal or vegetable cells or carbon compounds are known as~~

Non-metallic materials can be divided into two categories i.e. Organic and non-organic materials.

Materials which contain animal or vegetable cells or carbon compounds are known as Organic materials. Ex. Leather, wood etc.

Materials which do not contain animal or vegetable cells or carbon compounds are known as Non-organic (inorganic) materials. Ex. Stone, Ceramics, Clay, Porcelain, Glass etc.

Non-metallic Materials are ^{also} classified ~~as~~ according to composition or Bonding structure of Atoms:-

- (1) Ceramics
- (2) Polymers (Plastic)
- (3) Composites

(1) CERAMICS - Ceramics are usually combination of metals or semiconductors with oxygen, nitrogen or carbon (oxides or nitrides and carbides). Ceramic materials are used in electronic devices because, depending on their composition, they may be semiconducting, superconducting, ferroelectric or insulator.

Ex: Clay, Bricks, Glass, Tiles, cement and many materials.
Alumina, Silicon Carbides, Silicon Oxides etc.

Ceramics are stiff and strong, very hard (tool material), extremely brittle, lack of ductility, heat and ~~etc~~ electricity resistant.

Optical behavior of ceramics - It can be transparent, translucent and opaque.

COMPOSITES -

A composite material is made from two or more materials with different physical or chemical properties. When two materials combined, produce a material with different characteristics than the individual components. The individual components remain separate and distinct within the finished composite structure.

- Composites are stronger, lighter or less expensive than traditional material.
- They are generally used for buildings, structures, bridges, Aircrafts etc.

They are divided into three major categories:-

- (1) Particulate (Small particles embedded in a dissimilar material)
- (2) Laminate Composites
- (3) Fibre Reinforced Composites (Fiber Glass)

Ex Fiber glass with wood, Mortars with concrete, Reinforced Plastics, Ceramics composites (~~con~~ ceramic and metal matrices) metal composites, Racing car bodies, Boat, Bathtubs, Tennis Rackets etc.

DIFFERENCE BETWEEN Ferrous and Non Ferrous Metal

Ferrous Metals

- 1) Higher melting point
- 2) Higher strength
- 3) Higher Density
- 4) Less soft
- 5) Highly magnetic due to iron content.
- (6) Shrinkage is ~~more~~ less
- (7) ~~is~~ Susceptible to corrosion
- (8) Economical to use
- (9) Relatively heavy

Non-ferrous Metals

- Lower melting point
- Lower strength
- Lower Density
- Softer is more
- Anti-magnetic
- Shrinkage is generally more.
- High resistance to corrosion
- More costly.
- Light in weight.

Difference between Metals and Non-Metals

(1) These are solids at room temperature except mercury

2) These are very hard except sodium

3) These are malleable and ductile

(4) These are electropositive in nature

(5) These have high densities

(6) Their melting point and boiling point is large

(7) A metallic bond exists between metals.

(8) Their structure is hard.

(9) They are good conductors of heat and electricity

These exist in all three states.

These are soft except diamond.

These are brittle and can break down into pieces.

These are electronegative in nature.

These have low densities.

Their melting point is less than the metals.

A covalent bond is present between the nonmetals atoms.

Their structure is soft compare to the metals.

They are bad conductors of heat and electricity.

10 Steel, Bronze Brass

Silicon, boron

11) Such substances that has one to three number of electrons in the outermost shell are called metals except for hydrogen

Such substances that have four to seven electrons in the valence shell are called non-metals.

12) Metal formed cations

~~Non~~ Non-metal formed anions.

13) ~~They~~ They present in the periodic table on the left side.

13/ ~~Non~~ Non-metals present in the right side of the periodic table.

14) After reaction with ^{the} oxygen metals form basic oxides.

14) After reaction with the oxygen they create acidic oxides.

FERROUS METAL

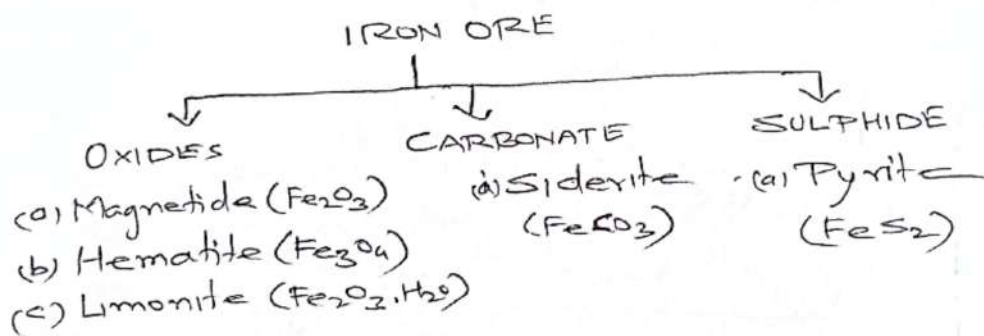
(PIG IRON)

Pig iron was produced by reduction of iron ores in Blast Furnace and when the total output of the blast furnace was sandcast into pigs (a mass of iron roughly resembling a reclining pig). It is called pig iron. Pig iron for foundry use is roughly 20" x 9" x 4" in size.

Pig iron produced in a blast furnace, is the first product in the process of converting ore into useful metal. The iron ore on initial refining and heating in blast furnace becomes Pig iron, when the impurities are burnt out in a blast furnace.

The charge in the blast furnace for manufacturing Pig iron is:

(a) ORE - Consisting of iron oxide or carbonate or sulphide associated with earth impurities.



(b) COKE - Used as fuel. (The most commonly used fuel in a blast furnace is hard coke. It provides the required heat for melting the iron ore.)

The coke used should have following properties:

- (1) It should be hard.
- (2) It should have high calorific value.
- (3) It should have low ash contents.

(4) It should be uniform in size.

(5) It should have good porosity,

(C) LIMESTONE - Used as flux. (The most commonly used flux in a blast furnace is limestone. The flux is used for removing impurities such as ash, sulphur and the residues of the burnt fuel. The flux melts and dries away the impurities in the form of slag leaving pure iron.

Pig iron, has the following composition (Approx):

Carbon - 1 to 5%

Phosphorus - 1-2%

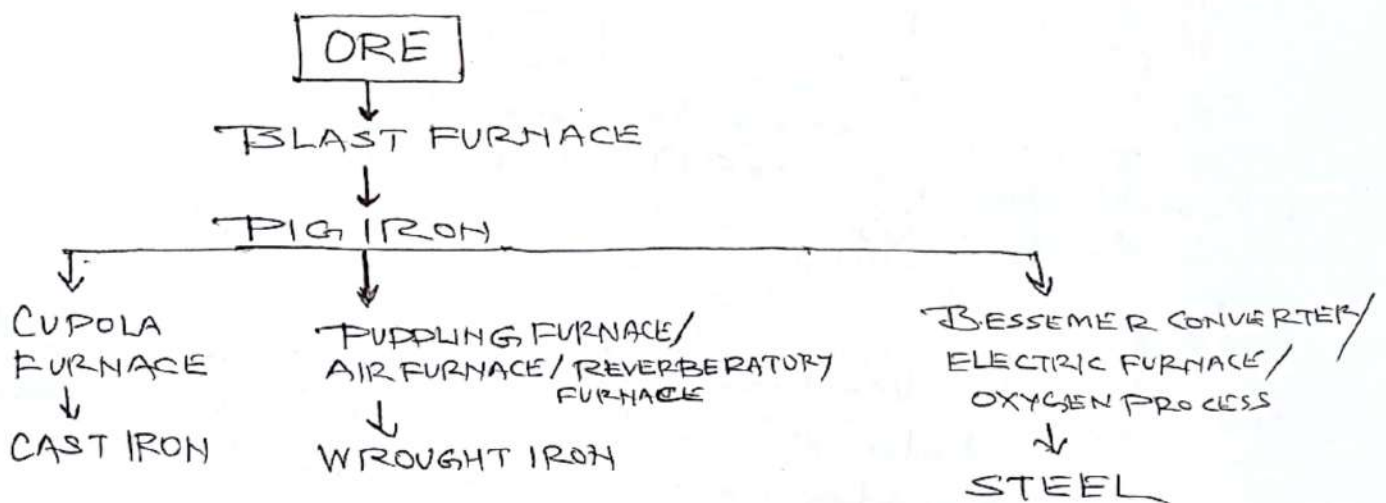
Silicon - 1 to 3%

Sulphur - Under 1.0%

Magnesium - 1-2%

IRON - Remainder

Pig iron is the raw-material for all iron and steel products. Pig iron is of great importance in the foundry and in the steel making process:



USES → It is used for ~~at~~ steel making and is low in silicon (1-5% max) to prevent attack of the refractory lining of refining furnaces and to control slag formation.

WROUGHT IRON

Wrought iron is the mechanical mixture of very pure iron and a silicate slag. It is the purest iron which contains at least 99.5% iron.

This iron is produced from pig iron by remelting it in the puddling furnace or air-furnace or reverberatory furnace.

The molten metal free from impurities is removed from the furnace as a pasty mass of iron and slag. The balls of this pasty mass, each about 45 kg to 65 kg in weight, are formed. The balls are then mechanically worked to squeeze out the slag and to form it into some commercial shape.

CHEMICAL COMPOSITION

C - 0.02% - 0.03%

P - 0.05 - 0.25%

Si - 0.02% - ~~0.01~~ 0.1%

Slag 0.05 - 1.5%

S - 0.008% - 0.02%

Fe (IRON) - REMAINDER

Mn - Nil - 0.02%

PROPERTIES

- Wrought iron is never cast. All shaping is done by hammering, pressing, forging etc.
- It has high ductility and plasticity with which it can be forged and welded easily.
- Wrought iron possess a high resistance toward corrosion.
- It can ~~are~~ bears sudden and excessive shocks loads without permanent injury.
- It has a high resistance towards fatigue.
- It can be elongated considerably by cold working.

- It has a high electrical conductivity.
- Its ultimate tensile strength varies from 2500 Kg/cm^2 to 5000 Kg/cm^2 .
- Its ultimate compressive strength is about 3000 Kg/cm^2 .
- Melting point of wrought iron is about 1510°C .

Application :-

- It is used for making chains, ~~crank~~ Crane hooks, railway couplings and water and steam pipes.
- Wrought iron is available in the form of plates, sheets, bars, structural components, rivets and wide range of tubular products (including pipe, tubes and casings), electrical conduits, cold drawn tubing, nipples and welding fittings.
- Bridge railing, blast plates, drainage lines, ~~gas~~ Gas collection hoods, cooling tower, spray pipe spray pound piping, condenser tubes, heat exchangers.

CAST IRON

Cast iron is an alloy of iron and carbon. It is obtained by re-melting pig iron with coke, limestone and steel scrap in a furnace known as Cupola furnace.

The carbon content in cast iron varies from 1.7% to 6.67%, but most cast iron has a carbon percentage about 2% to 4.5%. It also contains small amounts of silicon, manganese, phosphorus and sulphur in form of impurities elements.

The carbon in cast iron is present either of the following form:-

1. Free Carbon or graphite
2. Combined Carbon or Cementite (Fe_3C).

* PROPERTIES OF CAST IRON *

- Cast iron is very brittle and weak in tension and therefore it cannot be used for making machine parts which are in tension.
- It has low cost.
- It has good casting characteristics, high compressive strength, high wear resistance and excellent machinability.
- Low melting point (about 1200°C)
- Its tensile strength varies from 1000 kg/cm^2 - 2000 kg/cm^2 and compressive strength varies from 4000 kg/cm^2 - 10000 kg/cm^2
- It is unsuitable for forging work.

CLASSIFICATION OF CAST IRON

Cast iron is classified as follows:-

- (1) GREY CAST IRON
- (2) WHITE CAST IRON
- (3) MALLEABLE CAST IRON
- (4) NODULAR CAST IRON
- (5) MEEHANITE CAST IRON.

GREY CAST IRON

Its grey colour is due to the carbon present in the form of free graphite. Grey cast iron is obtained by allowing the molten metal to cool and solidify slowly. On solidifying the iron contains the greater part of carbon in the form of graphite flakes. Graphite flakes occupy about 10% of the metal volume. It is produced in Cupola furnace, Grey cast iron gives grey appearance, when fractured. Grey C.I. is basically an alloy of carbon and silicon with iron.

It contains:

C = 2.5% to 3.8% Si. - 1.1 to 2.8% P - less than 0.15% - 1%
S - less than 0.1% Mn - 0.4 to 1.0%

Fe - remaining.

PROPERTIES OF GREY C.I. :

- It gives grey colour, when fractured.
- It can be easily CAST.
- It can be easily machined and possesses machinability better than steel.
- It has lowest melting point of the ferrous metal (1150°C to 1200°C).
- It has high resistance to wear (including sliding wear).
- It has high compressive strength (600 N/mm^2 to 750 N/mm^2) and tensile strength varies between 120 N/mm^2 to 300 N/mm^2 .
- It has high vibration damping capacity,
- The free graphite in its structure seems to act as lubricant and when large machine slide are made of it a very free working action is obtained.
- Excellent casting quality to producing simple and complex shapes,

Applications:-

- 1) It is used for manufacturing those component which require a hard and abrasion resistant surface such as rim of CAR.
- (2) Railway brake block,
- (3) For producing malleable iron castings.

MALLEABLE CAST IRON

It is made from white cast iron by a heat treatment process called Annealing. Due to annealing cementite decomposes to ferrite and produces malleable cast iron. Malleable cast iron is one which can be hammered and rolled to obtain different shapes.

PROPERTIES →

- It has low coefficient of thermal expansion.
- It has good wear resistance.
- It has vibration damping capacity.
- Its solidification range of $2550 - 2065^{\circ}\text{F}$
- It shrinks 1.5 mm per 100mm.

Chemical Composition:

C - 2% to 3% C, ~~Si~~ Si - 0.6% to 1.3%
Mn - 0.2 to 0.6% P - about 0.15% Sulphur 0.1%.

USES:

- 1, Automobile Industry for making different parts, Railway Rolling brake supports.
- 2) Agricultural machinery
- (3) Conveyor chain links, Gear Case, Crank Shaft, Pipe fittings, Spanners.

APPLICATIONS :-

- (I) Machine tool structure such as m/c Bed, frames, column etc,
- (II) Gas or water pipes for under ground purposes.
- (III) Man hole covers, piston rings, Rolling mill, Cylinder Blocks and heads for I.C. engines.
- (IV) Frames for electric motor, General machinery parts and Agricultural equipments.

WHITE CAST IRON -

White cast iron derives its name from the fact that its freshly broken surface shows a bright white fracture. White Cast Iron has almost all its carbon, chemically bonded with the iron as Iron Carbide (Fe_3C). Iron carbide is a very hard and brittle constituent. It is produced in cupola furnace by pig iron.

The chemical Composition of white cast iron is :-

C = 1.75% - 2.3% Si = 0.85% to 1.2% , Mg = 0.1% to 0.4%

P = less than 0.2% S = less than 0.3% .

Fe = remaining.

PROPERTIES :-

- 1) It is very hard and brittle material.
- 2) It has excellent abrasive wear resistant.
- 3) Since it is extremely hard, therefore it is very difficult to machine.
- 4) Its solidification range is 2650°F - 2065°F .
- 5) Shrinkage is $\frac{1}{8}$ inch per foot.
- 6) It has tensile strength and low compressive strength and poor machinability.

STEEL

Steel is an alloy of iron and carbon with carbon content maximum upto 0.05% to 1.5%. The carbon is distributed throughout the mass of the metal in the form Iron carbide. Iron Carbide increases the hardness and strength of the steel.

Besides carbon, there are other elements present in steel are sulphur, silicon, phosphorous, manganese. to impart certain desired properties to it.

Steel is classified as:-

- (1) Plain Carbon Steel
- (2) Alloy Steel.

Processes ~~Used~~ Used for making steel are:

- (1) Cementation Process
- (2) Crucible Process
- (3) Bessemer Converter Process
- (4) Open Hearth Process
- (5) Duplex Process
- (6) L-D Process (Linz-Donawitz Process)
- (7) Electric Process.

(1) Plain Carbon Steel -

Plain carbon steel is an alloy of iron and carbon. It contains carbon from 0.05% to 1.5%. It has good machinability and malleability.

Plain Carbon Steel can be classified as:-

- (1) Dead Carbon Steel: upto 0.15% Carbon (0.05% - 0.15%) by wt
- (2) Low Carbon Steel: 0.15% to 0.3% Carbon by wt.
(Mild Steel)
- (3) Medium Carbon Steel: 0.3% to 0.5% by wt
- (4) High Carbon Steel: 0.5% to 1.5% Carbon by wt.

(1) Dead Carbon Steel:

- It has very low percentage of carbon varying from 0.05% to 0.15% by weight.
- It has a tensile strength of 390 N/mm²
- It has a hardness of about 100 BHN - 110 BHN

Use: It is used for making steel wire, sheets, rivets, screws, pipe, chain, camshaft, automobile body.

NODULAR OR SPHEROIDAL GRAPHITE CAST IRON

The nodular cast iron is also called ductile cast iron or high strength cast iron. This type of cast iron is obtained by adding small amount of Magnesium (0.1 to 1.8%) to the molten grey iron just after tapping. The addition of magnesium causes the graphite to take form of small nodules instead of the normal angular flakes.

Chemical Composition:

C = 3.2% to 4.2% Si = 1.0% to 4.0% Mg = 0.1% to 0.8%
Ni = 0.0% to 3.5% Mn = 0.05% to 0.1%
Fe (IRON) - Remaining.

PROPERTIES:

- It has very good machinability
- It has very excellent castability and weldability.
- It has toughness, excellent wear resistance and pressure tightness.

Uses: - It used for making -

- (1) Paper industries Machinery
- (2) Hydraulic Cylinders, valves, cylinder heads for compressors.
- (3) Earth moving machinery, rolls for rolling mill, pipes.

1) LOW CARBON STEEL OR MILD STEEL -

- Low carbon steel is also known as mild steel. It contains 0.15% to 0.3% Carbon.
- Its tensile strength is 555 N/mm² and hardness is 140 BHN.
- It has bright fibrous structure.
- Its melting point is about 1400°C.
- It is tough, malleable, ductile and more elastic than wrought iron.
- It can be easily forged and welded.
- It can absorb shocks and rusts easily.

Application:

- Mild steel containing 0.15% to 0.2% ~~carb~~ carbon is used in structural steels, beams, screws, case hardening steel, bars, tubes, angles and channels, fan blades etc.
- Mild steel containing 0.2% - 0.3% carbon is used in making machine structure, gears, shafts and forged components, connecting rods, railway axles, valves fish plates etc.

MEDIUM CARBON STEEL -

- Medium carbon steel contains carbon from 0.3% - 0.5%.
- It is tough and it can easily absorb sudden shocks.
- It can be easily forged, welded, elongated due to ductility and beaten into sheets due to its good malleability.
- It can be hardened by heat treatment.
- Its melting point 1400°C.
- Its tensile strength is 750 N/mm² - 1230 N/mm² (according to % of carbon)
- Its hardness varies from 400 BHN - 450 BHN.

Application -

~~It~~ It is used for making -

Railway ~~and~~ axles, connecting rods, bolts, spring clips, gear shaft, turbine rotors, forgings, break leavers, wires and rods ~~and~~, crankpin, splineshaft, locotyes, crankshaft.

High Carbon Steel -

- High carbon steel contain carbon from 0.5% to 1.5%. It has high hardness, therefore it is used for wear resistant parts.
- It loses their hardness at temp from 200°C - 250°C .
- These steels are easy to forge and harden.
- Cutting tools made from this steel is operating at low cutting speed.

APPLICATIONS $\Rightarrow$

(1) High Carbon Steel Containing 0.5% to 0.9% Carbon

It possesses hardness of 450 BHN - 500 BHN and tensile strength about 1400 N/mm^2 . These steels are used of making -

Cold chisel, Wrenches, Jaws for vices, drill bits, structural wires, automatic clutch disc, Hacksaw, wheels for railway.

Rock drill, punches, dies, railway rails, clutch disc, Circular Saw, leaf spring, musical wires.

(2) High Carbon Steel containing 0.9% to 1.5% Carbon -

It is also known as high carbon tool steel and its hardness is 550 BHN - 600 BHN and tensile strength about 580 N/mm^2 . It is used for making -

Taps, mandrels, railway springs, Machine tools, thread metal dies, twist drills, thread dies, Knives, Files, Reamers, metal cutting tools, Wire drawing dies, Paper knives, Tools for turning operations, Broaches.

ALLOY STEELS

(19)

Alloys

Alloy steel is defined as steels to which elements other than carbon are added in sufficient amounts to produce improvements in properties. The most common alloying elements added to steel are chromium, nickel, manganese, silicon, vanadium, molybdenum, tungsten, phosphorous, copper, titanium, cobalt, aluminum.

PURPOSE OF ALLOYING:

The purpose of alloying steels are:

1. ~~Strengthening~~ 1. strengthening of the ferrite.
2. Improved corrosion resistance.
3. Better hardenability.
4. GRAIN size control.
5. GREATER strength.
6. Improve machinability.
7. Improved high and low temp stability.
8. Improved ductility.
9. Better wear resistance.
10. Improved cutting ability.
11. Improved toughness
12. Improved case hardening properties.

EFFECT OF ALLOYING ELEMENTS:

CARBON ÷ Carbon content in steel affects

- Hardness
- Tensile strength.
- Machinability
- Melting point

NICKEL:
- Increases toughness and resistance to impact.
- Lesser distortion in quenching.
- Lowers the critical temp. of steel
- strengthens steels.

SILICON:

- Strengthens low alloy steel
- Improves oxidation resistance
- Improves toughness and hardenability.
- Improves corrosion resistance property.

- Improves magnetic permeability and hysteresis losses.

um : Joins with carbon to form chromium carbide which improves to depth hardenability. (28)

- Improves resistance to abrasion and wear.
- It decreases malleability of steel.
- Increases heat resisting property:

TITANIUM :

- It acts as a good deoxidizer and promote grain growth.
- Reduces hardenability in medium chromium steel.
- It is the strongest carbide former.

TUNGSTEN :

- Increases hardness and toughness at high temp.
- Promotes strength at high temp.
- Promotes fine grain.
- Resists heat and shock.

VANADIUM -

- Promote fine grains in steel.
- Increases hardenability.
- ~~Imparts~~ Imparts toughness to heat-treated steel.
- Increase ductility and fatigue resistance.

Manganese : - It increases hardness, toughness and wear resistance.

- Counteracts brittleness from sulphur.
- Lowers ductility and weldability if it is present in high percentage.

COPPER : - Increase resistance to atmospheric corrosion.

- It increases strength.

ALUMINIUM : - It used as a deoxidizer.

COBALT : - Improves mechanical properties such as tensile strength, fatigue strength and hardness.

- Improves heat resistance.

Mechanical Properties of Materials

The mechanical properties of materials define the behavior of materials under the action of external forces called loads.

They are a measure of strength and lasting characteristic of the material in service and are of good importance in the design of tools, machines and structures.

The mechanical properties of metals are determined by the range of usefulness of the metal and establish the service that is expected.

Mechanical properties are also useful for helping to specify and identify metals.

List of Mechanical Properties of Materials

1. Strength (2) Elasticity (3) PLASTICITY (4) HARDNESS (5) TOUGHNESS (6) BRITTLINESS (7) STIFFNESS (8) DUCTILITY (9) MALLEABILITY (10) COMPRESSION (11) IMPACT STRENGTH (12) FATIGUE (13) CREEP

(1) STRENGTH: Strength is the mechanical property that enables a metal to resist deformation load. The strength of a material is its capacity to withstand destruction under the action of external loads. The stronger the materials the greater the load it can withstand.

(2) ELASTICITY: Elasticity is the ability of an object or material to regain its normal shape after removing the load. When a material is under load, the load causes the material to deform.

The elasticity of a material is its power of coming back to its original position after deformation when the stress or load is released.

ex. Heat treated springs, rubber etc are good example of elastic materials.

(3) PLASTICITY :

The plasticity of a material is its ability to undergo some ~~some~~ permanent deformation without rupture or break. Plastic deformation will take place only after the elastic range ~~has~~ has been exceeded.

Plastic action in structural materials are called yield, plastic flow and creep.

Materials such as clay, lead etc are plastic at room temperature, and steel, plastic when at bright red-heat.

4) HARDNESS :

~~The resistance~~ The hardness is the ability of a material to resist scratching, abrasion, cutting or ~~pen~~ penetration.

The resistance of a material to force penetration or bending is hardness.

It is a very important property of the metals ~~and~~ and has a wide variety of meanings, like It also means the ability of a metal to cut another metal.

⑤ TOUGHNESS -

- It is the property of material which enables it to withstand shock or impact.
- Toughness is the opposite condition of brittleness.
- The toughness is may be considering the combination of strength and plasticity.
- Manganese steel, wrought iron, mild steel etc. are example of toughness materials.

Brittleness - It is the property of a material opposite to ductility. It is property of breaking of material with little permanent distortion. The brittleness of a property of a material which enables it to withstand permanent deformation.

Brittle materials when subjected to tensile loads, break without giving any sensible elongation. ~~They will break~~ Generally, the brittle metals have high compressive strength but low in tensile strength.
ex. Cast iron, Glass, Diamond is a brittle material.

(7) STIFFNESS -

- It is the ability of material to resist the elastic deformation or deflection.
- In stiffness, a material which shows slight deformation under load has a high degree of stiffness.
- The stiffness of a structure is important in many engineering applications, so the modulus of elasticity is often one of the primary properties when selecting a material.

(8) DUCTILITY:

The ductility is a property of a material which ~~can~~ enables it to be drawn out into a thin wire, without breaking.

ex. mild steel, copper, aluminium are the good examples of a ductile material.

(9) MALLEABILITY:

The malleability is a property of a material which permits it to be hammered or rolled into sheets of ~~other~~ other sizes and shapes.

The ~~malleability~~ malleable material should be plastic but it is not essential to be so strong.

ex. ~~Aluminium~~, Aluminium, copper, tin, lead, soft steel, wrought iron. are example of malleable metals.

b) Impact Strength,

The impact strength is the ability of a metal to resist suddenly applied loads.

(11) ~~FATIGUE~~ CREEP,

- The creep is a slow and progressive deformation of a material with time at a ~~low~~ constant force.
- Some metals are generally show creep at high temperature whereas plastic, rubber, and similar amorphous material are very temperature sensitive to creep.
- The force for a specified rate of strain at const. temperature is called creep strength.

(12) FATIGUE

The fatigue is defined as long effect of ~~repeated~~ uneven repeated loading or straining action which causes the strain or break of the material.

or It is the term, 'Fatigue' use to describe the fatigue of material under repeatedly applied forces.

Fatigue is defined as a process of progressive localized plastic deformation, occurring in a localized plastic deformation, occurring in a material subjected to cyclic stresses and strain at high stress concentration locations that may cause in cracks or complete fracture after a sufficient number of fluctuation.

UNIT-II

CASTING

It is a process in which molten metal will be allowed to solidify in a pre-defined mould cavity. After solidification, by breaking the mould required shape of the object can be produced. This object is called casting.

ADVANTAGE OF CASTING -

- (1) Complex shape of the object can be easily produced.
- (2) It is a simple & less expensive process.
- (3) Ductile & Brittle materials can be produced.
- (4) Large size objects can be produced by casting only.

Like (a) Machine Table (b) Engine blocks
(c) Gear box housing (d) Road Rollers Parts.

LIMITATIONS OF THE CASTING PROCESS -

- (1) Surface finish of the castings are very poor.
- (2) It is labourious and time consuming process.
- (3) There is a ~~possibility~~ possibility of gas defects can be expected.
- (4) Casting objects are not having uniform mechanical properties due to non-uniform cooling.

SELECTION OF CASTING PROCESSES:

~~It is~~ Selection of casting process will depends on -

- (a) Shape and size of the object
- (b) Properties required by the object
- (c) Surface finish required.
- (d) No. of components to be produced,
- (e) Cost of the object.

MOULD-

Mould is a cavity created by the Pattern.

PATTERN-

Pattern is a replica of final casting to be produced with some allowances. ~~A pattern is~~

There are several materials commonly used ~~There~~ in the construction of patterns. It is important that the materials used can be easily shaped and are durable. ~~Pattern~~ Pattern materials chosen are depend upon the following factors:

- (1) The design of castings
- (2) The number of castings to be produced
- (3) The casting process used in foundry.

COMMON PATTERN MATERIALS :

1. WOOD : It is cheap and light. It can be easily worked and shaped as desired. It is easily sanded to smooth surface.

(2) METAL : When large number of castings are required the pattern is made of a metal. The metal patterns are more durable and produces moulds to a close dimensional accuracy. Common metals used for pattern making are Cast Iron, Brass, Aluminum and its alloy, white metal, steel.

(3) PLASTER-

The plaster of Paris or gypsum cement is used as a pattern material because it can be easily casted into different shapes.

(4) PLASTICS-

The thermo-setting resins are used as plastic materials. The plastics are light in weight, have high strength, high wear resistance, high corrosion resistance, low solid shrinkage and have very smooth surface finish.

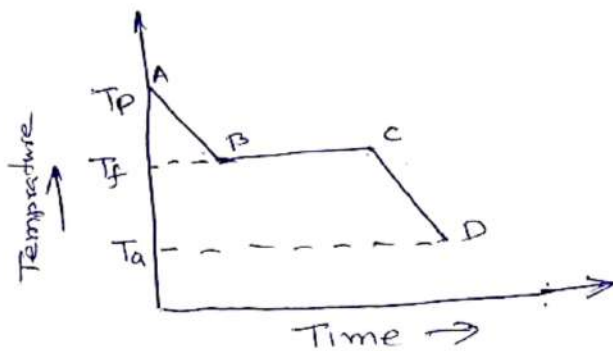
5) WAX: It is used for investment casting process. It helps in high degree of surface finish and dimensional accuracy to castings.

PATTERN ALLOWANCES

A pattern is always made larger than the required size because of material may be shrink after solidify cooling. Therefore, some pattern allowances are given on pattern due to shrinkage of material or some other purpose. The Pattern Allowances are:

- (1) Shrinkage or Contraction Allowances.
- (2) Draft or Taper Allowances
- (3) Machining Allowances
- (4) Rapping or Shaking Allowances.
- (5) Distortion Allowances or Camber Allowances.

① SHRINKAGE ALLOWANCE



A-B → liquid Shrinkage
 B-C → solidification Shrinkage
 C-D → solid Shrinkage

} compensated by riser
 } compensated by pattern

When the liquid metal is solidify in the cavity, there is a possibility of shrinkage of the material. Due to this size of the casting will be decreased.

A to B and B to C
 When the liquid metal is cooled from pouring temperature to freezing temperature, shrinkage is liquid shrinkage. During phase transformation the shrinkage is solidification shrinkage.

C to D
 When the solid metal is cooled from freezing to ambient temperature the shrinkage is solid shrinkage.

Liquid and solidification shrinkage can be compensated by providing riser.

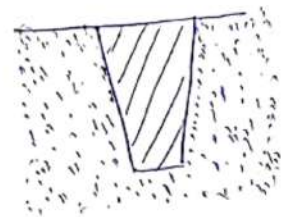
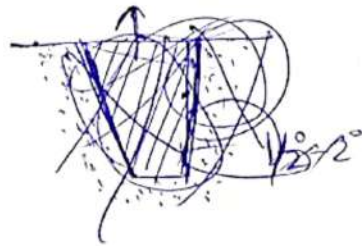
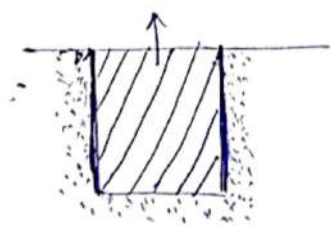
Solid shrinkage can be compensated by providing shrinkage allowance on the pattern.

ex Cast iron 1 mm/m , Aluminium - 13 mm/m , steel 20 mm/m .

2) DRAFT OR TAPER ALLOWANCES -

For easy removal of the pattern from the mould or the vertical surface of the pattern to minimise continuous contact between pattern and mould surface, draft or Tapered allowances is provided.

External surface will require less draft when compare to internal surface.



Taper $\frac{1}{2}^\circ - 2^\circ$

(3) MACHINING OR FINISH ALLOWANCES -

Casting objects are not having smooth surface finish. To get smooth surface finish machining is required.

Due to machining, size of the casting will be decreases. To overcome this, size of the pattern can be increased by providing machining allowance.

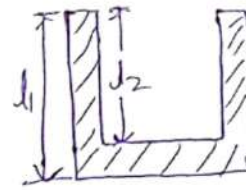
(4) SHAKE OR RAPPING ALLOWANCES -

Due to ramming, moulding sand will be stick ~~to~~ to the surface of the pattern. For easy removal of the pattern from the mould, some clearance is required between the pattern and mould surface. This can be produced by shaking the pattern. Due to shaking, size of the cavity will be slightly increased. To overcome this size of the pattern can be reduced by providing shake allowance.

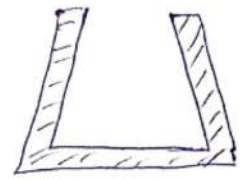
It is a negative allowance provided on the pattern,

5) DISTORTION OR CAMBER ALLOWANCE

Depending on shape and size of the casting due to difference in linear dimensions, there is a possibility of distortion of the casting. To overcome this, distortion allowances is provided on the pattern opposite to the direction of distortion. These values will depend on length to thickness ratio (L/t).



$$l_1 > l_2$$



TYPES OF PATTERNS

- (1) Single piece OR Solid piece Patterns
 - (2) SPLIT Piece Pattern
 - (3) Loose Piece Pattern
 - (4) Gated Pattern
 - (5) Match Plate Patterns
 - (6) Sweep Patterns
 - (7) Follow board patterns
- (10)

MOULDING SAND

The principal material used in making a mould is ^{silica} sand. The silica sand is found in nature on the bottoms and banks of rivers, ^{and} lakes.

A good moulding sand contains the following ingredients:-

Silica Sand : 70% - 85%

Clay : 10% - 20%

Water : 2% - 8%

Additives : 1% - 6%

The pure silica sand is not used because it lacks an binding quality. Any material added to improve the binding qualities ~~is~~ are Binder.

Additives - A material which do not promote binding action, when added to the sand, but it improves some other properties like permeability, collapsibility, surface finish, strength and hardness is called Additives. They Sawdust, Coal dust, linseed oil, molasses etc. →

PROPERTIES OF MOULDING SAND -

(1) REFRACTORINESS: It is the ability of moulding sand to withstand high temp. of the liquid metal without fusion.

(2) PERMEABILITY: It is the ability of moulding sand to allow the gasses to escape. It is expressed by permeability no.

(3) FLOWABILITY - It is the ability of moulding sand to flow into all the ~~are~~ corners of the mould Box due to ramming force,

(4) STRENGTH - To retain the shape and size of the cavity and to withstand forces applied by the liquid metal on the mould surface, mould must be having ~~suffien~~ sufficient strength.

(5) HARDNESS - Hardness is a surface property to minimize erosion and to withstand forces applied by the liquid metal. Mould must be having sufficient hardness.

⑥ ADHESIVE PROPERTY -

It is the property of bond formation between two different materials.
(her ~~had~~ adhesive property between moulding sand and moulding box).

(7) COHESIVE PROPERTIES -

It is the property of bond formation between similar material.

(8) Collapsibility → Ability of the moulding sand due to which mould surface will not provide any resistance due to solid contraction of the casting.

moulding sand also requires sufficient thermal conductivity & low coefficient of linear expansion (K, α)

CLASSIFICATION OF CASTING TECHNIQUES :

(1) Expandable moulds :
(Temporary moulds)

- Sand Castings
- Shell Moulding
- Investment Casting
- Full moulding
- CO_2 moulding

(2) PERMANENT MOULDS
(Metallic moulds)

- Centrifugal Castings
- Die Casting
- Slush Casting

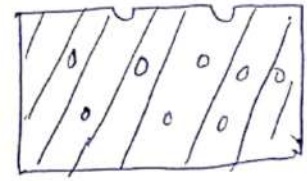
(3) CONTINUOUS CASTING

CASTING DEFECTS

(1) GAS DEFECTS -

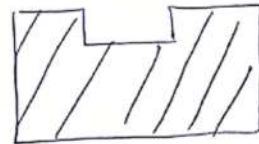
(a) BLOW HOLES AND OPEN BLOWS :

Gas defects which is formed on the surface of the casting are open blow and which are formed inside the castings are blow holes.



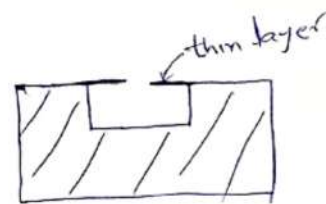
(b) SCAR :

A shallow blow which is formed on the surface of the casting.



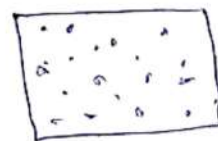
(c) BLISTER -

It is a scar covered by thin layer of metal is blister



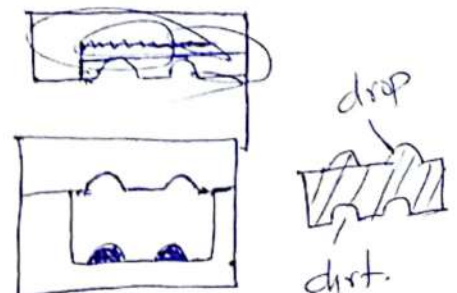
(d) PIN HOLES

Small size holes which are formed due to hydrogen gas is known as pin hole porosity.



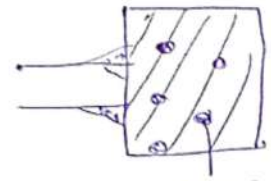
(2) MOULDING MATERIAL AND METHODS -

Due to improper ramming, if the moulding sand will be dropped from cope box to drag box will form a projection on the surface of the casting known as Drop. ~~At the~~
At the bottom surface of the casting, a cavity is formed known as Dirt.



(b) CUTS AND WASHES -

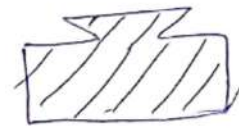
Due to improper ramming and gating design, if the moulding sand will be eroded from the mould surface and washed into the cavity will ~~form~~ form some projections on the casting known as cuts and washes.



Silica Sand
(Silicon Carbide)
hard brittle formation
difficult to machine.

(c) SCAB :

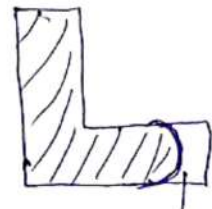
Due to improper ramming, if the liquid metal can be penetrated into loose sand layers will form a projection on the surface of the casting known as scab.



(3) POURING METAL DEFECTS ->

(a) MISRUN

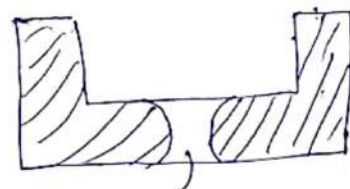
Due to insufficient fluidity, and pouring temperature before reaching the cavity, the liquid metal is getting solidify will form a defect known as misrun.



Unfilled
Cavity.

(b) COLD SHUTS -

Two streams of liquid metal will not fuse properly will form a discontinuity in the casting.



CAVITY.

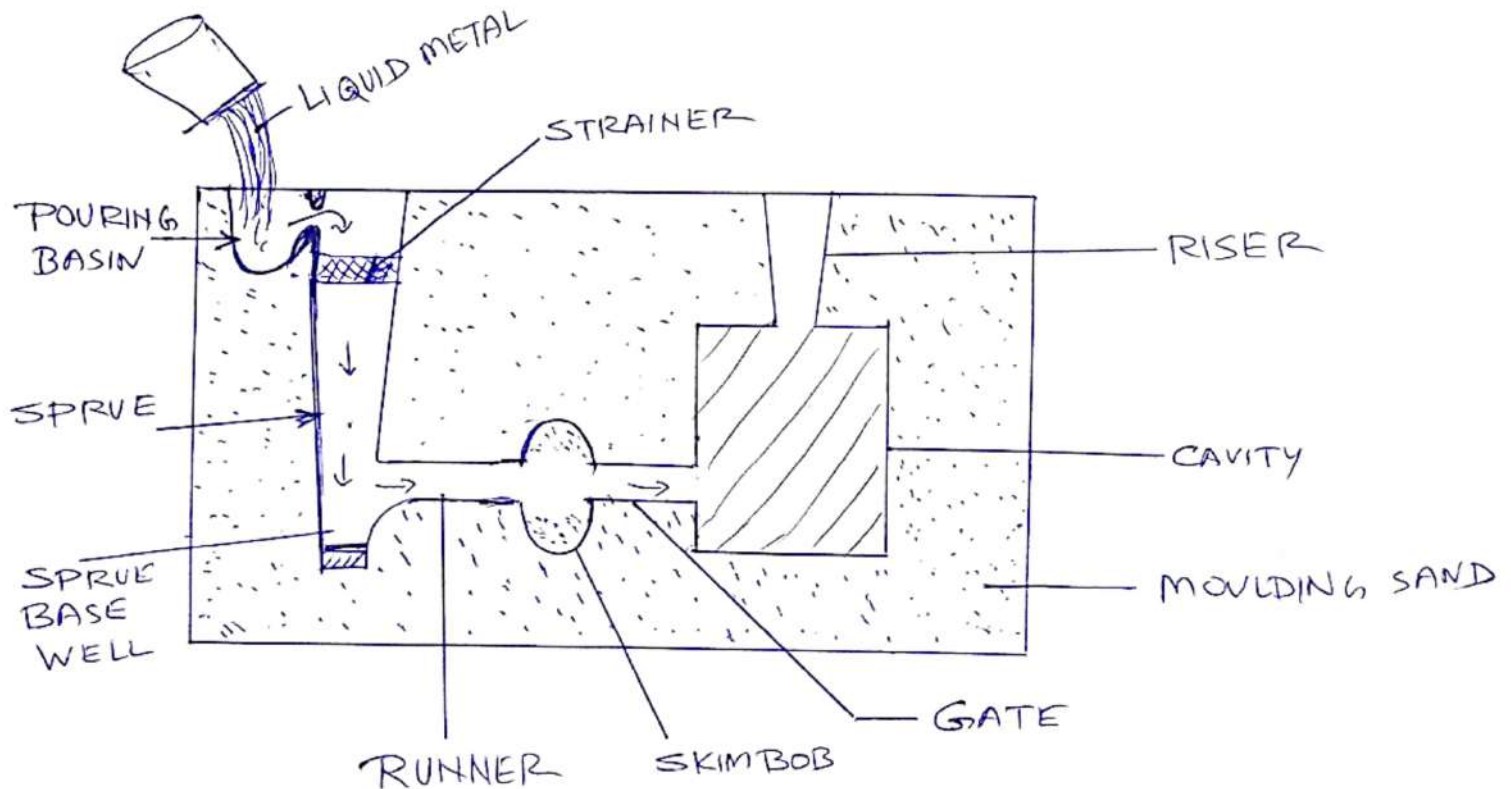
GATING SYSTEM

Objectives of Gating Systems -

- 1) The main objective of gating system is that the liquid metal can be enter into the cavity with optimum velocity within a given time without causing turbulence, splashing and erosion.
- 2) Design the gating elements so that pure liquid metal can be enter into the cavity without air aspiration effect.
- 3) Produce the gating elements for maximum casting yield.

$$\text{Casting Yield} = \frac{\text{Volume of Casting } (V_c)}{V_c + \text{Volume of gating Elements } (V_g)}$$

ELEMENTS OF GATE DESIGN -

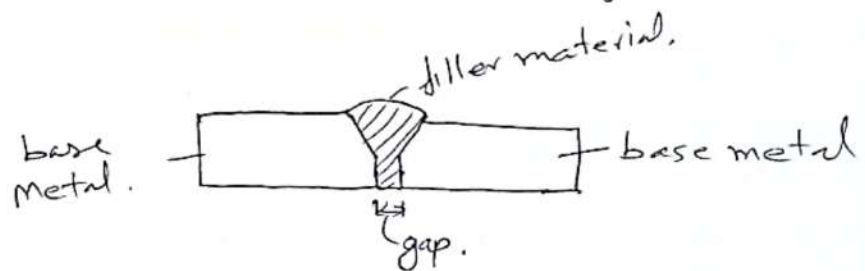


WELDING

The welding is a processes of joining two or more, similar or dissimilar metals by ~~the~~ the application of heat, with or without application of pressure and with or without application of filler material.

The heat may be supplied by electric arc (in case of arc welding) or by combustion of gas (in case of gas welding) or electrical resistance (in case of resistance welding) or by black smith's fire (in case of forge welding)

The filler material has a similar composition and melting point less than of the base metal. The filler rod is used to supply the extra material to fill the gap between joint to produce a round, oval or fillet.



WELDABILITY

Weldability is defined as, the property of a metal which indicates the ease with which it can be welded ~~and~~ and form an inseparable and strong joint, having a homogeneous structure of proper strength.

Weldability of metal depends upon the following factors:

- (1) Composition of metal
- (2) Melting point of metal
- (3) Thermal expansion of metal

- (4) Thermal conductivity of metal
- (5) Micro Structure of Material

ADVANTAGES OF WELDING.

- (1) Welding is more economical and is much faster processes compared to other processes (riveting, bolting, casting etc).
- (2) A good weld is as strong as the base metal.
- (3) Large number of metals and alloy both similar and dissimilar can be joined by welding.
- (4) Welding permits considerable freedom in design.
- (5) Portable welding equipments are available.
- (6) The welding equipment are cheaper, portable and everywhere available.
- (7) The welding structure looks smooth and pleasing in appearance.
- (8) In welded structures, addition and alteration can be easily made. This process provides flexibility of further expansion or correction work.
- (9) Welding can join workpieces through spots, as continuous pressure tight seams, end to end welding or any other configuration.
- (10) Welding can be mechanized.

DISADVANTAGES OF WELDING -

- 1) Welding gives out harmful radiations (light) and fumes.
- 2) Welding results in residual stresses and distortion of the workpieces.
- 3) Welded joints need stress relieving and heat treatment.
- 4) Jig and fixtures are generally required to hold and position the job.
- 5) Edge preparation of the workpieces is generally required before welding processes.
- 6) The welding process requires high degree of skill.

CLASSIFICATION OF WELDING

This can be divided in following three groups:

(a) Autogenous Welding -

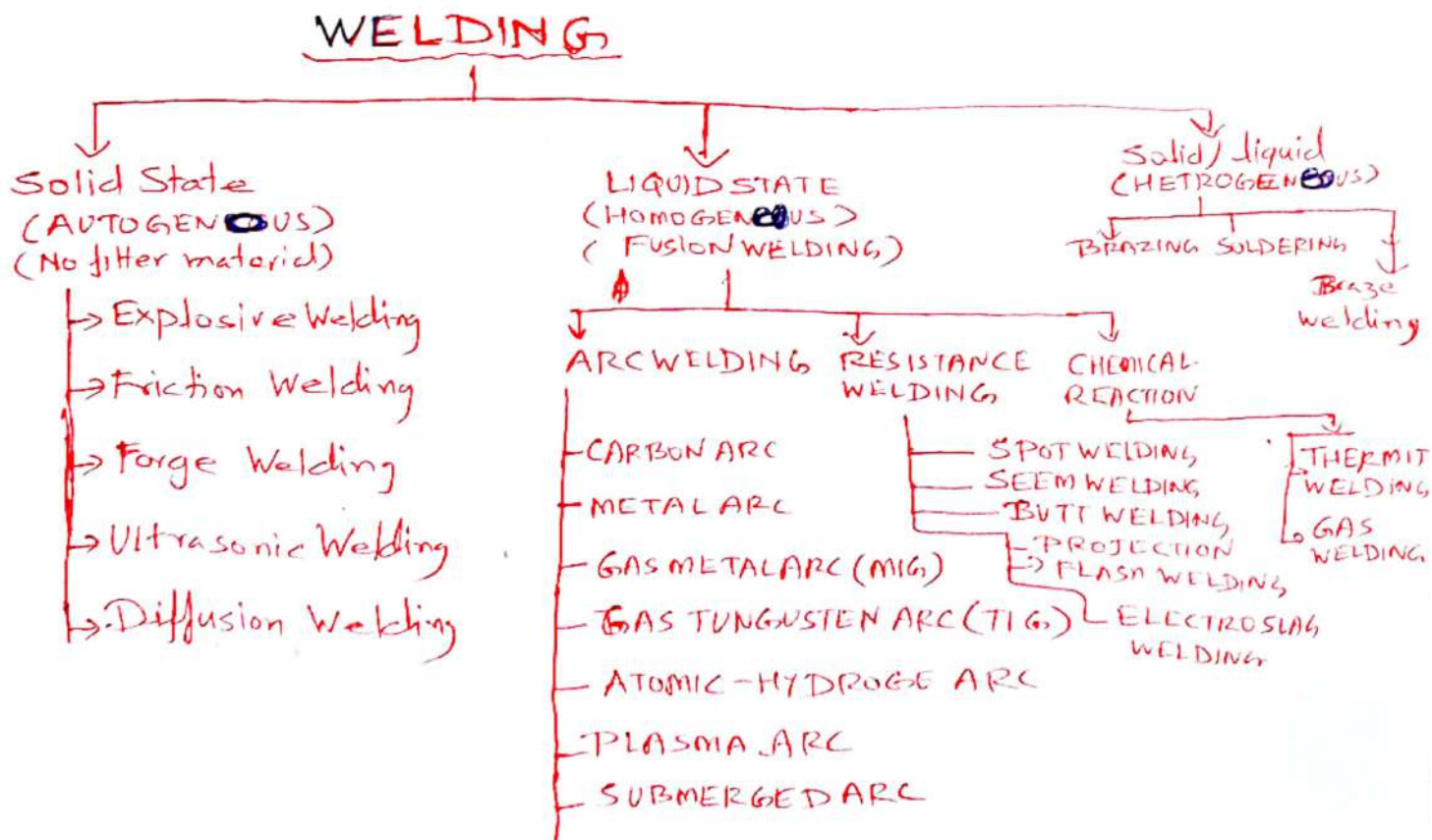
The process of joining ~~similar~~ metals without the addition of filler material is known as Autogenous welding.

(b) ~~Heterogeneous~~ Homogeneous Welding

The process of joining similar metals with the addition of filler material, is known as Homogeneous welding.

(c) Heterogeneous Welding:-

The process of joining dis-similar metals with the addition of filler material, is known as Heterogeneous welding.



APPLICATIONS OF WELDING

- 1 AUTOMOBILE Industries
- 2 BRIDGE APPLICATIONS
- 3) AEROSPACE Industries
- 4) Railway
- 6) Building Construction
- (7) Electrical Transmission ~~Towers~~ Towers.
- (8) Ship Building.
- (9) Medical Equipment Industries.

ARC WELDING PROCESS

The arc welding is a fusion welding process in which the heat required to fuse the metal is obtained from an electric arc between the base metal and an electrode.

The ~~electric~~ electric arc is produced when two conductors are touched together and then separated by a small gap of 2 to 4 mm, such that the current ~~continues~~ continues to flow, through the air.

The temperature produced by the electric arc is about $4000^{\circ}\text{C} - 6000^{\circ}\text{C}$. A metal electrode is used which supplies the filler metal. The electrode may be flux coated or bare.

Both direct current (DC) and Alternating current (AC) can be used for arc welding.

When DC current is used then due to movement of e^{-} from negative to positive $\frac{2}{3}$ rd of heat will be generated on Anode and due to movement of $+ve$ ions from $+ve$ to negative, $\frac{1}{3}$ rd of heat will be generated on the cathode.

When AC current is used, continuous changing the polarity, uniform heat will be generated on cathode.

and anode.

To concentrate more heat on the electrode and workpiece, DC Arc welding can be used.
The AC for arc is obtained by a step down transformer.

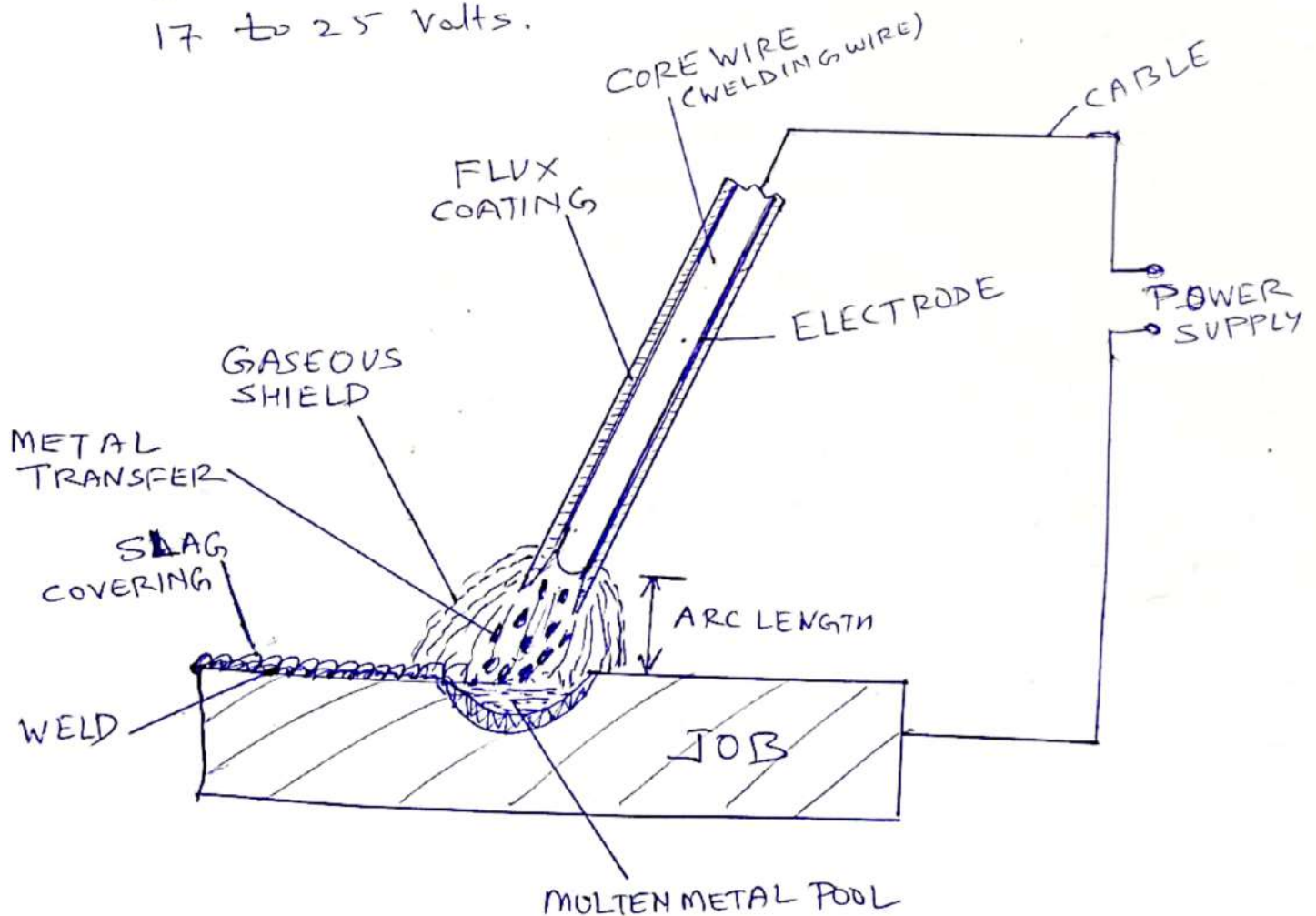
POLARITY IN DC ARC WELDING:-

~~INTRODUCTION~~

The step down transformer receives current from the main supply at 220 to 440 volts and step down to required voltage 80 to 100 volts.

For AC an open circuit voltage is about 75-80 V is required and should be capable of delivering 100-300 amp.

For DC an open circuit voltage is kept around 45 to 95 volts and in closed circuit it is kept around 17 to 25 volts.



ARC WELDING

POLARITY IN DC ARC WELDING

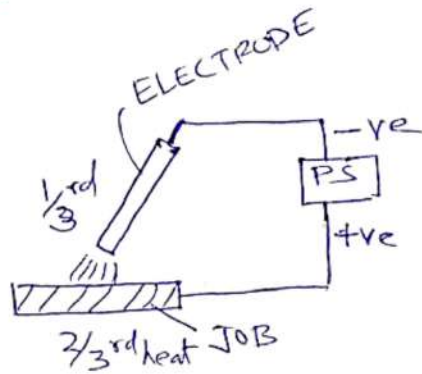
DC Current can be given in two ways :-

- (a) STRAIGHT POLARITY
- (b) REVERSE POLARITY.

(a) STRAIGHT POLARITY -

(DCSP, DCEN)

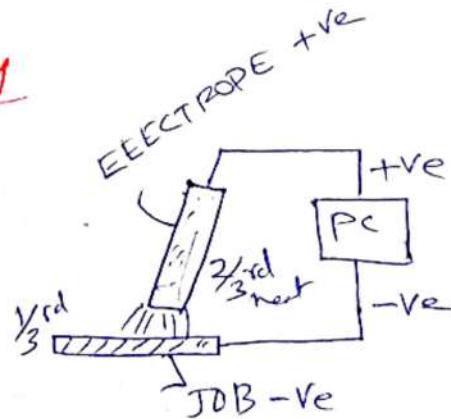
In this electrode is negative and workpiece is +ve. More heat will be generated on the workpiece when compared to electrode.



- It is used for welding of high thickness and high ~~MP~~ melting Point materials.
- Depth of penetration is more
- Weld deposition rate is less.

(b) REVERSE POLARITY

In this electrode is +ve and workpiece will be -ve pole. More ~~at~~ heat will be on electrode when compared to workpiece.



- Used for less thickness and Low Melting Point Materials.
- Depth of penetration is less
- Weld deposition rate is high.

ARC WELDING EQUIPMENT -

(1) WELDING MACHINE -

The welding machine used can be AC or DC welding m/c.
The A.C. welding machine has a step down transformer to reduce the input voltage 220V - 440V to 80V - 100V.
For DC current generator set and Rectifier welding set is used.

(2) EQUIPMENTS

- (a) Power Cables
- (b) Electrode Holder
- (c) Connectors
- (d) Ground Clamps

(3) OPERATOR'S TOOL

- (a) Chipping ~~hammer~~ hammer
- (b) Wire brush
- (c) Face Shield
- (d) Closed Shoe.

DIFFERENCE BETWEEN AC and DC Welding

<u>AC WELDING</u>	<u>D.C. WELDING</u>
1) Equipment is cheaper and simple in operation.	1) Equipment is costlier and complicated in operation.
2) In AC transformer there is no moving part, therefore it is easy to maintain.	2) DC generator set has many moving parts and its maintenance cost is higher than AC transformer.
3) Only Coated electrodes can be used in AC welding.	3) Both Coated and bare electrodes can be used.
4) It can be operated at large distance from power sources as the voltage drop is negligible.	4) In DC voltage drop is very high. Therefore shorter cables are used.
5) Less problem of Arc blow.	5) More problem of Arc blow.
6) It can not be used when AC current is available.	6) An engine generator can be used in case of non-availability of A.C. power.

Generally
7) It can not be used for welding
non-ferrous metals

~~It can be used in case~~
Almost all the metals can be welded.

WELDING DEFECTS

1) GAS POROSITY -

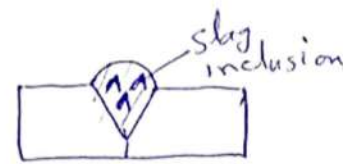
Due to trapping of atmospheric gases inside the liquid metal during the solidification process, Porosity can be produced.



Remedies - Provide sufficient amount of flux.

(2) SLAG INCLUSION -

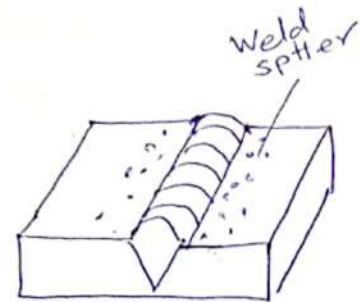
Due to lack of heat input, ~~with~~ the slag can be trapped inside the liquid metal, inclusion can be formed.



Remedies - Provide sufficient amount of heat input and clean the weld bead surface.

(3) WELD SPATTER -

Due to splashing of the liquid metal on the workpiece material, rough surface can be produced is ~~also~~ called as weld spatter.



Remedies - Reduce Arc blow or reduce current

(4) LACK OF FUSION AND PENETRATION -

Due to lack of heat input filler metal is not penetrated into base metal properly.



Remedies - Provide sufficient amount of heat input and select optimum ~~the~~ welding speed.

(5) WELD CRACK -

Due to non-uniform cooling internal stresses can be developed in the weld joint. If the stress will be more than the strength of material, crack will be formed.



Remedies : Provide Preheating and Post heating.

If the hydrogen gas is trapped inside the weld bead. It will penetrate

into base metal will form a crack known as hydrogen embrittlement.

⑥ WELD DECAY -

In case of stainless steel due to fast rate of cooling chromium will be converted into chromium carbide, due to absence of chromium in the base metal, there is possibility of corrosion. Due to this cavity is formed known as weld decay.



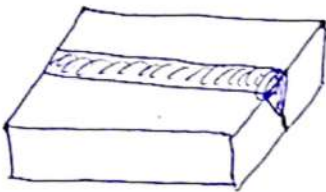
Remedies - Provide uniform cooling.

⑦ Under Cutting

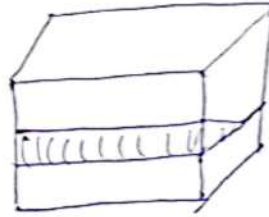
It is due to melting of material away from the base metal and create grooves in the weld.

Welding Position

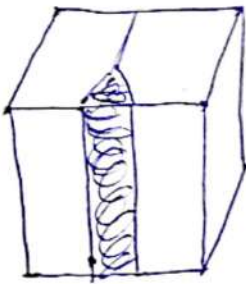
- 1) Flat Welding
- 2) Horizontal Welding
- 3) Vertical Welding
- 4) Overhead Welding



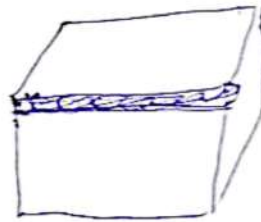
Flat Welding
POSITION



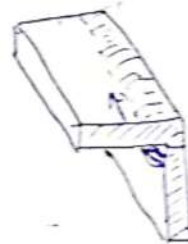
HORIZONTAL
POSITION



VERTICAL
POSITION

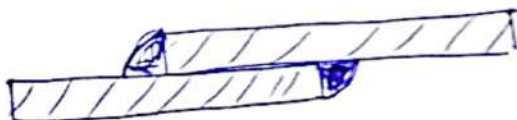


OVERHEAD
POSITION



TYPES OF WELDED JOINTS

- (1) LAP JOINT ÷ The lap joint is obtained by overlapping the two plates and welding the edges of the plates.



LAP JOINT

2) BUTT JOINT -

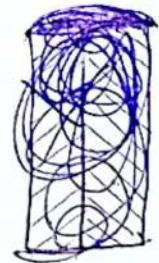
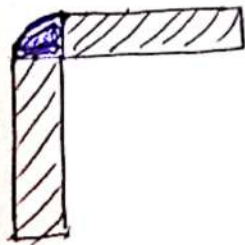
The butt joint is obtained by two plates laying in the same plane and welding the edges or ends of the plates. It is used to joint the plates having thickness of 3 mm to 12 mm.



BUTT JOINT

(3) CORNER JOINT :

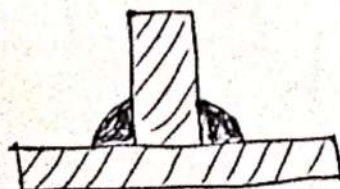
The corner joint is obtained by joining the edges of two plates whose surface are at 90° to each other. This joint is used for both light and heavy thickness sheet metal.



CORNER JOINT

(4) T-JOINT -

The T-joint is obtained by joining two plates whose surfaces are approximately at right angle to each other. The joint is suitable for the plates having thickness upto 3mm. For thickness more than this, welding should be done on both sides.



5) EDGE JOINT - The edge joint is obtained by joining two parallel plates. This joint is unsuitable for members subjected to direct tension or bending.



ARC WELDING ~~ED~~ ELECTRODES.

Arc welding electrodes can be classified into two broad categories:-

- (1) CONSUMABLE ELECTRODES
- (2) NON-CONSUMABLE ELECTRODES

(1) CONSUMABLE ELECTRODES -

These electrodes get melted during welding operation; and supply the filler material. They are generally made with similar composition as the metal to be welded.

The arc length is maintained by moving the electrode towards or away from the work.

These electrodes are of two types.

(1) Coated Electrodes -

Coated electrodes are generally applied in arc welding processes. A metallic core is coated with some suitable material. Metallic core is made by mild steel, nickel steel, chromium molybdenum steel etc. One end of the ~~coated~~ coated core is kept bare for holding the electrode in holder.

(2) BARE ELECTRODES -

Bare electrodes produced the welding of poor quality. These are cheaper than coated electrodes. These are generally used in modern welding process like MIG welding.

~~FOR~~

(2) NON-CONSUMABLE ELECTRODES -

These electrodes do not consumed during the welding operation, hence they named non-consumable electrodes.

They are generally made up of carbon, graphite or tungsten.

FUNCTIONS OF ELECTRODE COATINGS

- (1) To prevent oxidation
- (2) To provide an envelope of inert gas.
- (3) To reduce the viscosity of molten metal.
- (4) To maintain a steady arc in case of Arc welding
- (5) It also improves the properties of joint.

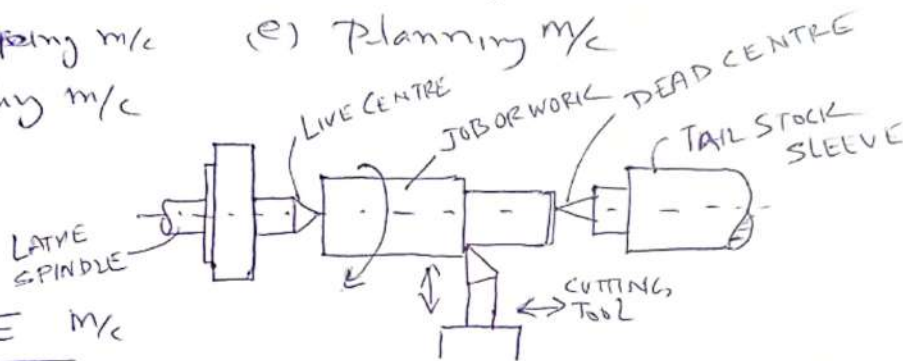
Functions of Machine Tools:

Machine tool has to perform following function:-

- (i) to hold and support the ~~cut~~ job to be machined.
- (ii) to hold and support the cutting tool in position.
- (iii) to move the cutting tool, work/ both of them in the desired direction.
- (iv) to regulate the cutting speed and provide the feeding movement to one of these.

Types of Machine tools are.

- | | |
|-----------------|------------------|
| (a) Lathe | (d) Drilling m/c |
| (b) Shaping m/c | (e) Planing m/c |
| (c) Milling m/c | |



LATHE M/C

Lathe is machine tool which holds and supports the job between two rigid and strong supports called centres, or in a chuck or in a face plate while the latter revolves.

The cutting tool is rigidly held and supported in a tool post and is fed against the revolving work.

While the work revolves about its own axis the tool is made to move either parallel to or at an inclination with the axis. The tool is made to move either parallel to or at an inclination with the axis, to cut the desired material.

- In doing so it produces a cylindrical surface, if it is fed parallel to the axis, or will produce a tapered surface if it is fed at an inclination.

TYPES OF LATHE - (1) SPEED LATHE (2) ENGINE or Centre lathe (3) Bench Lathe (4) Tool Room Lathe (5) CAPSTON AND TURRET LATHE (6) Automatic Lathe (7) Special Purpose Lathe

The main parts of a lathe are:

- (I) Bed (IV) Carriage
(II) Head stock (a) Saddle (c) Compound Rest
(III) Tail stock (b) Crossslide (d) Tool post
(e) Apron
(V) Drive Mechanism (Feed mechanism)

(1) BED -

The bed of a lathe acts as the base on which different fixed and movable operating parts are mounted. The bed consists of two heavy metal slider running lengthwise. Directly under the front way of the bed is a rack. A pinion gear ~~mechanism~~ mechanism with the rack for moving the carriage when the handwheel is turned.

The top of the bed is planed to form guide ways for the carriage and tail stock. The guide ways are of two types:

- (1) Flat guides (2) Flat and inverted vee guides.

It is made from grey cast iron. Grey cast iron has high lubricating ~~properties~~ as well as force absorbing capability.

(2) HEAD STOCK: All the transmission related parts are kept in headstock. It supports the main spindle in the bearing and ~~aligned~~ aligns it properly. ^{It is also called drive centre.} It consists of following main parts:

- (I) Cone Pulley (IV) Live Centre
(II) Back gear and back gear lever (V) Fixed reverse lever
(III) Main spindle and head stock spindle

The complete head stock consists of the headstock casting which is located on the ways of the bed at the left side of the operator. It has the necessary gears and mechanisms for obtaining the various spindle gears.

tailstock :

The tailstock is the counter part of the headstock and is situated at the right hand side of the bed. It is used for supporting the work when turning on centres or when a long components is to be held in a chuck. It is also used for holding and feeding the tools such as drills, reamers, boring tools etc.

The tailstock can be moved toward or away from the operator. It is also called dead centre.

(4) CARRIAGE -

The carriage controls and supports the cutting tool.

The carriage has the following five major parts:

- (a) Saddle (b) Cross-slide (c) Compound rest
(d) Tool post (e) Apron.

(a) SADDLE : It is a H-shaped casting that fits over the bed and slides along the ways between the headstock and tailstock.

(b) Cross-Slide : It is mounted on the saddle. It supports the compound rest. The transverse movement of the cross-slide is obtained by ~~turning~~ moving the cross-slide hand wheel.

(c) COMPOUND REST : It is mounted on the top of the cross-slide. It can be swivelled to any desired angle in a horizontal plane and its base is graduated in degrees to indicate its angular setting.

(d) TOOL POST : It is mounted ~~on~~ above the compound rest. A T-slot is machined in the compound rest to accommodate the tool post. It serves to rigidly clamp the cutting tool or tool holder, in a desired position.

(e) APRON :

It is fastened to the saddle and hangs over the front of the bed. It contains gears, clutches and levers for operating the carriage by hand and power feeds. The apron hand wheel can be turned to move the carriage longitudinally back and forth by hand.

(5) Feed Mechanism :

The feed mechanism of a lathe is employed for giving various feeds to the cutting tool. The feed i.e. the movement of the tool relative to the work may be longitudinal, cross and angular.

Longitudinal feed - The feed is said to be longitudinal when the tool moves parallel to the work.

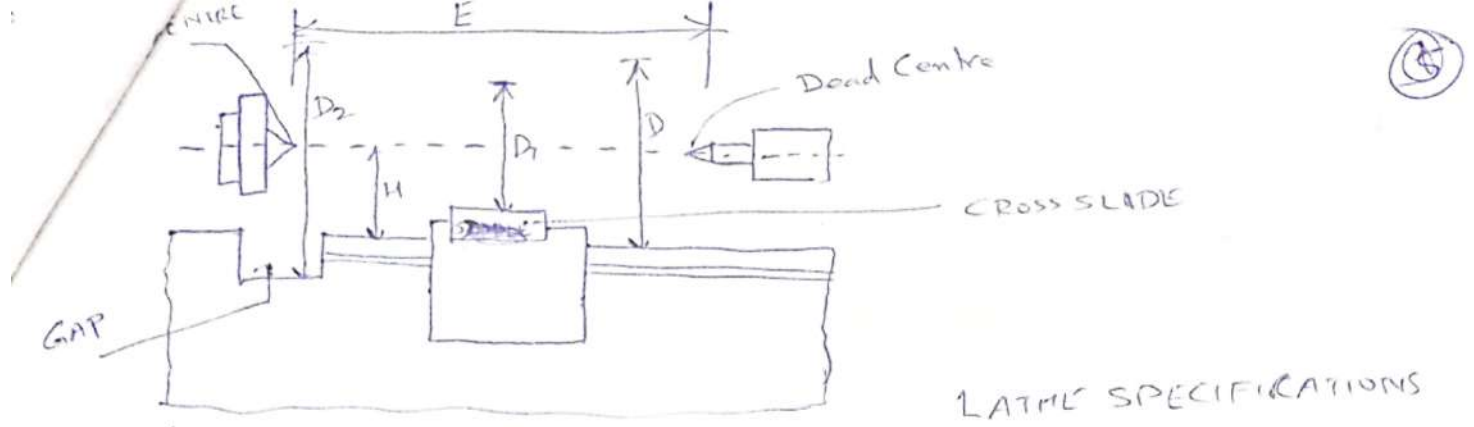
CROSS FEED :

The feed is said to be cross when the tool moves perpendicular to the work.

Angular Feed :

The feed is said to be angular when the tool moves at an angle to the work.

The feed mechanism consists of feed reverse lever, Tumbler reversing mechanism, change gears, feed gearbox, lead screw, feed rod, half nut mechanism.



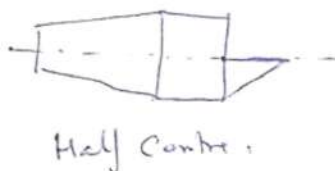
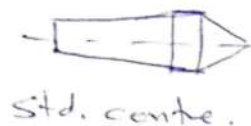
- H - Height of the centres above the top of the bed.
- $D \rightarrow$ The scoring or maximum diameter of the work that can be rotated over the ways of the bed.
- $E \rightarrow$ Maximum length that can be accommodated between the lathe centres.
- $D_1 \rightarrow$ Maximum diameter of the work that can be rotated over the cross-slide.
- $D_2 \rightarrow$ The maximum diameter of the work that can be accommodated in the gap for a gap bed lathe.

In addition to the above, the following specifications are necessary to provide while ordering a lathe:

- 1) The length, width and depth of bed.
- 2) The depth and width of the gap.
- (3) The number and range of spindle speeds.
- (4) Pitch of the lead screw.
- (5) Tailstock set over
- (6) Back gear Ratio
- (7) Power of the motor
- (8) Std. Taper on spindle
- (9) The range of metric or inch threads that can be cut.

Lathe Accessories :

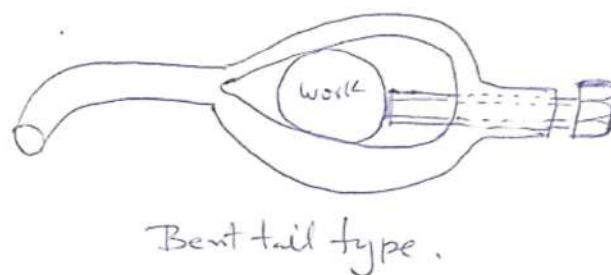
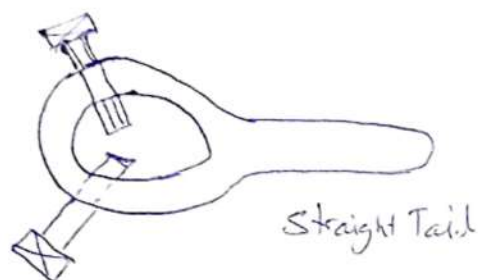
1) Center →



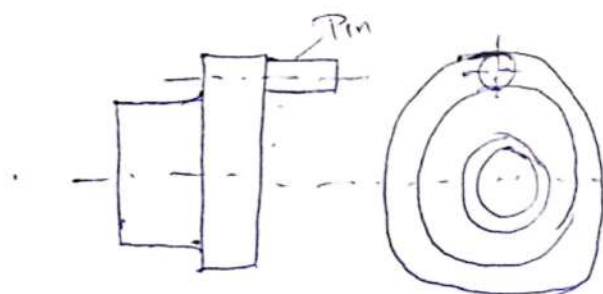
(2) CHUCKS

- (a) Three jaw Chuck (c) Pneumatic Chuck (e) Magnetic Chuck.
(b) Four Jaw chuck (d) Hydraulic Chuck

(3) Lathe dog or carrier

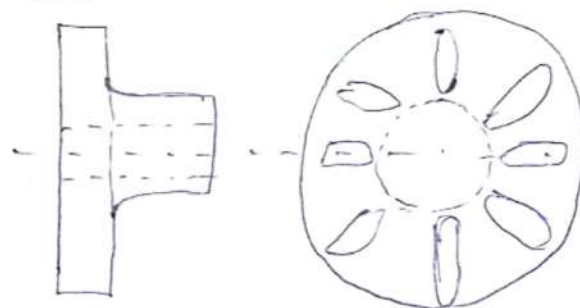


(4) Drive Plate



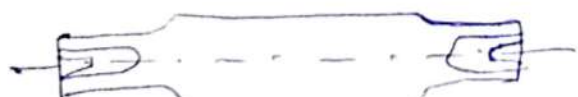
Drive Plate

(5)

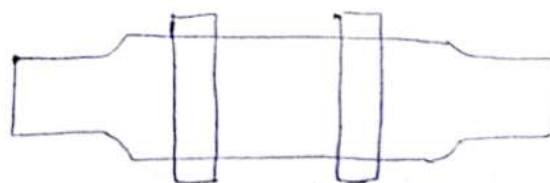


Face Plate

(6) Mandrels ~~the lathe~~



Plain or Solid Mandrel



Collars
collar mandrel

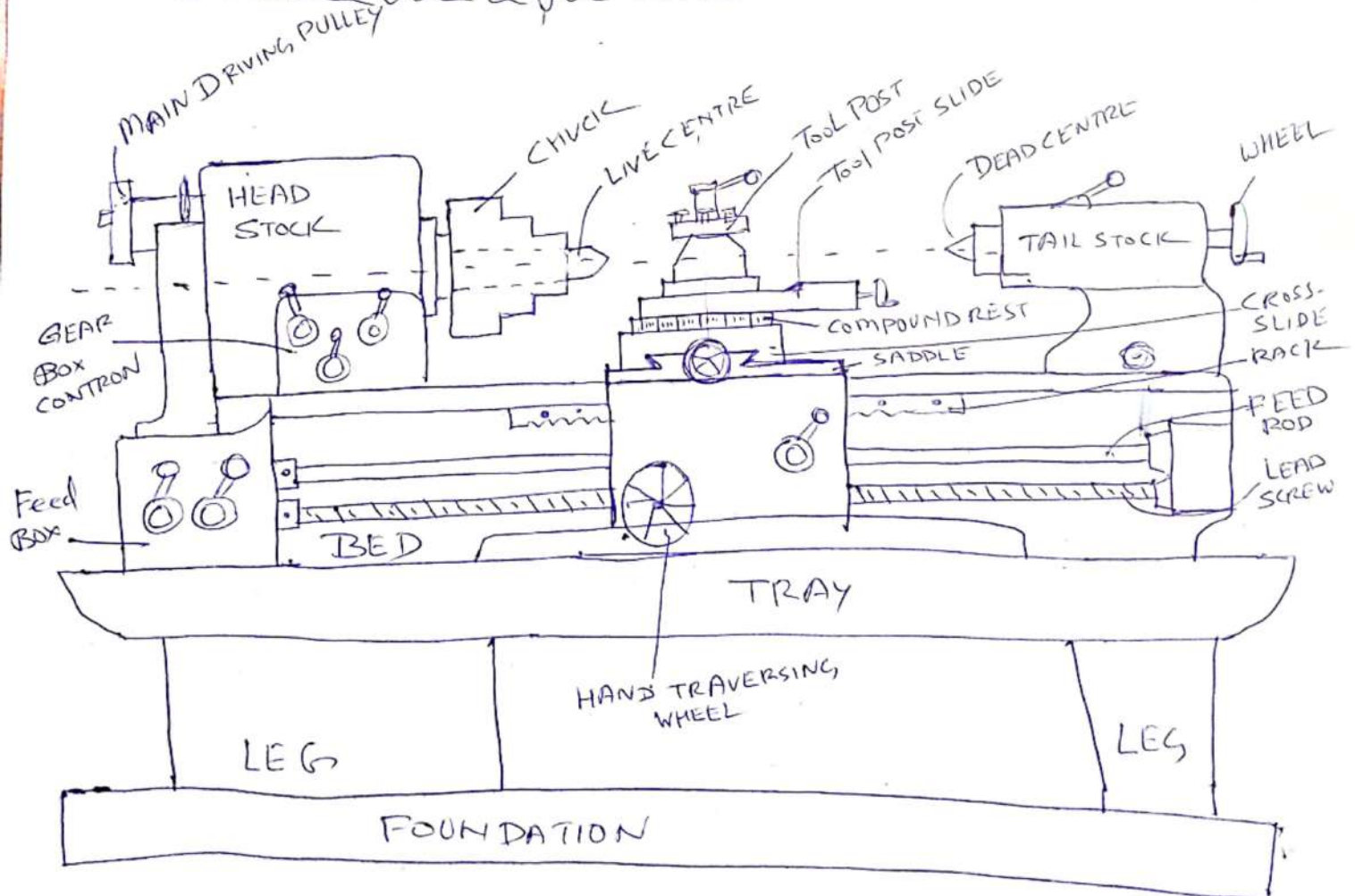
IRON - CARBON DIAGRAM

The iron-carbon diagram is also known as iron-iron carbide diagram. It concerns transformations that occur in alloys having compositions from pure iron to cementite (6.67% carbon). Any point in the diagram represents a definite alloy at definite temperature.

The carbon contents are shown on the horizontal axis and temperature on the vertical axis. Whenever an alloy is heated or cooled so that a line on the diagram is crossed, a phase change occurs.

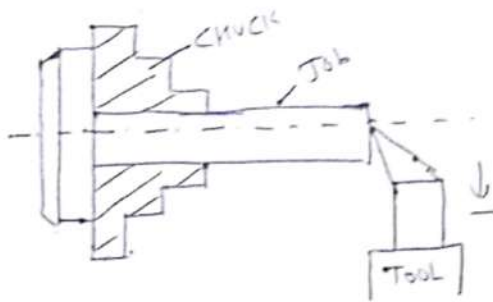
Cooling Curve for steel

Cooling Behaviour of Pure Iron

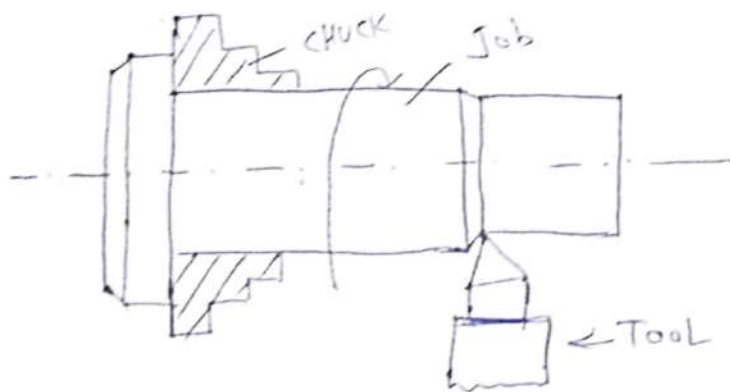


- 1/6 Facing (2) Plan Turning (3) Step Turning (4) Taper Turning
 5) Drilling (6) Boring (7) Grooving or Undercutting (8) Threading
 (9) Knurling

(1) Facing : This operation is almost essential for all works. In this operation, the workpiece is held in the chuck and the Facing Tool is fed from the centre of the workpiece towards the outer surface or from the outer surface to the centre, with the help of cross-slide.

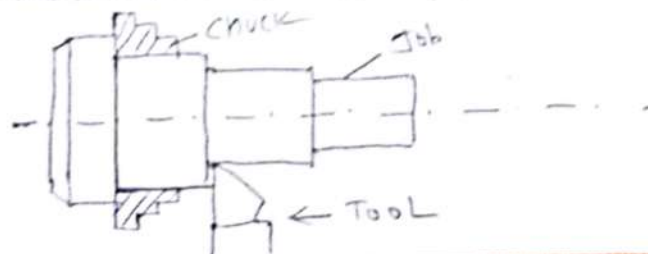


2) Plan Turning : It is an operation of removing excess amount of material from the surface of the cylindrical workpiece. In this operation, the work is held either in the chuck or between centres and the longitudinal feed is given to the tool either by hand or power.



(3) STEP TURNING -

It is the operation of producing various steps of different diameters in the workpiece.



④ TAPER TURNING -

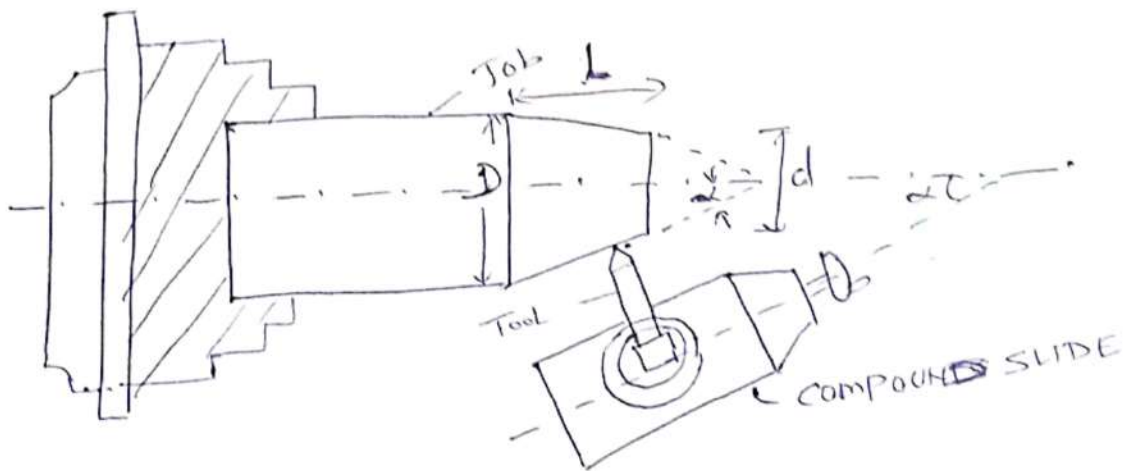
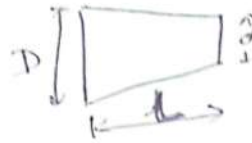
It is an operation of producing an external conical surface on a workpiece. A small taper may be produced with the help of a forming tool or chamfering tool, but the larger tapers are produced by following methods:

- (1) By swivelling of compound rest
- (2) By Taper Turning Attachment.
- (3) By Tailstock setover method.
- (4) By Form nose taper turning Tool.

Compound rest is swivelled by an angle by using this formula

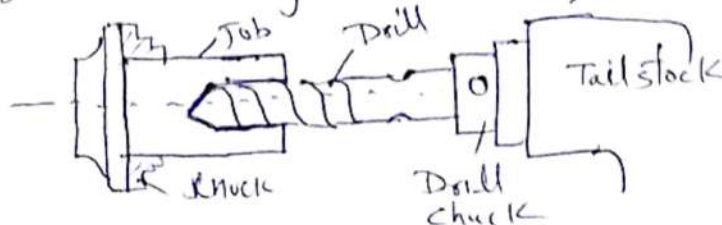
$$\tan \alpha = \frac{D-d}{2L}$$

where,
 α - required angle
 D - large diameter
 d - Small diameter
 L - length of the Taper



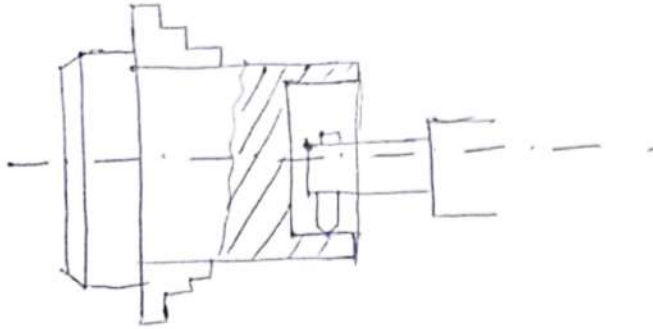
⑤ DRILLING OPERATION -

It is an operation of making a hole in a workpiece with the help of a drill. In this operation, the workpiece is held in a chuck and the drill is held in the tailstock. The drill is fed manually into the rotating workpiece by rotating the tailstock handwheel.



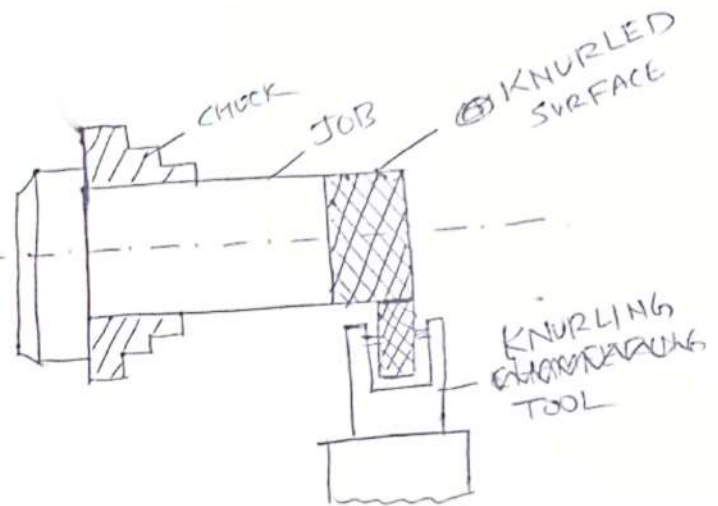
⑥ BORING →

It is an operation of enlarging of a hole already made in a workpiece. In this operation, a boring tool or a bit mounted on a rigid bar is held in the tool post and fed into the work by hand or power in the similar manner way as job turning.



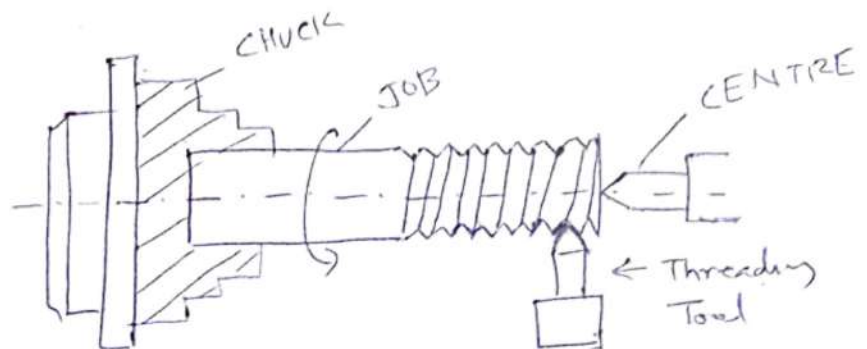
⑦ KNURLING OPERATION -

It is an operation of providing knurled surface on the workpiece. In this operation, a knurling tool is moved longitudinally a revolving job. The projections on the knurled tool reproduce depressions on the work surface. The purpose of knurling operation is creating a hand grip of roughened surface on the workpiece.



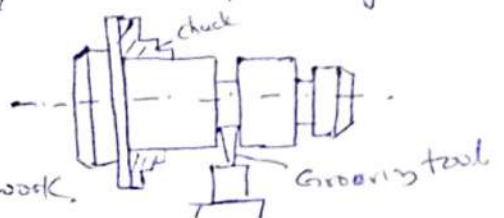
⑧ THREADING -

It is an operation of cutting helical grooves on the external cylindrical surface of workpiece. In this operation, the work is held in chuck or between centres and threading tool is fed ~~long~~ longitudinally to the revolving work. The longitudinal feed is equal to the pitch of the thread to be cut.



⑨ Under cutting or Grooving -

It is an operation of reducing the diameter of a workpiece over a very narrow surface. In this a tool of appropriate shape is fed into the revolving work.

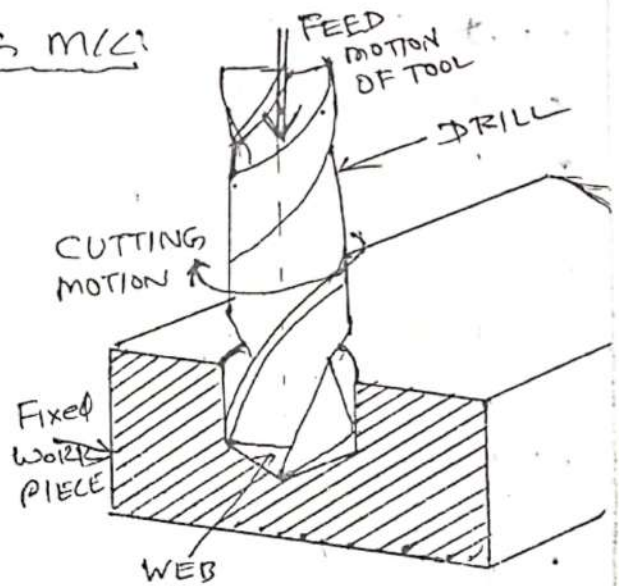


DRILLING

Drilling is an operation through which holes are produced in a solid metal by means of a revolving tool called DRILL. The drill is fixed in a rotating spindle and can be fed towards the workpiece which may be fixed to the table or to the base of machine. The speed of the spindle and the feed can be adjusted according to the workpiece.

WORKING PRINCIPLE OF A DRILLING M/C:

The cutting tools used for drilling holes in the workpiece is called twist drill and is provided two cutting edges. In order to cut off chips, two motions are given to the drill simultaneously:



1. ROTARY MOTION: The rotary motion is called as main motion or cutting motion. The cutting motion is generally measured in m/min . The highest cutting speed is on the periphery of the drill and it decreases towards the centre of the drill.
2. LINER MOTION TOWARDS THE FIXED WORKPIECE: The motion is called as feed and it controls the thickness of the chip. In small bench type drilling machines, instead of giving feed to the drill, the workpiece is moved towards the rotating drill by raising the table. The feed is generally measured in $mm/revolution$. As the drill is provided with two cutting edges, the thickness of the drill is half the feed.

SPECIFICATIONS OF DRILLING MACHINE

Drilling machine is specified by following parameters:

- (1) Drilling capacity.
- (2) Taper in Spindle (Morse No)
- (3) Distance between spindle and column (max. and min) in case of radial drilling machine.
- (4) Travel of spindle
- (5) Minimum distance between spindle and table.
- (6) Minimum distance between spindle and baseplate.
- (7) Working surface of Table (diameter)
- (8) Range of spindle speed.
- (9) Motor Power.

TYPES OF DRILL MACHINE

- (1) Portable drilling machine.
- (2) Sensitive or Bench Drill machine.
- (3) Radial Drill machine
- (4) Multiple Spindle Drilling Machine
- (5) Deep hole ~~di~~ Drilling Machine.
- (6) AUTOMATIC Drilling Machine.

DRILL MACHINE

MAIN PARTS OF DRILL MACHINE

- (1) BASE (2) PILLAR (3) HEAD (4) DRILL SPINDLE (5) FEED HANDLE

BASE:- It is heavy casting and it supports the drilling machine structure.

PILLAR:- It is a vertical round section which rests on the base and supports the head and the work table.

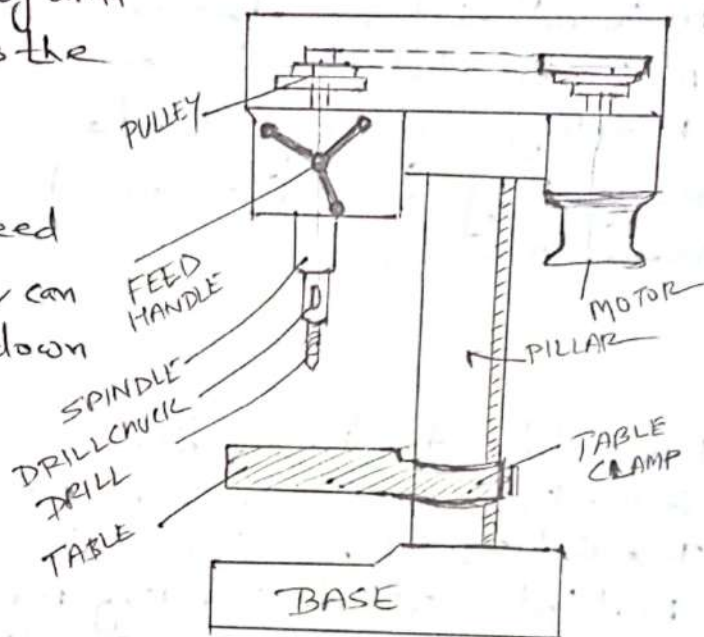
HEAD! It contains main drive (electric motor, V-pulleys and V-belt), which transmits rotary motion to the drill spindle at a number of speeds.

DRILL SPINDLE!

Drill spindle is made up of alloy steel. It rotates as well as moves up and down in sleeve. Drill chuck is held at the end of drill spindle and it holds the drill bit.

FEED HANDLE!

With the help of feed handle, the worker can move the drill up or down for drilling.

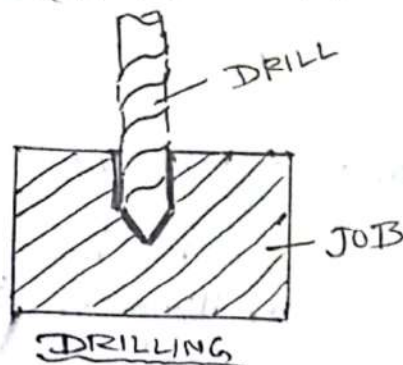


OPERATIONS DONE OF DRILLING MACHINE

- (1) DRILLING (2) REAMING (3) BORING (4) COUNTER-BORING
(5) COUNTER SINKING (6) SPOT FACING (7) TAPPING.

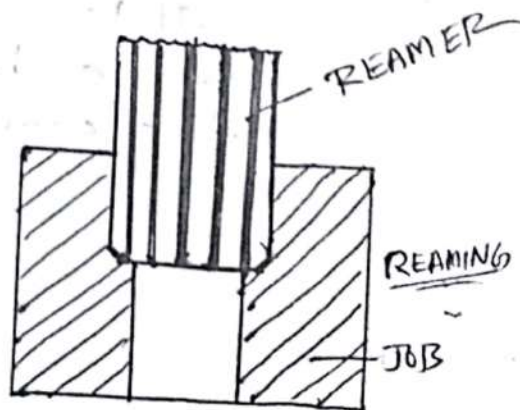
DRILLING!

It is the main operation done on this machine. It is the operation of producing a circular hole in a solid body.

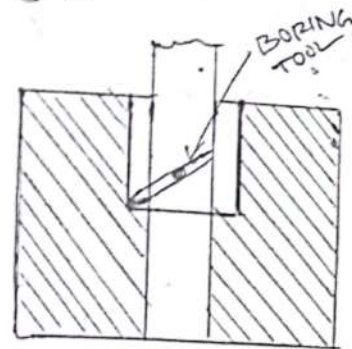


REAMING!

It is the operation of finishing a hole to bring it to accurate size and have a fine surface finish. This operation is done by multi-point tool called REAMER.

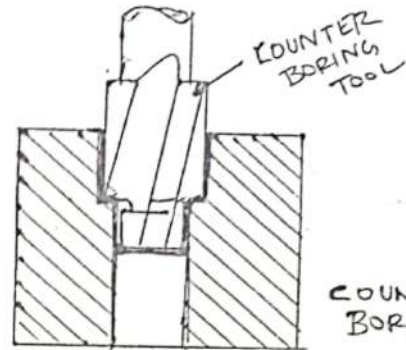


BORING: It is an operation used for enlarging a hole to bring it to the required size and have a better finish. It involves the use of an adjustable cutting tool having a single cutting edge. A boring tool is employed for this purpose. It is slower process than reaming. The accuracy is expected is within ± 0.0125 mm.



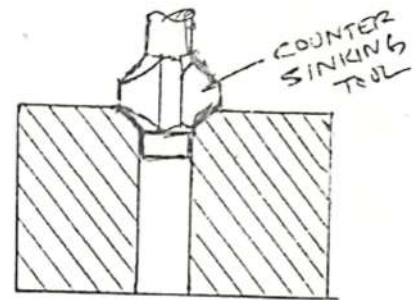
BORING

COUNTER BORING: The operation used for enlarging only a limited portion of the hole is called counter-boring. It can be performed either by means of a double-tool boring bar or a counter-boring tool. This operation is used to set bolt heads and nuts below the surface so that they may not project out from the surface level. The counter-boring tool is guided by a pilot pin which fits into the drilled hole.



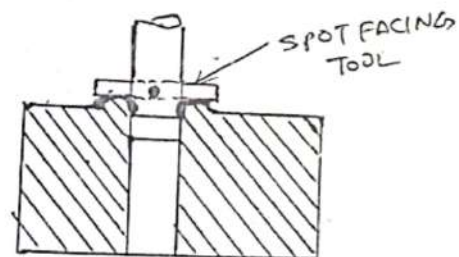
COUNTER BORING

COUNTER-SINKING: It is operation used for enlarging the end of a hole to give it a conical shape for a short distance. This is done for providing a seat for the counter-sunk heads of the screws, so that the latter may give the be flush with the main surface of the work. The standard counter sinks carry included angles of 60° , 82° , or 90° .



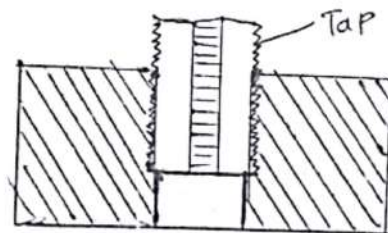
COUNTER-SINKING

SPOT FACING: This operation is used for finish off a small portion of rough surface around a drilled hole to provide smooth seat for bolt heads or collars. This is usually done on casting or forgings. Spot facing tool is a single blade (which is little larger than the bolt head dia) ground to give two cutting edges and is guided by a stem which runs in a pilot hole.



SPOT FACING

TAPPING: It is the operation of cutting internal threads by using a tool called a tap. A tap is similar to a bolt with accurate threads cut on it. To perform the tapping operation, a tap is screwed into the hole by hand or by machine. The tap removes the metal and cuts internal threads.



TAPPING OPERATION

Measurements

①

Measurement is the process of determinations of anything that exists in ~~some~~ ~~amount~~ amount.

If those things that exist are related to mechanical engineering the determination of such amounts are referred to as mechanical measurements, if it is related to other field ~~it is called~~ ~~electrical~~ like electrical, electronic, ~~then~~ it is called electrical measurement and electronics measurement.

Functions of Measurements

An engineer is interested in

1. the measurement of physical variables
2. is concerned with their controls.

Our daily activity

Buying things - grocery, gold, petrol, cloth, level of vehicle.
Inspecting work pieces produced in a shift, measuring blood pressure, sugar level, height.

- These two functions are closely related because one must be able to measure a variable such as temperature, or flow in order to control it.

- The accuracy of control is essentially dependent on the accuracy of measurement, which requires the measured discrepancy between the actual and the desired performances.

Therefore, a good knowledge of measurement techniques is necessary for the design of control system.

Seven basic Units

mass - kg

time - sec.

temp - °C or K

electrical temp - A (Ampere)

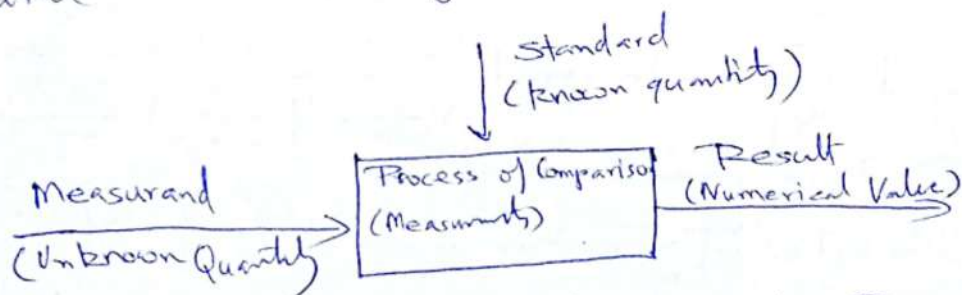
mole - unit of substance (mol)

Candela (cd) luminous intensity

distance - m

Definition of Measurements

Measurement is defined as the process or act of obtaining a quantitative comparison between a predefined standard and a unknown magnitude.



Fundamental Measuring Process

IMPORTANCE OF MEASUREMENTS -

- Measurement is everywhere, and is playing a vital role in our lives.
- To ensure safety and effectiveness of healthcare diagnostic and treatment.
- Measuring composition of material.
- To ensure safe operation of vehicles, machine tools.
- To ensure proper food supply.
- To ensure consistency of time standards.
- To ensure fairness between buyers and sellers.
- To ensure structural health of bridges and buildings.
- To evaluate newly developed products and processes.
- To get accurate and precise data in scientific research.

CLASSIFICATION OF METHODS OF MEASUREMENT

In measurement systems, various methods of measurement are followed depending on accuracy and precision requirements.

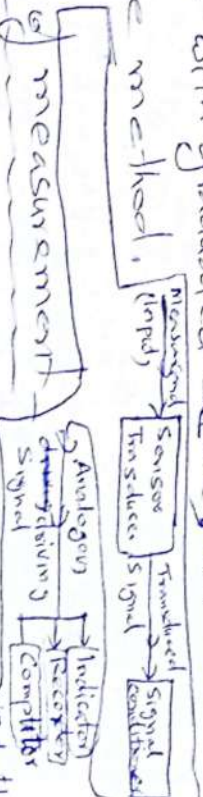
(1) DIRECT Methods of Measurements :-

In this method, unknown quantity is found out by direct comparison with standards. We get direct reading.

Eg. measuring length with graduated scale, but this is not very accurate method.

(2) INDIRECT Methods of measurement

~~Unknown~~ In this method unknown quantity is indirectly calculated. Indirect comparison makes use of some form of measuring device sensor, converts, and finally presents an analog or digital displacement on a scale or chart finding eg Density is calculated by measuring mass and finding Volume by measuring dimensions.



CONTACT and Contactless methods of measurements -

Contact measurement involves use of mechanical probe or other device that makes contact with the object being measured. ~~Atwood~~ This method is used in inspection processes. Contact inspection is usually concerned with measuring or gauging some physical dimension of parts.

Non contact methods utilise a sensor located a certain distance from the object to measure or gauge features. These methods are faster and do not damage the part being checked. ^{Non optical,} These can be classified as optical and non-optical, ^{laser,} machine vision system are used and in non-optical, electric field, radiation techniques and ultrasonics are used.

(4) Rave Coincidence Method of measurement:

On this Scales differ by small amount. By observing the difference between given quantity and reference is determine by observation of coincidence of scale make. eg. Vernier Caliper.

(5) Deflection Method of measurement:

Quantity is directly indicated by deflection of a pointer on calibrated scale.

Classification of measuring instruments -

- (1) According to function
 - (i) Length measuring instruments → (a)
 - (ii) Angle measuring instruments → (b)
 - (iii) Instruments for checking geometrical shapes,
 - (iv) ~~Surface~~ ^{Plane} Measuring instruments for Plane Surface → (c)

1) Length Measuring Instruments -

- (i) Steel rule (ii) Vernier Calliper (iii) Micrometer (iv) Depth gauge
- (v) Vernier Height Gauge (vi) Dial gauge (vii) Slip gauges.
- (viii) Limit gauges (ix) Caliper. (x) Comparators

→

(5) For Angular Measurements:

The following are the various instruments used for angular measurements:

- (i) Bevel Protractor (ii) Sine Bar (iii) Combination Set
- (iv) Angle Gauge Block (v) Dividing head (vi) Clinometer
- (viii) Auto-collimator.

(6) For Plane Surface Measurements

- (i) Spirit Level (ii) Surface Gauge (iii) OPTICAL FLAT
- (iv) Profilometer (v) Interferometer.

STANDARDS OF MEASUREMENT:

Depending upon the degree of accuracy required for the purpose for which a standard is to be used, the standards of measurement are sub-divided into the following categories or grades:

(i) Primary STD:

They are one material standards and are very carefully preserved under controlled conditions of atmosphere. These standards are not ~~practically~~ frequent or common use. Their use is comparison with secondary standards, which is needed after long intervals. In this sense we can call them Master standards.

2. Secondary Standards

They are more or less similar to the primary stds and are made as close in accuracy as possible to the latter. But unlike primary standards, they are distributed to a number of places where they are kept under safe custody. They are compared with the primary stds at regular intervals and a record of their deviations is maintained. They are used for comparing the tertiary standards with them.

They act as reference standards for the tertiary stds.

3) TERTIARY STANDARDS

They are properly maintained in laboratories and workshops as reference standards for comparison of the working standards. They are also not used as frequently and commonly as the working standards, but more frequently than the secondary standards.

(4) WORKING STANDARDS

These standards find daily use in laboratories and workshops in actual measurement work. But, the endeavour is to make these standards also as accurate and near as possible to their reference ~~standards~~ standards.

Due to cost factor, lower grades of materials can be used for their manufacture.

ERRORS IN MEASUREMENT →

All engineers, regardless of branch of profession to which they belong, are constantly faced with problem of measurement. It may be of time, mass, force, temperature, length, pressure etc, and so on.

Results obtained by measurements provide information upon which decisions are made.

DEFINITION →

Measurement error is the difference between indicated and actual values of measurement:

Actual ~~val~~ value or true size is the theoretical size of a dimension, which is free from any errors of measurement.

The errors in measurement system can be result of errors in instruments with which measurement is taken, error in reference standards with which instrument is calibrated and set, effects of environment and forces on instruments, method used to measure and operator taking the measurement.

TYPES OF ERRORS -

(1) Controllable errors or Systematic Errors -

- (a) Avoidable errors ~~or systematic errors~~ (misreading an instrument and Arithmetic error)
- (b) Alignment error
- (c) Environmental error.
- (d) Deflection error
- (e) Elastic Deformation
- (f) Parallax Error.
- (g) Error due to improper instrument

(2) GROSS ERROR

~~(1) Controllable Error OR RANDOM ERRORS~~

(2) RANDOM ERRORS

(1) Controllable Error:

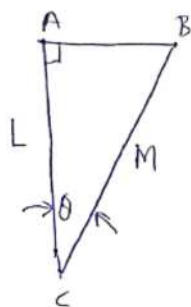
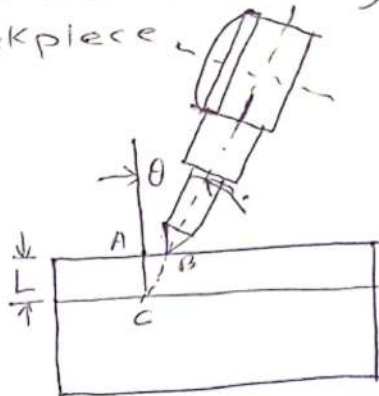
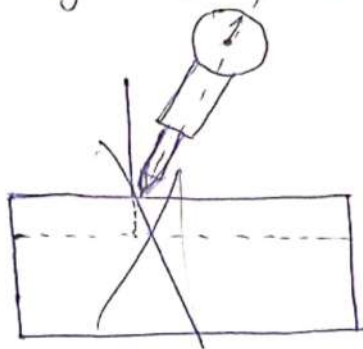
(a) Avoidable Error -

- (i) Misreading an Instrument: A vernier is read faulty as 20.5 mm or 19.5 mm instead of correct reading 20.1 mm.

In most cases the above errors give results so different from expectation that it is obvious that when error has occurred measurement is repeated and error is detected.

Alignment Errors:

This type of errors occurs when measuring instrument misaligned relative to work piece.



Length to be measured = L

Actual measurement = M

$$\text{Error} = M - L$$

$$= M - M \cos \theta = M(1 - \cos \theta)$$

Because plunger of the dial is not held vertically but it is at an angle θ to the required line of measurement.

So, this ~~align~~ misalignment error induced in measurement = $m(1 - \cos \theta)$. This is also called cosine error.

Environmental Error:

Environmental errors are due to effect of the surrounding temperature, pressure and humidity on the measuring system. Improper datum surface, presence of dirt, chips.

- Standard temperature 20°C , it should be maintained at that level.
- Allow for temperature stabilization
- Temperature compensation: $\text{Error} = L(\alpha(t - t_2))$

Where L = nominal value

α = Coefficient of thermal expansion

$(t - t_2)$ = deviation from std. temperature.

Errors due to elastic deformation :-

- Stylus pressure : Too large pressure applied on the workpiece causes stylus pressure. This can be controlled by using ratchet mechanisms or dial indicator.
- Overhang of elastic body subjected to load undergoes elastic deformation and it changes the size.
- Adjust stylus pressure depending on the workpiece.

Error due to deflection - Deflection of parts occurs due to contact gauging pressure. To avoid deflection, errors gauging pressure should be as small as possible.

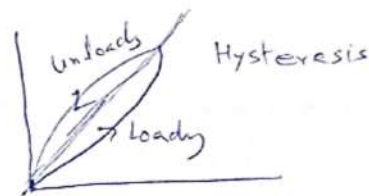
- Clamps should be secured properly
- Use of proper supports

Parallax Error :-

The error that occurs when the pointer on scale is not observed along a line normal to the scale. It is avoided by reduce distance between pointer and scale.

Error due to Instruments:

- Occur due to wrong construction of the measuring instruments
- due to hysteresis or friction
- misuse of instruments.



② GROSS ERROR

- Caused by human mistake.
- Reading of the instrument value before it reaches steady state.
- Mistake due to recording the data.
- Calculating a derived measurand wrongly.

RANDOM ERRORS:

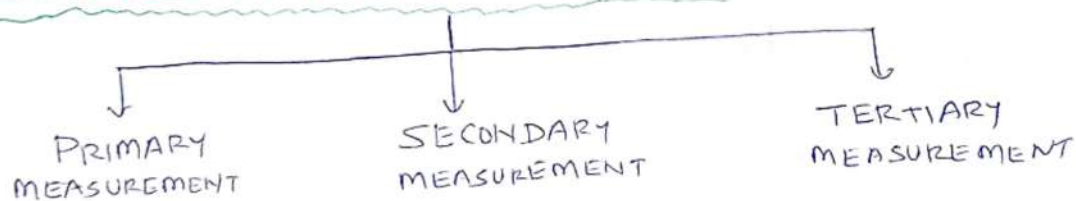
This type of errors occur randomly and cannot be eliminated because no definite causes are determined.

Likely sources of this types of error are

- Small variations in the position of setting standards and workpiece.
- Slight displacement of lever joints in the measuring instruments
- Transient fluctuation due to friction.
- ~~In~~ Due voltage fluctuation
- Due to some vibration occur.

This type of errors avoided by ^{using} Arithmetic means, Standard deviation to assess these random errors by taking sets of repeated readings and results of measurement can be corrected.

LEVELS OF MEASUREMENT



PRIMARY MEASUREMENT

A primary measurement is one that can be made by direct observation without involving any conversion (translation) of the measured quantity into length.

Examples

- (i) The matching of two lengths, such as when determining the length of an object with a metre rod.
- (ii) The matching of two colors, such as when judging the color of red hot metals.

SECONDARY MEASUREMENT -

- A secondary measurement involves only one translation (conversion) to be done on the quantity under measurement to convert it into a change of length.
- The measured quantity may be pressure of gas and therefore may not be observable.
- Therefore, a secondary measurement requires:
 - (i) an instrument which translates pressure changes into length changes.
 - (ii) a length scale or a standard which is calibrated in length units equivalent to ~~known~~ known changes in pressure.

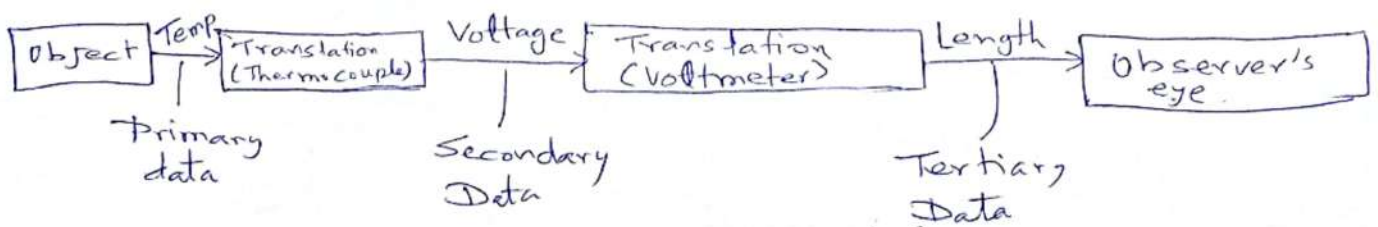
Therefore, in a pressure gauge, the primary signal (pressure) is transmitted to a translator and the secondary signal (length) is transmitted to observer's eye.

TERTIARY MEASUREMENTS -

A tertiary measurement involves two translations:

e.g.

- The measurement of temperature of an object by thermocouple.
 - The primary signal (temp. of object) is transmitted to a translator which generates a voltage which is a function of the temperature.
1. First translation is temperature to voltage.
 2. The voltage, in turn, is applied to a voltmeter through a pair of wires.
 3. The second translation is then voltage into length.
 4. The tertiary signal, length change, is transmitted to the observer's brain.



VERNIER CALIPER

It is a precision instrument which is used for measuring external as well as internal diameter of shafts, thickness of parts etc., to an accuracy of 0.02 mm.

The principle of vernier is that when two scales or divisions slightly different in size are used, the difference between them can be utilised to determine the accuracy of measurement.

Construction of Vernier Caliper

The vernier caliper consists of a beam on which the fixed graduations, which is known as the Main Scale is engraved. On end of the beam has a fixed or stationary jaw. The Vernier Head, which carries the sliding or movable jaw, has a Vernier scale engraved on it. This jaw moves along the guiding surfaces provided by the beam.

When the measuring faces of the fixed and sliding jaws are brought in contact with each other, the scale shows a zero reading. The final adjustment of the movable jaw, which depends upon the sense of correct feel, is made by the adjusting screw, provided on the ~~auxiliary~~ auxiliary head and it is clamped by clamping screw.

READING A VERNIER CALIPER :

The smallest division on the main scale is either 0.5 mm or 1 mm and the vernier scale may have 25 or 50 divisions.

The ratio of the smallest division on the main scale to the number of divisions on the vernier scale is ~~known~~ known as Least Count of the Vernier Caliper.

$$\text{Least Count} = \frac{\text{Smallest division on main scale}}{\text{Number of divisions on vernier scale}} = \frac{0.5}{25} = 0.02 \text{ mm}$$

The least count is usually marked on the vernier caliper

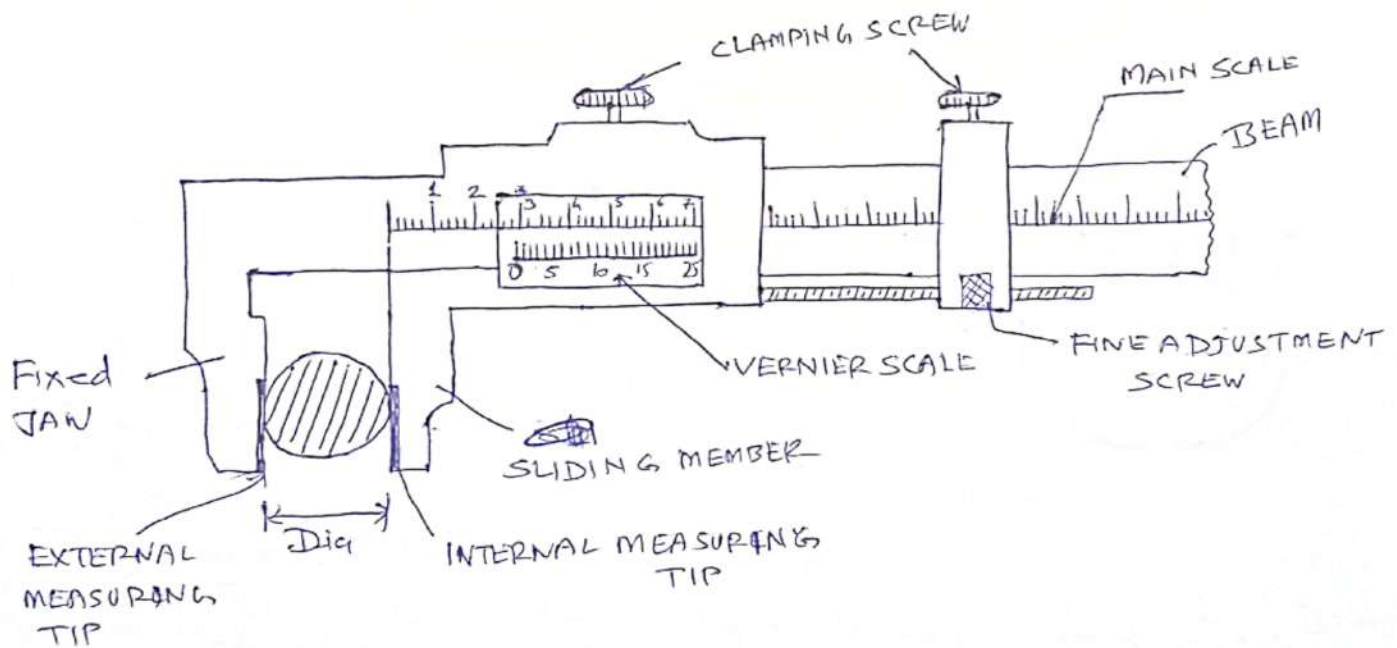
A dimension on a Vernier Caliper scale is read as follows:

Note the reading on main scale against zero mark on Vernier scale. Then count the number of divisions on vernier scale which coincides with a division (mark or graduation) on main scale.

Then,

Total Reading = (Reading on main scale against zero mark on vernier scale) + (Least count $\times$ number of div on vernier scale which coincides with a mark on main scale).

$$\text{Total Reading} = \text{MSR} + (\text{VSR} \times \text{LC})$$



VERNIER CALIPER

TYPES OF VERIER CALIPER

- (1) Vernie Caliper
- (2) Vernier height Gauge
- (3) Vernier Depth Gauge
- (4) Vernier Gear-Tooth Caliper

MICROMETER

The micrometers are precision measuring instruments. There are available in English system or in metric system.

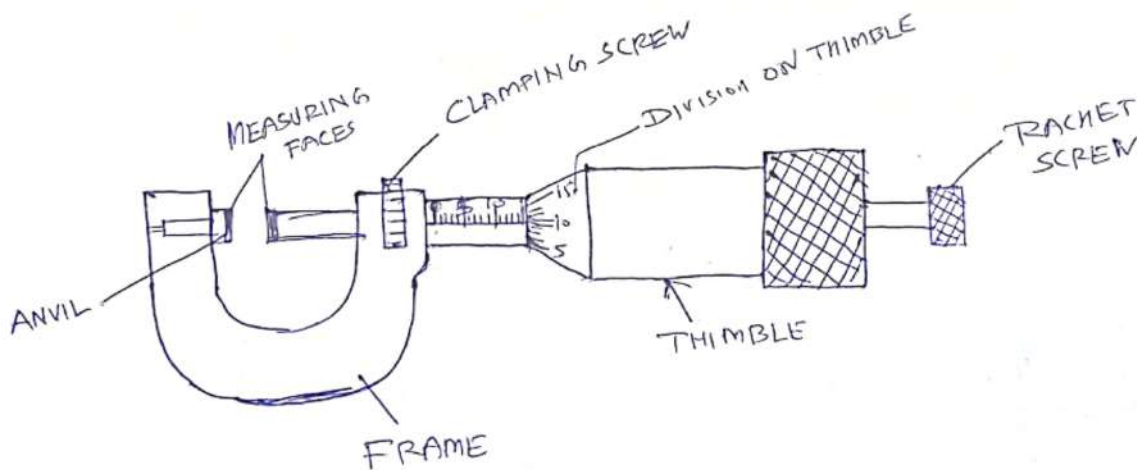
The various types of micrometers are as follow:-

- (1) Outside Micrometer (3) Screwthread Micrometer
- (2) Inside Micrometer (4) Depth gauge micrometer.

OUTSIDE MICROMETER

It is mainly used to measure the outside diameter of a job or length of a small job. It can measure the dimension to an accuracy of 0.01 mm. The main parts of micrometer are:-

- (1) Frame (2) Anvil and Spindle (3) Spindle clamp or locknut
- (4) Barrel and thimble (5) Ratchet or friction stop



1) **FRAME**: The frame may be U-shaped or C-shaped; in order to permit measurements of a cylinder of diameter equal to the range of micrometer. It is made of cast steel, malleable steel, or light alloy.

2) ANVIL AND SPINDLE-

The anvil of the micrometer is fixed and it is on the left hand side of the frame. There is a screwed spindle on the right hand side of the frame and have threads of 0.5 mm pitch. The anvil and spindle are generally made of high grade tool steel. The diameter of the anvil and spindle should be equal.

3) **~~SPINDLE~~ SPINDLE CLAMP OR LOCK NUT** - A lock nut is provided on the micrometer to lock the spindle when the micrometer is at its maximum reading.

BARREL AND THIMBLE -

- The barrel has datum or reference line and fixed graduations.
- The thimble is a tubular cover fastened with the spindle and moves with the spindle. The bevelled edge of the thimble is divided into 50 equal parts and every fifth part is numbered.

5) RATCHET OR FRICTION STOP -

The micrometer is provided with a ratchet in order to enable satisfactory operation. It is used to prevent excessive pressure on the spindle.

~~LAST COUNT~~

LEAST COUNT -

The least distance which can be measured accurately with micrometer is called least count of micrometer.

It is the ratio of pitch of the spindle screw to the number of division on the thimble.

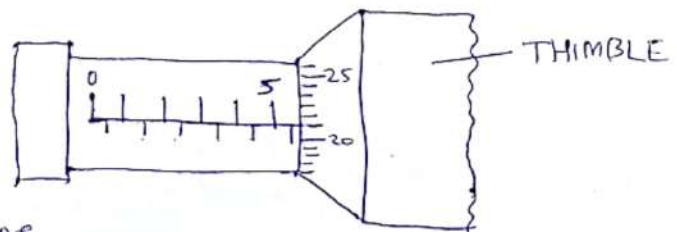
$$\begin{aligned}\text{Least Count} &= \frac{\text{Pitch of the Screw}}{\text{Number of division on the thimble}} \\ &= \frac{0.5}{50} = 0.01 \text{ mm}\end{aligned}$$

READING A MICROMETER -

Reading shown in fig. are

- Number of division above reference line
line = $5 \times 1 \text{ mm} = 5 \text{ mm}$

- Number of division below reference line
= $1 \times 0.5 \text{ mm} = 0.5 \text{ mm}$



- Number of divisions on the thimble coinciding with the reference line
= $21 \times 0.01 = 0.21 \text{ mm}$

$$\text{Total reading} = 5 + 0.5 + 0.21 = 5.71 \text{ mm}$$

SLIP GAUGES

Slip gauges are rectangular blocks of steel having a ~~can~~ cross-section of about 30 by 10 mm. The essential purpose of slip gauges is to make available ~~end~~ standards of specific lengths by temporarily combining several individual elements, each representing a standard dimension, into a single gauge bar.

The combination is made by pressing the faces into contact and then use a small twisting motion while maintaining the contact pressure. This is called Wringing. Wringing occurs due to molecular adhesions between a liquid film (thickness about 6 μm to 7 μm) and the mating surface.

Uses :

- It can be used as reference for transferring the dimensions of the unit of length from the primary standard to gauge block of lower accuracy.
- It is also used for the verification and graduation of measuring ~~appara~~ apparatus ~~and~~.
- For direct measurement of linear dimensions of industrial components.

According to accuracy, the slip gauges can be graded into ~~three~~ ^{Four} categories i.e. Grade 00, ^{Grade 0} Grade I and Grade II.
 (Reference grade) $\rightarrow$ CALIBRATION GRADE, Grade I - Inspection grade, Grade II - Workshop grade.

Generally, two sets of slip gauges are available. Normal Set $\rightarrow$ Slip ~~gauge~~ gauges of the following dimensions are available in this type of set.

NORMAL SET

Range	Step	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.1	9
1 to 9	1	9
10 to 90	10	9
Total		45

SPECIAL SET

RANGE	STEP	PIECES
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
		86

SELECTION OF SLP GAUGES

Standard procedure is followed in selecting slip gauges. It should be such that minimum number of slip gauges is chosen for

GRADE 00: It is only for reference purpose.

GRADE 0: It is used in laboratories and std. room for periodic calibration of Grade I and II gauges.

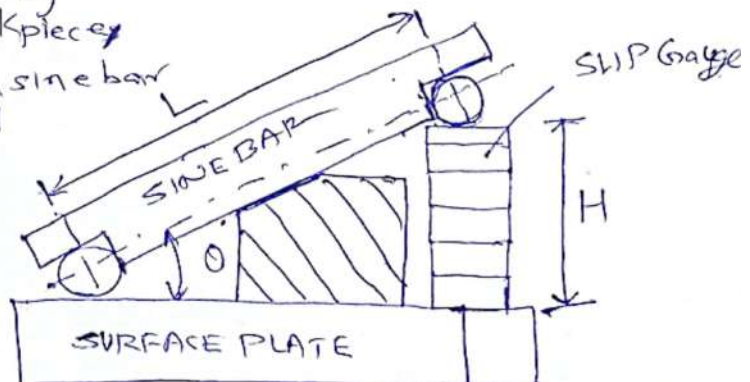
GRADE I: It is of higher accuracy for use in inspection department.

GRADE II: It is used in workshops during actual production

SINE BAR

- Sin Bar is an indirect measuring instrument used for measuring small angles. From this high accuracy can be expected when measuring smaller angles that is less than 45° .
- It consists of a flat bar provided with two cylindrical plugs. The axes of these cylinders are mutually parallel to each other and also to the top surface of the sine bar. The distance between centres of the plugs is fixed for a particular sine bar and the same is always written over the bar.

The use of sine bar for measuring angles is shown in fig. The workpiece is placed over a surface plate and sine bar made to rest against the inclined surface of the workpiece. On one side of bar is supported on the plug resting on the surface plate and on the other side it rests over a set of slip gauges. Now if θ be the angle made by lower face of the sine bar with the datum surface then



$$\sin \theta = \frac{H}{L}$$

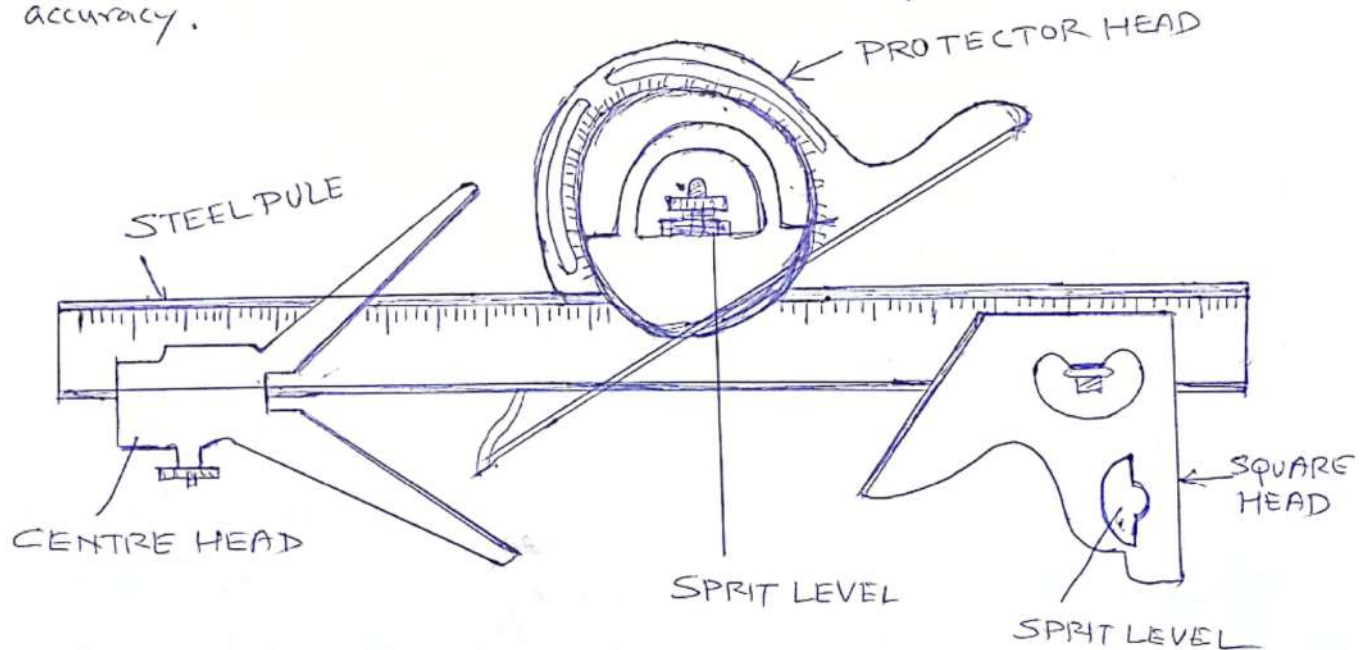
$$\theta = \sin^{-1} \left(\frac{H}{L} \right)$$

COMBINATION SET

Combination Set is the most useful instrument in engineering applications. As the name indicates this instrument consists of set of several instruments. It fulfills all the requirements of a square, set square, bevel protector, centre square rule and scriber. It also provides the work to be kept horizontal.

Construction :

It consists of square head, central head, a bevel ~~protector~~^{or rule} protractor head, spirit level and beam on which the other three parts slide. They are located in a groove in the blade. These parts are manufactured with high accuracy.



WORKING -

The different parts are used separately. A clamping bolt with a nut and spiral spring is provided in each part so as these could be secured in any desired position on the whole length of the beam.

The working of different parts can be explained as :-

- (a) STEEL RULE - The beam of the ~~rule~~ instrument which acts as a rule is marked either in inches or centimetres or in both for measuring the length and height. Length of the rule varies from 200 to 6000 mm.

(b) SQUARE HEAD:

The square head has two edges, one at 90° and the other at 45° to the rule. It can be used both as square (90°) and (45°). It is also provided with a spirit level. Spirit level enables the work to be kept horizontal.

(c) CENTRE HEAD:

The centre head with the rule fastened to it is called a Centre Head. It has two arms at right angles to one another. It is so arranged that the blade exactly bisects the angle between the machined surfaces. This may used to find the centre of a round bar or shaft.

(d) PROTRACTOR HEAD -

The protractor head can be used with the rule to measure angles as to measure the slope of the surfaces. The scale on the protractor may be divided into degrees or a vernier attached whereby the angles can be measured in degrees and minutes. A spirit level is also fitted to set the work horizontally or setting it at an angle.

UNIT-III

SYLLABUS

Fluid properties, Pressure, Density and viscosity etc.
Types of fluids, Newton's Law of viscosity, Pascal's Law,
Bernoulli's equation for incompressible fluids, only working
principle of Hydraulic machines, pumps, turbines, Reciprocating
Pumps.

Fluid

A fluid may be defined as "a substance which is capable of flowing". Every fluid has some characteristics by which its physical condition can be determined. These characteristics are called properties of the fluid. ~~Which may be ideal or real~~ It has no definite shape of its own, it can take the shape of vessel containing it. The fluid particles readily change their relative positions. All liquid and gases are termed as fluids. It is of two types:

(1) Ideal fluid:

An ideal fluid is one which has no properties other than its density. Ideal fluid is a fluid which is incompressible and inviscid. A fluid for which viscosity (μ) is zero, is called inviscid fluid. For an ideal fluid surface tension (σ) is zero. Ideal fluids are imaginary and do not exist in nature. However, fluids which are very low viscosity can be treated as ideal fluid like water and air. Water is more near to an ideal fluid than air.

(2) Real fluid:

All fluids are real fluids. They have viscosity, surface tension, compressibility and density. These fluids are actually available in nature. A certain amount of resistance is always offered by these fluids when they are set in motion.

FLUID PROPERTIES -

(a) Pressure:

When a fluid (oil or water) is in a container, it exerts forces at all points on the surface area of the sides and bottom of the container. As the fluid is in rest position so the force is normal to the surface area.

The normal force exerted on a unit area of surface is called as intensity of pressure or simply pressure.

$$\text{Intensity of Pressure} = \frac{\text{Normal Force (F)}}{\text{Surface Area (A)}} = \frac{N}{m^2} = Pa \text{ (Pascal)}$$

Other Units - KPa, MPa, GPa, 1 bar = 10^5 Pa., Torr, mm of Column of liquid.

② Density -

It is also known as specific mass or mass density of fluid. It is defined as a fluid possesses mass per unit volume. It is generally represented as (ρ) rho.

$$\text{Mass density } (\rho) = \frac{\text{Mass of fluid}}{\text{Volume}}$$

$$(\rho) = \frac{m}{V} \quad \text{Kg/m}^3$$

(3) Specific Volume -

Specific Volume of a fluid is the volume occupied by its unit mass or it is a reciprocal of mass density.

$$(\nu) = \frac{V}{m} = \frac{1}{\rho} \quad \left(\frac{\text{m}^3}{\text{Kg}}\right)$$

Specific volume term is always given to the gasses. because for a given mass of the gas, it may be occupy different volumes.

(4) SPECIFIC WEIGHT OR WEIGHT DENSITY (w)

It is the weight of liquid per unit volume.

$$(w) = \frac{W}{V} = \frac{mg}{V} = \rho g$$

$$\boxed{(w) = \rho g}$$

Since weight density depends on 'g', hence it is not called an absolute quantity.

⑤ SPECIFIC GRAVITY:

Specific gravity of a fluid is the ratio of its weight density to that of a standard substance. For liquids, pure water is considered as a std. substance at 4°C .

$$\text{Specific Gravity (S)} = \frac{\text{Density of fluid}}{\text{Density of std. fluid}} \times \frac{g}{g}$$

$$= \frac{\text{wt. density of fluid}}{\text{wt. density of std. fluid.}}$$

The std fluids : for liquids $\rightarrow$ water at 4°C
for gases $\rightarrow$ air at 0°C

Specific Gravity of water $S_{\text{H}_2\text{O}} = 1 \text{ gm/mL}$ (1000 Kg/m^3)

Specific Gravity of Hg $S_{\text{Hg}} = 13.6 \text{ gm/mL}$ (13545.848 Kg/m^3)
at 20°C

$$1 \text{ m}^3 = 1000 \text{ liter}$$

$$1000 \text{ Kg/m}^3 = 1 \text{ gm/cm}^3$$

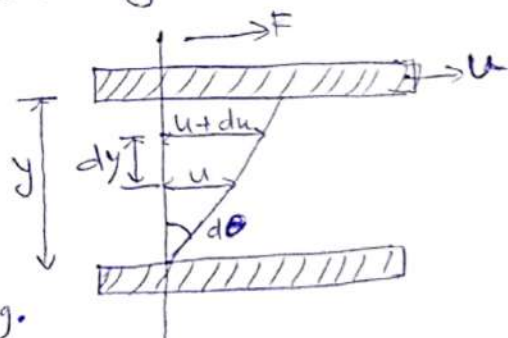
$$= 1 \text{ gm/mL}$$

~~TRANSFORM~~

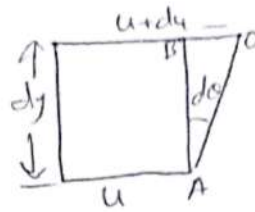
⑥ Viscosity $\rightarrow$

It is the internal resistance offered by the one fluid layer for the movement of ~~adjacent~~ adjacent fluid layer. It is due to the inter molecular exchange and the cohesive forces between the molecules.

When two layer of fluid, move a distance ~~by~~ by dy one over the other at different velocities say u and $u+du$ as shown in fig.



The viscosity together relative ~~velocity~~ velocity causes a shear stress between the layers of fluid. This is mainly ~~caused~~



from $\triangle BAO$,

$$\tan d\theta = \frac{du \cdot dt}{dy}$$

But angle is very small then ~~$\tan d\theta \approx d\theta$~~ $\tan d\theta \approx d\theta$

$$d\theta = \frac{du \cdot dt}{dy}$$

$$\frac{d\theta}{dt} = \frac{du}{dy} \quad \dots \text{--- (1)}$$

$\frac{d\theta}{dt} \rightarrow$ rate of shear strain or rate of angular ~~strain~~ deformation.

We know that if shear force F increases, the rate of angular deformation $\frac{d\theta}{dt}$ also increases.

$$\therefore F \propto \frac{d\theta}{dt}$$

We know that ~~τ~~ $\tau = \frac{F}{A}$ (τ is shear force)

or $\tau \propto F$ (because Area of plate is const.)

$$\therefore \tau \propto \frac{d\theta}{dt}$$

$$\text{or } \boxed{\tau = \mu \frac{d\theta}{dt}} \quad \dots \text{--- (2)}$$

~~This equation is known as Newton's law of viscosity~~
where μ is the proportionality const. and is known as Coefficient of dynamic viscosity or simply viscosity

$$\text{or } \boxed{\mu = \frac{\tau}{\frac{d\theta}{dt}}} \quad \dots \text{--- (3)}$$

amount of

Thus, dynamic viscosity or viscosity is the shear stress required to produce unit ~~strain~~ rate of angular deformation or rate of shear strain.

from equation ① and ②

$$\tau = \mu \frac{d\theta}{dt} = \mu$$

We know that,

$$u = \frac{d}{t}$$

$$\text{or } d = u \times t$$

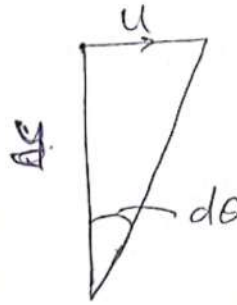
For the fluid particle which is on the top plate, travelled a distance $= u \times dt$

$$\tan \theta = \frac{u}{y}$$

For small angles $\tan \theta \approx d\theta$

$$d\theta = \frac{u \times dt}{y}$$

$$\text{or } \boxed{\frac{d\theta}{dt} = \frac{u}{y}} \quad \text{--- ①}$$



The term $\frac{d\theta}{dt}$ is called "Rate of Angular deformation".

from equation ① and ② & ③

$$\tau = \mu \frac{u}{y} = \mu \frac{du}{dy}$$

$$\text{or } \boxed{\tau = \mu \frac{du}{dy}} \quad \text{or } \mu = \frac{\tau}{\frac{du}{dy}} = \frac{\frac{\text{N/m}^2}{\frac{\text{m/s}}{\text{m}}}}{\frac{\text{m/s}}{\text{m}}} = \frac{\text{N}}{\text{m}^2} \cdot \text{s} = \text{Pa} \cdot \text{s}$$

This equation is known as "Newton's Law of Viscosity".

The term $\frac{du}{dy}$ has unit of $\frac{\text{m/s}}{\text{m}} = \text{s}^{-1}$. This term is known as "Velocity Gradient".

Note:

If $\mu = 0$, then $\tau = 0$, The fluid is called an "Ideal fluid".

The fluids which satisfies 'Newton's Law of viscosity' is called "Newtonian Fluid".

$\therefore$ For Newtonian fluid, $\tau = \mu \left(\frac{du}{dy} \right)$ Ex. Petrol, Diesel, Water etc.

The fluids which does not obey 'Newton's Law of viscosity' is called Non-Newtonian fluid.
ex. Blood, milk, clay ~~and~~ toothpaste, Lipstick, gypsum solution in water etc.

The relationship between shear-stress and velocity gradient for Non-Newtonian fluids is :

$$\tau = A \left(\frac{du}{dy} \right)^n + B$$

Where A - flow consistency index
B - flow behaviour index
n - Index

⑦ VAPOUR Pressure -

~~Consider a closed~~ The pressure exerted by the vapour upon the liquid surface is called "Vapour Pressure".

It is a very important property of fluid. In any fluid flow problems, at any section, the pressure should not fall less than or equal to vapour pressure, to avoid the cavitation.

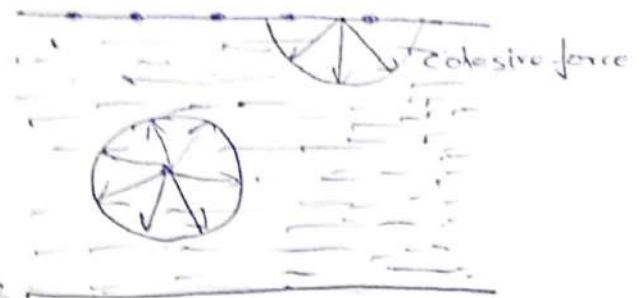
Consider a closed container in which a liquid is filled by leaving an empty space above the liquid surface. If the temperature increased, the vapour bubbles will start forming and leaves from the liquid surface and get collected in empty space. The stage will reach where the rate of ~~formation~~ formation of the new vapour bubbles will be equal to the rate of collapsing of vapour bubbles into the liquid surface.

Under this condition, the vapour phase is said to be in phase equilibrium with the liquid.

- If the Partial pressure of water vapour is less than the vapour pressure, then no water is present in the lake.
- If the partial pressure of water vapour is equal to the vapour pressure then water is present in the lake.

Tension exerted by the fluid at the surface is called Surface Tension.

Consider a molecule which is completely inside the liquid and it is surrounded by equal no. of molecules. Therefore the net force acting upon such molecule is zero.



If we consider another molecule which is at the surface, it is under the influence of attractive force by its own molecule and the gas molecules attractive force.

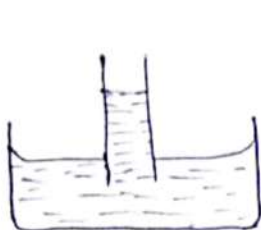
The cohesive force are greater than the adhesive force and therefore it is acted by a net downward vertical force. As well as, the surface molecules are also subjected to cohesive forces by the molecules which lies to the left and right of the molecule. Therefore the surface of the liquid is under tension.

This tension per unit length is called "Surface Tension".
 Unit: J/m^2 or N/m Surface tension decreases with increase in temperature.

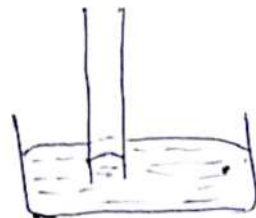
- ex (a) A small needle can float.
 (b) Collection of dust particles on the liquid surface.
 (c) Small birds can sit in the ponds for drinking water.
 (d) Formation of liquid droplets.

9) CAPILLARITY -

The rise or fall of the liquid level in a narrow vertical tube when its inserted in a liquid from the level of the liquid in a container.



→ Capillary rise
 → Adhesive > Cohesive



→ Capillary depression
 → Cohesive > adhesive

Capillary is due to both cohesion & adhesion

Types of Pressures.

1. Atmospheric Pressure (P_{atm}).

It is defined as pressure exerted by the atmospheric air upon the surfaces.

$$P_{atm} = 760 \text{ mm of Hg} \\ = 10.33 \text{ m of H}_2\text{O}$$

$$P_{atm} = \rho_{Hg} \times g \times h \\ = 13.6 \times 1000 \times 9.81 \times 760 \times 10^{-3} \text{ Pa} \\ = 101.396 \text{ kPa} \\ = 1.01396 \text{ bar} \\ \approx 1 \text{ bar}$$

OR

$$P_{atm} = \rho_{H_2O} \times g \times h_{H_2O} \\ = 1000 \times 9.81 \times 10.33 \\ = 1.01337 \text{ bar (at MSL)}$$

(2) GAUGE PRESSURE -

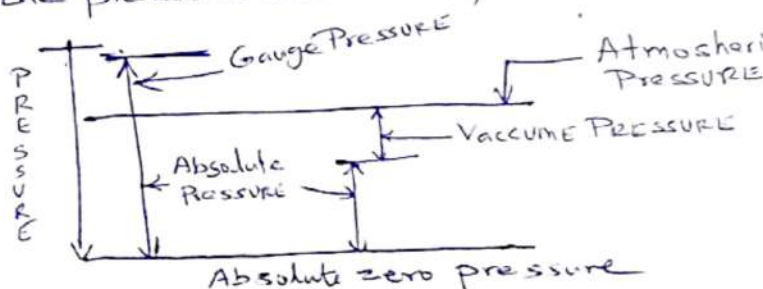
It is defined as the pressure measured by the gauge (instruments) in which atmospheric pressure is taken as datum. ~~It is~~

(3) VACUUM PRESSURE -

If the measured pressure is lower than atmospheric pressure, then it is called 'Negative pressure' or Vacuum Pressure.

(4) ABSOLUTE PRESSURE -

It is the pressure exerted by the absolute vacuum.



Mathematically

$$P_{absolute} = P_{atm} + P_{gauge}$$
$$P_{absolute} = P_{atm} - P_{vacuum}$$

BERNAULLI'S EQUATION FOR INCOMPRESSIBLE FLUIDS

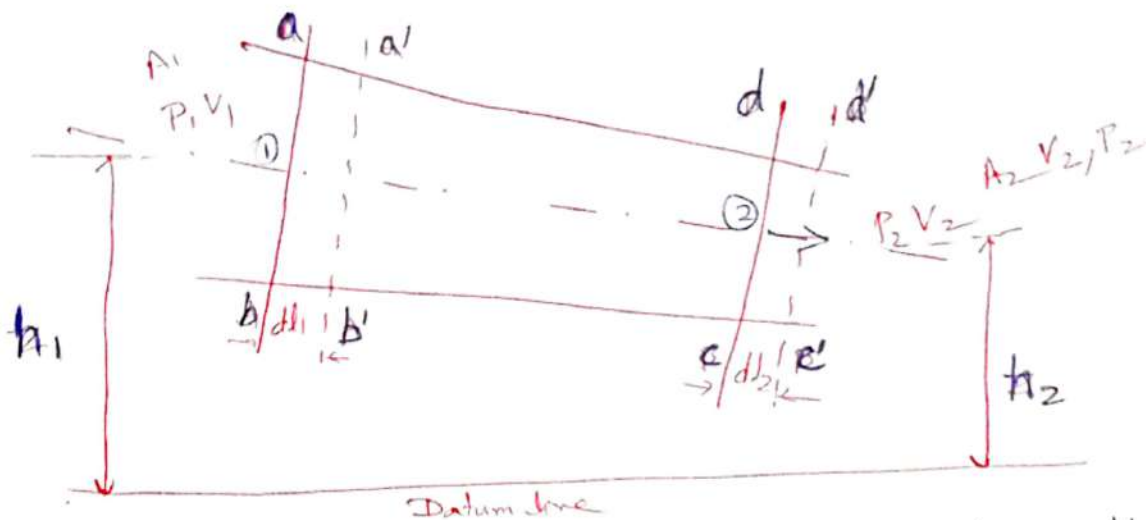
Bernoulli's equation states that:

"In an incompressible fluid when the flow is steady and continuous, the sum of Pressure energy, Potential energy and Kinetic energy is constant at every section".

Since in incompressible fluid flow, there is no significant change in temperature, hence internal energy is not considered.

While deriving Bernoulli's equation, the following assumptions have been considered:

- (1) Flow is ~~static~~ Steady: at a ^{given} point there is no variation of fluid ~~mass~~ properties with respect to time.
- (2) Fluid is ideal - It does not exhibit any frictional effects due to fluid viscosity.
- (3) Flow is incompressible: no variation in fluid density.
- (4) Flow is one-dimensional: along a stream line.
- (5) Flow is continuous and velocity is uniform over a section.
- (6) Only potential, pressure and kinetic energy are present. No energy in the form of heat or work is either added to or subtracted from the fluid.



Consider steady flow, incompressible fluid flowing through a non-uniform area (i.e. a converging tube).

At entrance (1) if fluid mass has an Area = A_1 , Velocity = V_1 and pressure P_1 .

and the corresponding values at exit (2) are, A_2 , V_2 and P_2 .

The mass of the fluid in the region abcd shifts to new position a'b'c'd', during small interval of time. As the a'b'c'd' is common to both the regions abcd and a'b'c'd', so only energy changes in area ab b'a' and cc'd'd'.

(1) Using mass conservation principle at entrance and exit areas :-

Fluid mass in area ab b'a' = fluid mass in area cc'd'd'

$$m = \rho A_1 ds_1 = \rho A_2 ds_2 \quad \left(\rho A ds = \frac{\text{kg}}{\text{m}^3} \times \text{m}^2 \times \text{m} = \text{kg} \right)$$

(2) Net fluid flow work = Work done at entrance - Work done at exit
(Work done = force $\times$ displacement)
= $(P \times A \times ds)$

$$= P_1 A_1 ds_1 - P_2 A_2 ds_2 \quad \left[\text{Volume} = \text{Constant} \right. \\ \left. A_1 ds_1 = A_2 ds_2 = \frac{m}{\rho} \right]$$

$$= \frac{m}{\rho} (P_1 - P_2)$$

(3) Total Potential energy = Potential energy at (1) - Potential energy at (2)
= $mg h_1 - mg h_2$
= $mg (h_1 - h_2)$

$$(4) \text{ Total Kinetic energy} = \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2 = \frac{1}{2} m (v_2^2 - v_1^2)$$

From the principle of conservation of energy

Net fluid flow work + Total potential energy = Total Kinetic energy

$$\frac{m}{\rho} (P_1 - P_2) + m g (h_1 - h_2) = \frac{1}{2} m (v_2^2 - v_1^2)$$

$$\frac{P_1 - P_2}{\rho} + g(h_1 - h_2) = \frac{v_2^2 - v_1^2}{2}$$

$$\frac{P_1}{\rho} - \frac{P_2}{\rho} + g h_1 - g h_2 = \frac{v_2^2}{2} - \frac{v_1^2}{2}$$

$$\frac{P_1}{\rho} + \frac{v_1^2}{2} + g h_1 = \frac{P_2}{\rho} + \frac{v_2^2}{2} + g h_2$$

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + h_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + h_2$$

$$\boxed{\frac{P}{\rho g} + \frac{v^2}{2g} + h = \text{Constant}}$$

This equation is known as the Bernoulli's equation for incompressible fluid flow.

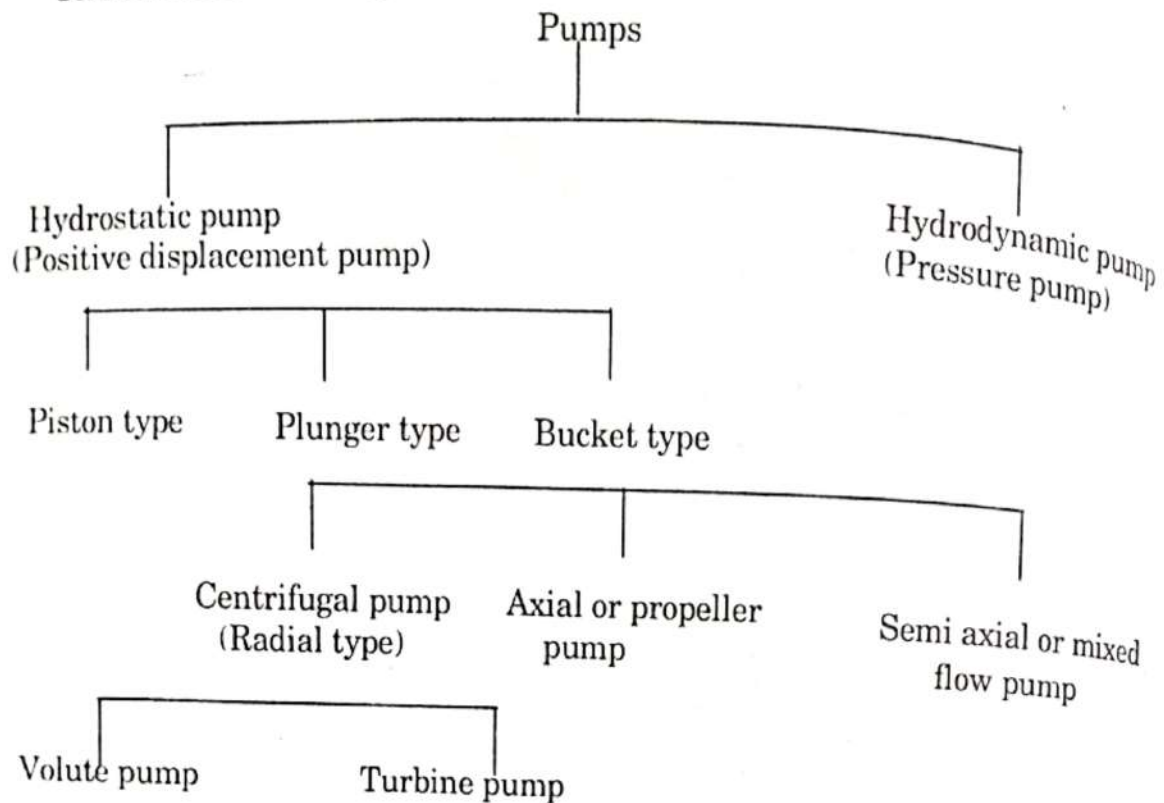
3.9.1 Classification of Pumps

There are different types of pumps but the following two types are more frequently used :

(1) Positive displacement pumps.

(2) Centrifugal pumps.

The classification is given below :



3.9.2 Reciprocating Pumps

It consists of a piston or a plunger reciprocating inside a cylinder. The piston performs the suction and delivery strokes. These types of pumps deliver the same quantity of liquid against any head. A reciprocating pump works at low speed.

Piston pump. A piston pump may be single acting or double acting. A single acting piston pump is shown in the figure 3.5:

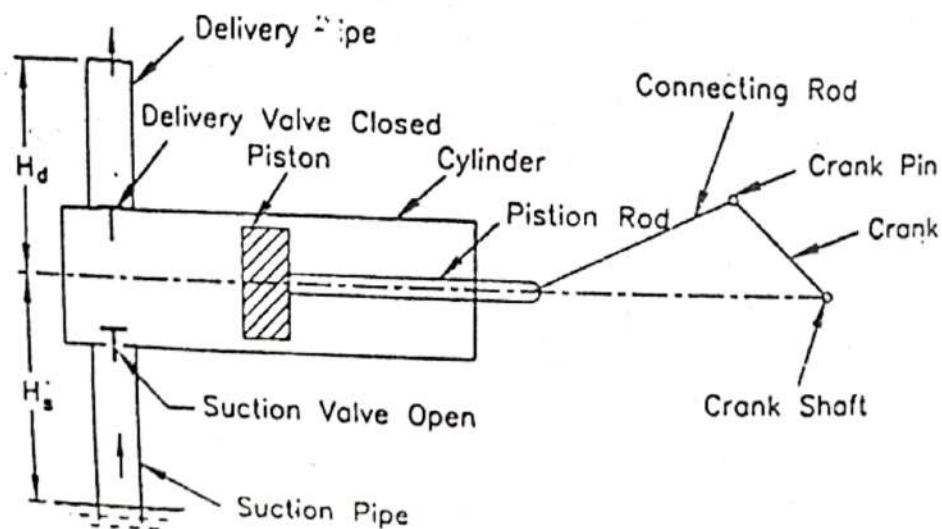


Fig. 3.5. Single acting piston pump.

As the piston moves outwards (towards right in the figure) partial vacuum will be created inside the cylinder. The atmospheric pressure acting on the surface of the liquid forces the liquid through the suction pipe into the cylinder. Liquid will enter the cylinder through the suction valve which will open into it.

When the piston moves backwards (inward stroke) the piston will compress the liquid in the cylinder and the pressure of the liquid will rise. This increased pressure of the liquid will automatically close the suction valve and open the delivery valve and the liquid will be pushed through the delivery pipe.

Double Acting Piston Pump. In double acting piston pump, in every stroke, there is suction on one side and delivery on the (left side) other side when it moves from left to right. On the left side of the piston, there is suction and on the right side there is delivery. When it moves from right to left, on the right side of the piston, there is suction and on the left side there is delivery. A double acting Piston pump is shown in Fig. 3.6. It has got two suction and two delivery pipes.

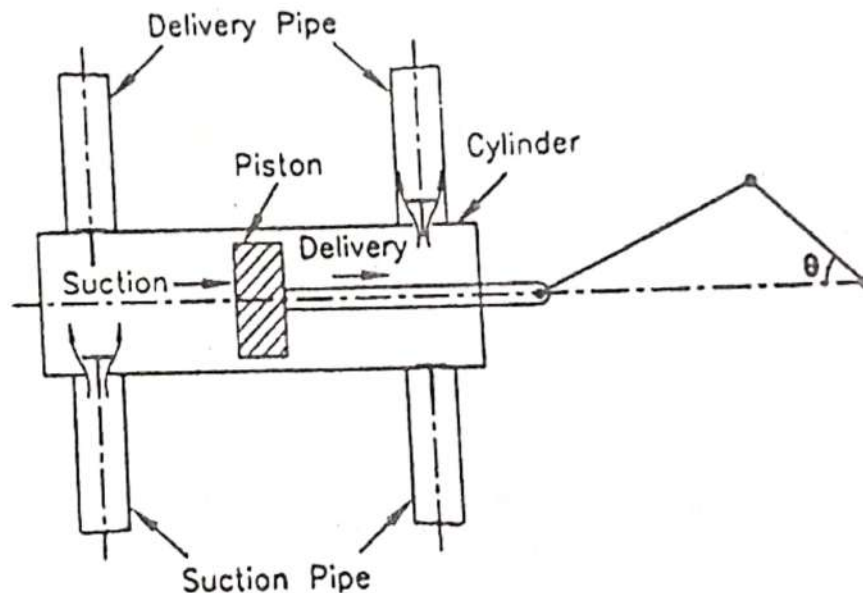
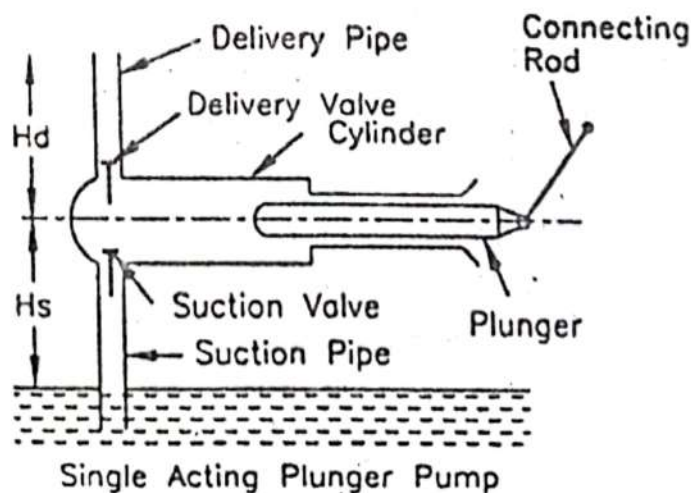


Fig. 3.6. Double acting Piston Pump.

Plunger Pump. There is no difference between a piston pump and a plunger pump except that in a plunger pump, plunger or ram is used in place of piston. Plunger pumps are generally used for rough work and can build up a very high pressure.



Single Acting Plunger Pump

UNIT-IV

1/9/16

Chapter 1

Basic Concepts

Cengel & Boles (McGraw Hill)
Moran, Shapiro, Boettner
Principles of Thermodynamics
Wiley
R. Yadav
P. K. Nag

"Thermodynamics" is a Branch of a science which deals with the study of energy interaction and its impact on the properties of system.

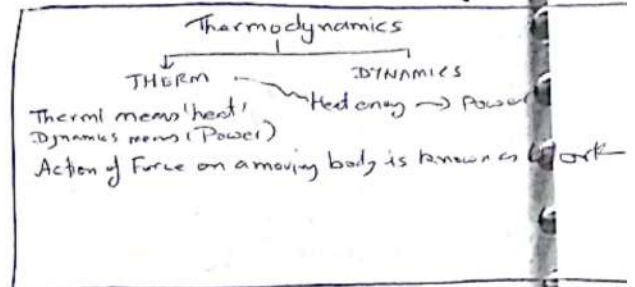
In other words, Thermodynamics is the branch of science which deals with heat and work interaction and its effect to the properties of system.

Thermodynamics is based on law of conservation of energy and law of conservation of mass.

It is the Branch of a science which deals with the study of 3 E's that is :-

- (a) Equilibrium
- (b) Energy
- (c) Entropy

or



It is the Branch of a science which deals with the conversion of disorganised form of energy into organised form.

Thermodynamics, basically contains four laws known as Zeroth Law, First, Second and third law of thermodynamics.

SYSTEM :- Anything under consideration.

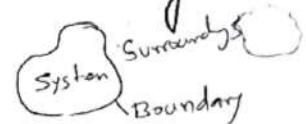
It is a control region ^{or quantity of matter} in space over which our attention is focused. In other words, it is a definite area or a space where some thermodynamic process is taking place. System may be as simple as a free body or as complex as a chemical refinery or thermal power plant.

SURROUNDING :- ^{Everything} external to the system is called surrounding. The space and matter external to the thermodynamic system and outside boundary is called the surrounding.

BOUNDARY :- which separates system from surrounding.

NOTE :- ① Boundary may be real or imaginary.

② Real Boundary are represented by continuous line or curve whereas imaginary Boundary are represented by dotted lines or curve.



- ③ Boundary may be fixed or movable.
④ It should be considered of nearly zero thickness.

UNIVERSE $\rightarrow$ When (system + surrounding) are put together it is called universe.

* **TYPES OF SYSTEM** $\rightarrow$ ① Open system $\rightarrow$ In a system in which both mass interaction and energy interaction takes place b/w system and surrounding. It is also called a flow system.

Example $\rightarrow$

- Boiler
- Turbine
- Condenser
- Pump
- Compressor
- nozzle
- diffuser
- evaporator.
- piston-cylinder arrangement with valves

In this system a certain region is considered for study. This region is called control volume.

② CLOSED system $\rightarrow$ in which only energy interaction takes place between system and surrounding. It is also called a non-flow system. A certain quantity of matter is considered for study. This region is called control mass.
Ex $\rightarrow$ • piston-cylinder arrangement without valves.
• Pressure cooker
• Refrigerator

This system is surrounded by a real boundary, which may be fixed or movable.

③ Isolated system $\rightarrow$ in which neither mass interaction nor energy interaction takes place b/w system and surrounding. It is a closed system, which is insulated at its boundaries, therefore it becomes isolated from its surroundings.

Ex $\rightarrow$ • Thermo flask
• Universe
• Ice Box

How to study TD

Microscopic Approach v/s Macroscopic Approach

view point

view point

Individual behavior of the molecule is considered.

Useful for low density and long pressure.

It is also known as statistical thermodynamics.

Our attention is focused on each and every molecule.

Its distribution is statistical thermodynamics.

Individual -

In the case of microscopic approach, single individual particle is under consideration. It is also known as statistical approach. whereas in the case of macroscopic approach, the time average behaviour of the molecules are under consideration and this approach is also known as classical approach.

NOTE $\Rightarrow$ In our thermodynamics, we are consist generally dealing with macroscopic approach.

Macroscopic View Point

- Our attention is focused on certain quantity of matter.
- Average behavior of the molecule is considered.
- It is also known as classical thermodynamics.

* CONTINUUM Approach $\Rightarrow$ In this approach, we are considering our matter as continuous.

In it we will try to establish the relation between measurable and non-measurable properties.

P, V, T $\downarrow$ $\downarrow$ $\downarrow$

Entropy, Enthalpy, Internal energy etc.

Where pressure is below atmospheric pressure.

NOTE $\Rightarrow$ (a) In case of Rarefied Gases theory, the concept of continuum is not valid.

* THERMODYNAMIC PROPERTY $\Rightarrow$ It represents the characteristics of the system which depends upon its state, but not upon how the state is reached. Every system has certain characteristics by which its physical condition may be described, ex V, T , pressure etc.

Types of Property $\Rightarrow$ (1) Intensive property or Intrinsic property $\Rightarrow$

These properties are independent of mass of the system. These are the basic properties and cannot be defined in terms of other properties. Their values can be assigned independently.

For Example:- P, T , conductivity (K), (α) coefficient of thermal expansion, specific heat, Ratio of two extensive property like density, specific energy (Energy/mass) etc. length, time, electric current.

(2) Extensive Property $\Rightarrow$ These are dependent on mass.

or
Extrinsic property

For example:- V , all forms of energy like kinetic energy, enthalpy, internal energy, heat capacity, entropy.

The main feature of a thermodynamic property are the following -

- (1) A property is measurable characteristic describing the state of a system.
- (2) It has a definite value when the system is in a particular state.
- (3) It also helps to differentiate one system to another.

(4) The magnitude of a property depends on the state of the system and it is independent of the path followed by a system.

s/a property is an exact differential.

* **THERMODYNAMIC EQUILIBRIUM** $\rightarrow$ A system is said to be

in thermodynamic equilibrium if they are in thermal equilibrium, mechanical equilibrium and chemical equilibrium.

Thermal equilibrium is equality of temp., mechanical equilibrium means equality of forces and pressure & chemical equilibrium means equality of chemical potential.

* **PURE SUBSTANCE** $\rightarrow$ It is a substance of constant chemical composition throughout its volume of mixture irrespective of phase.

Examples:- ① ice

② water

③ steam

④ ice + ⑤ liquid
H₂O

⑥ Liq + ⑦ steam
H₂O

⑧ ice + H₂O + steam
⑨ ⑩ ⑪

⑫ Gases air (dry air)

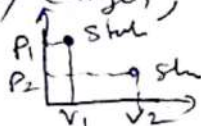
NOTE $\rightarrow$ ⑬ atmospheric air is not a pure substance because the % of water vapour content varies from place to place as we have seen that at some places, there is a high humidity and at some places, there is a low humidity.

* **THERMODYNAMIC STATE** $\rightarrow$ It represents the condition of the system or so that one state may be distinguished from all other states. The state may be identified by certain macroscopic properties such as T, P, pressure, V etc.

* **Path** $\rightarrow$ It is obtained by joining 2 equilibrium states.

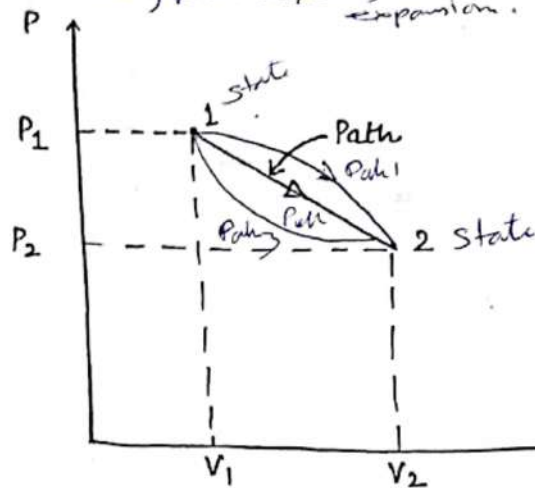
In other words, a locus of series of states through which a system passes between initial and final states is called path.

If any system is not undergoing any change then all of its properties can be measured or calculated and it completely describes the condition or state of the system. At this state, all thermodynamic properties of the system have the same value throughout the system. If the value of even one property changes, the system will change its state to a different one.



Scanned by CamScanner

The system may reach from state 1 to state 2 by a number of paths depends on the type of expansion.



PROCESS -

A change of state occurs when one or more of the properties of a system changes. When a system undergoes changes on its state, it is said to have undergone a process.

Process is named according to its specification -

- 1) REVERSIBLE & IRREVERSIBLE PROCESS
- 2) QUASI Static Process
- 3) CYCLIC PROCESS
- 4) Non flow process
- 5) Flow process
- 6) Const Volume process
- 7) Const Pressure process
- 8) Const Temp process

* REVERSIBLE PROCESS & IRREVERSIBLE PROCESS :-

A process is said to be reversible in which system returns to its original state without leaving any effect on the surrounding. Reversible process is ^{possible to achieve} practically.

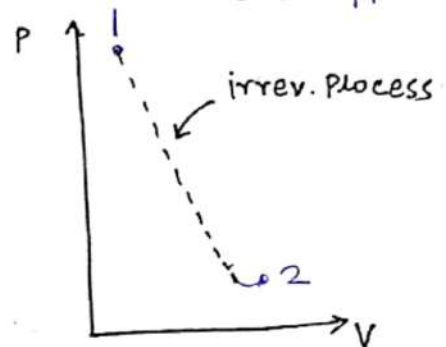
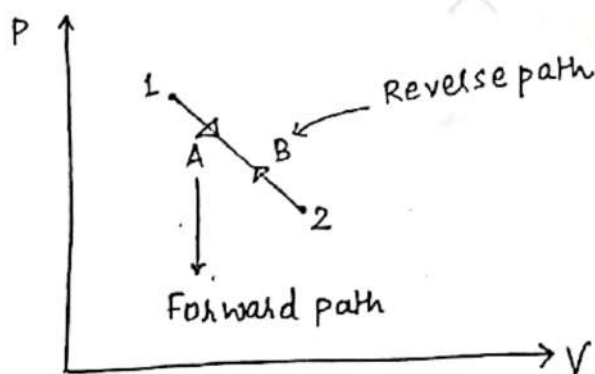
NOTE :- ^Q for the reversible process, both forward path and reversed path has to be same.

⑥ Reversible process are represented by continuous line or curve.

(c) It must pass through a continuous series of equilibrium states. No real process is

IRREVERSIBLE PROCESS: whereas irreversible process are represented by dotted lines

⑦ An irreversible process is one in which heat is transferred through a finite temperature difference. reversible but some may approach reversibility, close approximation.



* METHODS which makes the process irreversible :-

① Friction.

② Free expansion.

③ Plastic deformation

Some examples of reversible processes are:

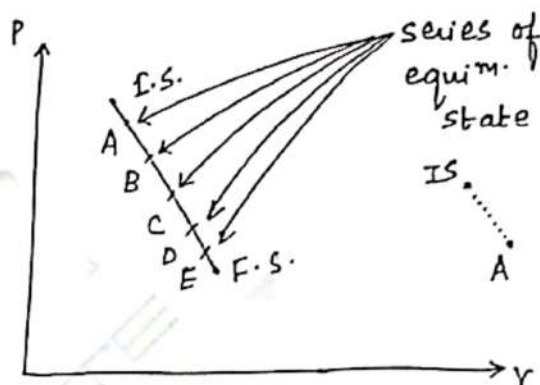
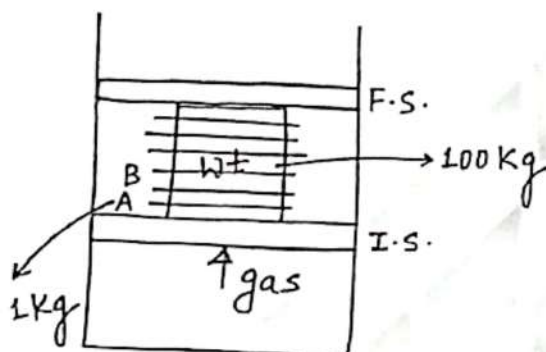
- (1) Frictionless relative motion.
- (2) Frictionless adiabatic expansion or compression of fluid.
- (3) Isothermal expansion or compression.
- (4) Polytropic expansion or compression of fluid.

③ Mixing of fluids.

④ Heat transfer through a finite temperature difference.

* **QUASI-STATIC PROCESS** $\rightarrow$ Infinite slowness is a characteristic of the quasi-static process over or it is a process by joining (almost) a series of equilibrium states.

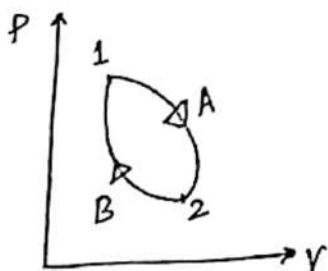
NOTE $\rightarrow$ Quasi-static without friction is a reversible process.



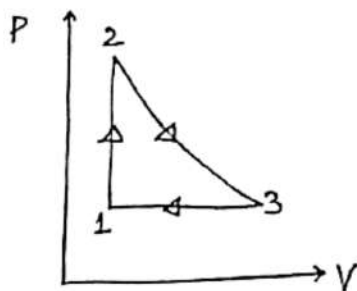
* **CYCLIC PROCESS** $\rightarrow$ A process is said to be cyclic in which initial state and final state are same.

NOTE $\rightarrow$ Minimum no. of process required to make a cycle are

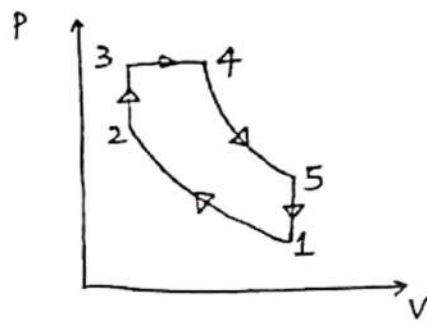
2.



2 Process cyclic

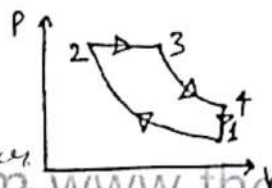


3 process cyclic



5 Process cyclic

(1) **Non Flow Process** - A process may be non-flow in which a fixed mass within the defined boundary is undergoing a change of state. A substance which is being heated in a closed cylinder undergoes a non-flow process. Closed system undergoes non-flow process.



4 process cyclic

(2) **Flow Process** - A process may be a flow process in which mass is entering and leaving through the boundary of an open system.

Scanned by CamScanner

* IDEAL GAS EQUATION:→

Any gas behaves as an ideal gas under low pressure and high temperature and the expression of ideal gas equation is

$$PV = mRT$$

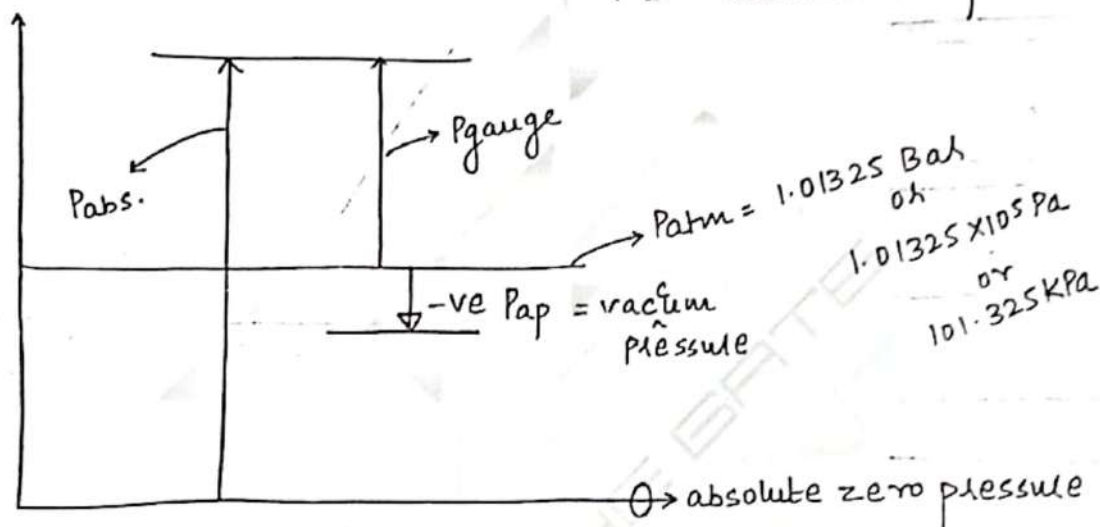
where P is absolute pressure.

V is volume

m is mass

R is characteristics gas constant

T is absolute temperature in (K).



$$P_{ABS.} = P_{atm} + P_{gp}$$

Now, the other form of equation is

$$PV = n\bar{R}T$$

$$n = \text{no. of moles} = \frac{\text{mass (m)}}{\text{Mol. wt. (M)}}$$

$$\therefore PV = \text{mass} \left(\frac{\bar{R}}{\text{Mol. wt.}} \right) T$$

$$PV = mRT$$

(2) In case of constant pressure and thermometer, Volume

so,

$$R = \frac{\bar{R}}{\text{Mol. wt}}$$

$$\bar{R} = 8.314 \text{ KJ/K mole K}$$

NOTE :-

(a) $t \rightarrow ^\circ\text{C}$

(b) $T \rightarrow \text{K}$

(c) $0^\circ\text{C} \rightarrow 273.15 \text{ K}$

(d) (T.P.)_{Temp H₂O} $\rightarrow$ 273.16 K
or
 0.01°C

(e) (T.P.)_{Pressure H₂O} $\rightarrow$ 4.587 mm Hg

$$P = \rho gh$$

$$P = 13.6 \times 1000 \times 9.81 \times 4.587 \times 10^{-3}$$

$$= 611.97 \text{ N/m}^2$$

or

$$0.611 \text{ KPa } (\text{N/m}^2 \times 10^3)$$

Unit Conversion

$$\frac{\text{kg}}{\text{m}^3} \times \frac{\text{m}}{\text{sec}^2} \times \text{m}$$

$$\frac{\text{kg}}{\text{m} \cdot \text{sec}^2}$$

$$F = m \times a$$

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

$$\frac{N}{\text{m}^2} = \frac{\text{kg}}{\text{s}^2}$$

* **THERMOMETRIC PROPERTY** :- The variable which helps us to calculate the value of temperature is known as thermometric property.

[Ex] :- (1) In case of constant volume gas thermometer, pressure will play the role of T.P.

(a) $V = C$

$$PV = nRT$$

$$P = \left(\frac{nR}{V} \right) T$$

$$T = f(P)$$

* POINT FUNCTION & PATH FUNCTION :-

P.F. $\rightarrow$ Point ^{fn.} are the variables whose values does not depend on

the path followed by the system or when two properties locate a point on the graph (co-ordinate axis) then those properties are called as point function.

Example $\rightarrow$ Pressure

• Volume

• temperature.

etc.

- The cyclic ~~integration~~ integral of the variable is equal to zero.

(an exact differential)

$$\int_1^2 dV = V_2 - V_1$$

This PDF was downloaded from www.thegatehunt.com

Scanned by CamScanner

Path functions $\rightarrow$ are the variables whose value depends on the

past history of the system or There are certain quantities which cannot be located on a graph by a point but are given by the area or 'So on' that graph. In that case, the area on

For example $\rightarrow$ heat and work.

the graph, pertaining to the particular process is a function of the path of the process. Such quantities are called Path function.

* **Exact Differential**

$\rightarrow$ The cyclic integral of the variable is equal to 0.
The cyclic integral of the variable is not equal to zero.

For example $\rightarrow$ P, V

heat & work are inexact differentials. Their change cannot be written as difference between their end states. Thus $\int_1^2 dQ \neq Q_2 - Q_1$ and is shown as Q_1-2 or Q_1-2 .

* **Inexact Differential**

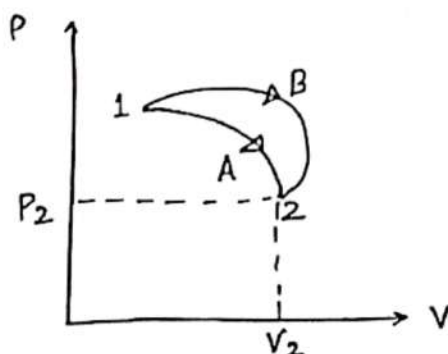
$\rightarrow$ The cyclic integral of the variable is not equal to 0.
Similarly $\int_1^2 dW \neq W_2 - W_1$ and is shown as W_1-2 or W_1-2 .

For example $\rightarrow$ heat & work.

The operator d is used to denote inexact differential and operator D is used to denote exact differentials.

NOTE $\rightarrow$ ① All properties are point function and exact differential.

② Heat and work are path function and inexact differential.



P_1 ✓
 V_1 ✓
 T_1 ✓

W_{1-A-2}

W_{1-B-2}

Q_{1-A-2}

Q_{1-B-2}

P_{1-2}
 V_{1-2}

W_1
 Q_1

W_{1-2}
 Q_{1-2}



Scanned with OKEN Scanner

POTENTIAL ENERGY -

The energy that a system possesses as a result of its elevation in a gravitational field is called potential energy (PE) and is expressed as,

$$PE = mgz \text{ (Joules)}$$

$$\text{on unit mass } PE = gz \text{ (J/Kg)}$$

where g is the acceleration due to gravity and z is the elevation of the system relative to some outside reference.

KINETIC ENERGY -

The energy that a system possesses, as a result of motion relative to some reference is called Kinetic energy.

When all parts of system move with the same velocity, the KE is expressed as

$$K.E. = \frac{1}{2} m v^2 \text{ (Joule)}$$

where m is the mass of body and v is the velocity of the system with respect to some reference.

INTERNAL ENERGY -

The sum of all the microscopic forms of energy is called internal energy. The internal energy of a system is the energy stored within the body resulting from the kinetic and potential energy of its molecules. Thus, it is related to molecular structure and degree of molecular activities. The molecules of any body may possess both kinetic and potential energy.

Thus, the internal energy of any system may be viewed as the sum of KE and PE of molecules.

It is denoted by U

$$U = K + P \quad \text{Joules.}$$

Where K = internal Kinetic energy of molecules
 P = internal Potential energy of molecules.

The balanced part of the energy is known as internal energy.
In a non-flow process usually there is no change of potential or kinetic energy and hence, change of mechanical energy will not enter the calculations.

In a flow-process, however, there may be changes in both potential and kinetic energy and these must be taken into account while considering the changes of stored energy.

Heat and work are form of energy in transition.

These are the only forms in which energy can cross the boundaries of a system. Neither heat or work can be stored energy.

~~W/O~~

WORK

In mechanics, mechanical work is defined as the product of an external force acting at the boundaries of a system and the distance through which the force moves along its line of action then,

$$W = F \cdot s$$

(F is force and s is distance
unit is N-m or Joule.)

If the force is not constant, the work done is obtained by adding the differential amount of work,

$$W = \int_1^2 F \cdot ds$$

However, this definition of work is not ~~quite~~ sufficient for the study of thermodynamics, because of the fact that thermodynamics deals with energy transfers between a system and surroundings, the energy transfer are of two kinds - heat and work.

In thermodynamics, there is a difference between heat and work. The definition of work used in mechanics fails to distinguish between heat and work.

In thermodynamics work is defined as energy in transition i.e. a form of energy interaction between two systems.

Energy can cross the boundary of the system as heat or work. Therefore, if the energy crossing the boundary is not heat, then it ~~is~~ must be work.

e.g. A moving piston, a rotating shaft, a rising weight are all associated with work interaction.

Work done during a process from the state ① to the state ② is denoted by W_{1-2} .

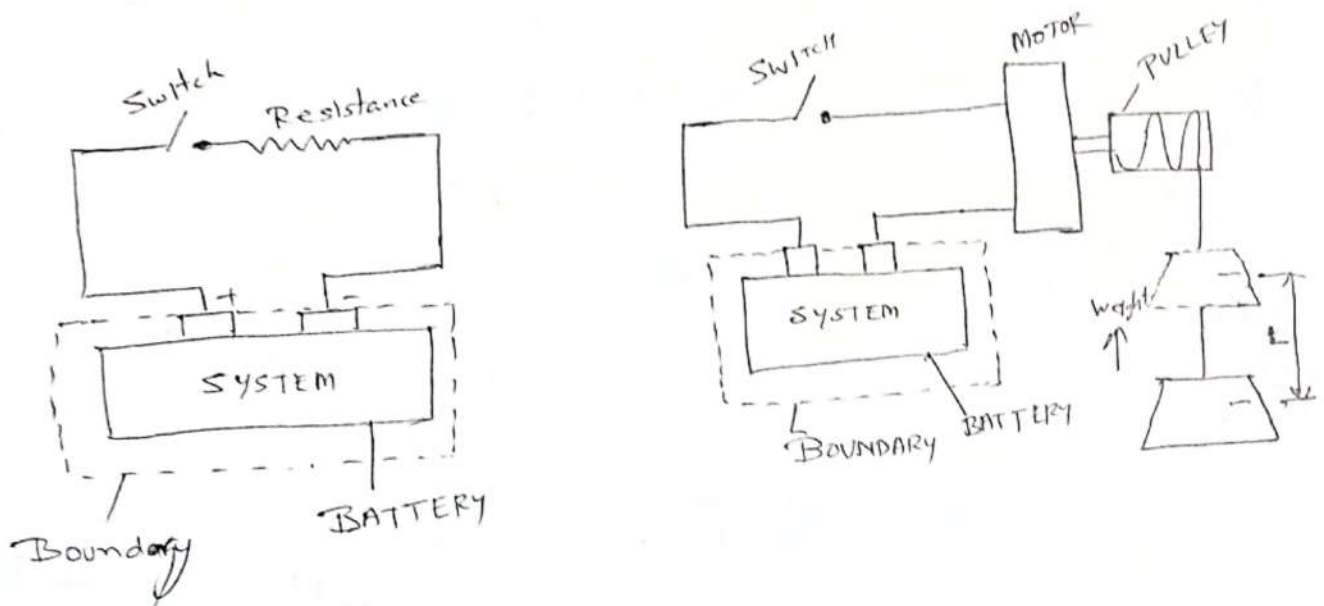
"Work is an interaction between system and surroundings and is done by the a system if the sole effect external to the boundaries of the system could have been the raising of a weight".

Thermodynamic work refers to transfer of energy due to potential difference other than temperature difference, without ~~transfer~~ transfer of mass across the system boundaries. It is an extension of the concept of work in mechanics.

Ex

Consider a system consisting of an electrical battery, switch and resistance coil outside the system. When the switch is closed, the current flows through the resistance coil. Thus, electrical energy crossing the boundary of the system is converted into heat energy.

In this system, According to the definition of work used in mechanics, the answer is 'no' because no force has moved through a distance. But according to definition of thermodynamics, the answer is 'yes' because, if we replace the resistance by an electric motor with a pulley and its shaft to wind up the rope on which weight is suspended. When the switch is closed on, the battery drives the motor, the pulley rotates and ~~under~~ the sole effect external to the system boundary has been the rise of weight. Therefore, the system does work.



CONCEPT OF WORK

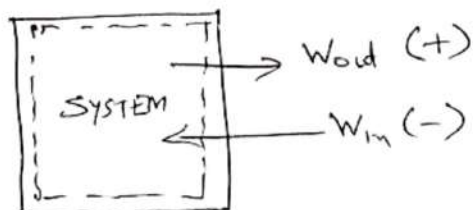
The word "Sole effect" used in the definition of work differentiate between heat and work.

The word "external" emphasizes that work is defined only with

with reference to a system boundary. i.e. work is an interaction across the boundary. It is to be noted that work like heat, is a transient quantity and can not be stored in a system. Only during a transfer of energy, work occurs.
i.e. it is an inexact differential as δW instead of dW .

SIGN CONVENTION OF WORK TRANSFER

The complete specification of work transfer also requires magnitude and direction. The universally accepted sign conventions for work transfer are shown in fig.



- (1) The work done by the system is considered (+) positive.
- (2) The work done on the system is considered (-) negative.

ex - By the sign convention, work produced by a car engine, hydraulic motor, steam and gas turbines is positive.
and work consumed in operation of a compressor, a pump, a refrigerator, a fan etc. is negative.

SALIENT FEATURE OF WORK TRANSFER

- (1) Work is recognized at the system boundary, thus it is a boundary phenomenon.
- (2) Work is transferred in specific direction in a process, thus it is a path function.
- (3) If the nature of the process changes between two given state, the magnitude of work may change.
- (4) Magnitude of work transfer can also be obtained by calculating the area under the path of the process.



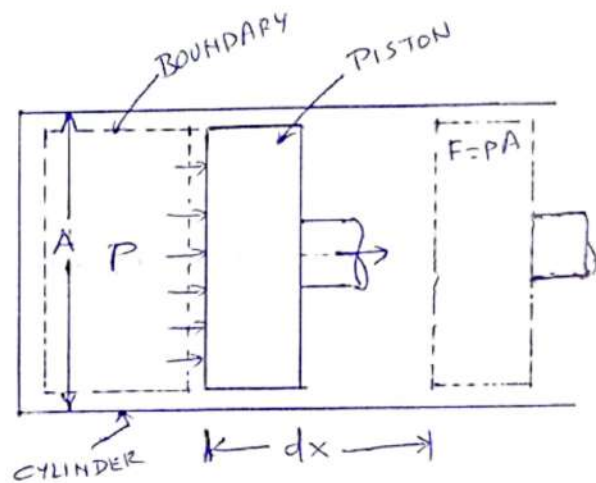
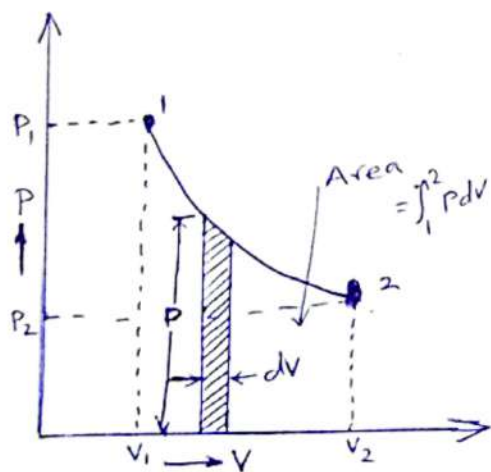
F. FORMS OF WORKS DURING QUASI-STATIC OR REVERSIBLE PROCESS:

EXPANSION OR COMPRESSION WORK of a fluid or pdV Work or Displacement Work or MOVING BOUNDARY WORK:

~~Diagram~~ For the expansion or compression work of a fluid during a quasi-static process, let us consider a piston-cylinder arrangement as shown in fig. In a piston-cylinder arrangement type machines, two types of works are observed, one is the work done by the system due to expansion process and other is work done on the system due to compression process.

Let the system be the fluid enclosed between the piston and the cylinder. The system will exert a pressure P on the piston face of Area A . If the piston is allowed to move a distance dx , the force F acting on the piston may vary but at any instant it is given by

$$F = \text{Pressure} \times \text{cross-sectional area of piston} \\ = PA \quad \text{Newton} \quad \text{--- (1)}$$



PdV Workdone in Quasi-Static Process

$$\text{Work (W)} = \text{Force} \times \text{distance}$$

$$SW = PA dx$$

$$\text{But } Adx = dV = \text{change in volume}$$

$$\therefore SW = P dV \quad \text{Nm or J} \quad \text{--- (2)}$$

The total work done at the moving system boundaries can be calculated by integrating equation (2)

The total boundary work can be obtained by adding all differential works from the initial state ① to the final state 2 $\Rightarrow$

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

$$\text{Or } W_{1-2} = P \int_1^2 dV = P(V_2 - V_1) \text{ Joule} \quad - (3)$$

This work transfer during a process is equal to the area under the curve on a p-v diagram and the work done by each kg of system is

$$W = \int_1^2 P dV \text{ (J/kg)}$$

Similarly, the workdone ~~and~~ during compression process i.e. from 2 to 1, is given by

$$\Delta W = - \int_2^1 P dV \quad - (4)$$

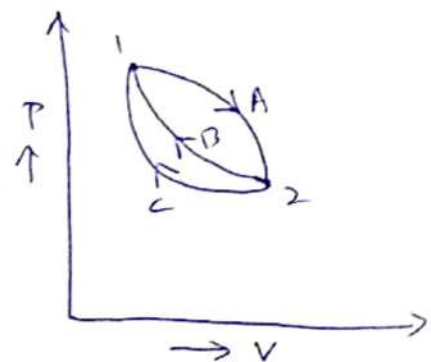
Negative sign is used to indicate ~~to~~ that during compression work is done on system.

Equation (2) is valid under the following conditions:

- (1) The process is frictionless.
- (2) System is closed.
- (3) There is no viscous effect within the system.
- (4) The process is quasi-static. ~~reversible~~ process.
- (5) The effect due to gravity, electricity or magnetism are negligible.

WORK AS A PATH FUNCTION:

Consider several reversible process such as A, B, C from state 1 to state 2 as shown in fig. The work interaction in each case is represented by the area underneath the corresponding path. From the fig it is clear that the work is different in each case because the path depends on the nature of the process. ~~the path~~



Work depends on path.

This suggests that work is not a property or a state function rather it is a path function and an infinitesimal increment of work is an inexact differential.

Hence, a system does not possess work but work is a mode of transfer of energy and this transfer of energy occurs only at the boundaries of the system during a change of state of the system.

Hence work is expressed by

$$W_{1-2} = \int_1^2 \delta W \quad \text{and not by } W_2 - W_1$$

Q. The properties of a closed system change following the relation between pressure and volume as $PV = 3.0$, where P is in bar, V is in m^3 . Calculate the work done when the pressure increases from 1.5 bar to 7.5 bar.

Q. Given that,
Initial pressure $P_1 = 1.5$ bar
Final pressure $P_2 = 7.5$ bar
Relation between P and V $\Rightarrow PV = 3$

Work done W ,

$$W = \int_{V_1}^{V_2} P dV$$

$$V_1 = \frac{3}{P_1} = \frac{3.0}{1.5} = 2 \text{ m}^3$$

$$V_2 = \frac{3}{P_2} = \frac{3}{7.5} = 0.4 \text{ m}^3$$

$$\begin{aligned} W &= 10^5 \int_2^{0.4} \frac{3}{V} dV \quad \text{N.m} \\ &= 10^5 \times 3 [\log_e V]_2^{0.4} \\ &= 10^5 \times 3 [\log_e 0.4 - \log_e 2] \\ &= -3 \times 10^5 \left[\log_e \frac{2}{0.4} \right] \\ &= -3 \times 10^5 \times \log_e 5 \\ &= -3 \times 10^5 \times 1.61 \text{ N.m} = -4.83 \times 10^5 \text{ N.m} \\ &= -483 \times 10^3 \text{ J} = -483 \text{ KJ.} \end{aligned}$$

Q To a closed system 150 kJ of work is applied. If the initial volume is 0.6 m^3 and pressure of system changes as $P = 8 - 4V$, where P is in bar and V is in m^3 , determine the final volume and pressure of the system. (Dec 2015)

Soln

Amount of work supplied to a closed system = 150 kJ

Initial volume $V_1 = 0.6 \text{ m}^3$

Given that pressure volume relationship $P = 8 - 4V$

Then work done during the process is given by,

$$W = \int_{V_1}^{V_2} P dV$$

$$W = 10^5 \int_{0.6}^{V_2} (8 - 4V) dV$$

$$\frac{+36}{-12}$$

$$W = 10^5 \left[8V - 4 \times \frac{V^2}{2} \right]_{0.6}^{V_2}$$

$$W = 10^5 \left[(8V_2 - 2V_2^2) - (8 \times 0.6 - 2 \times 0.6^2) \right]$$

$$W = 10^5 [8V_2 - 2V_2^2 - 4.08 + 0.72]$$

$$\frac{4.08}{-12}$$

$$W = 10^5 (8V_2 - 2V_2^2 - 4.08) \text{ N-m or J}$$

But this work is equal to $-150 \times 10^3 \text{ J}$ as this work is supplied to the system.

$$\therefore -150 \times 10^3 = 10^5 (8V_2 - 2V_2^2 - 4.08)$$

$$\frac{4.08}{1.50}$$

$$2V_2^2 - 8V_2 + 4.08 = \frac{150 \times 10^3}{10^5} = \frac{150}{100} = 1.50$$

$$2V_2^2 - 8V_2 + 4.08 - 1.50 = 0$$

$$2V_2^2 - 8V_2 + 2.58 = 0$$

$$V_2 = \frac{8 \pm \sqrt{64 - 4 \times 2 \times 2.58}}{4}$$

$$\left[= \frac{b \pm \sqrt{a^2 - 4ab}}{2a} \right]$$

$$= \frac{8 \pm 6.585}{4} = 0.354 \text{ m}^3 \quad \left[\begin{matrix} +3.646 \\ -0.354 \end{matrix} \right]$$

$$\frac{14.585}{4} = 3.646$$

Positive sign is ~~incorrect~~ not correct with this problem, therefore ~~we take~~ it is not considered.

$$\frac{2.1415}{2} = 0.354 \text{ m}$$

$\therefore$ Final Volume $V_2 = 0.354 \text{ m}^3$

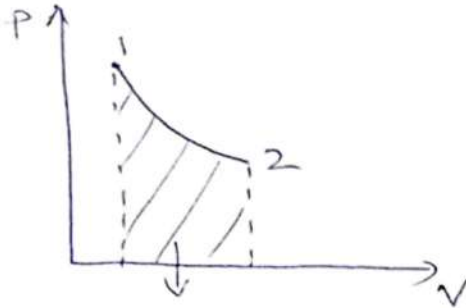
and final pressure, $P_2 = 8 - 4V = 8 - 4 \times 0.354 = 6.584 \text{ bar}$
 $= 6.584 \times 10^5 \text{ N/m}^2 \text{ or Pa}$

TYPES OF WORK -

(1) CLOSED SYSTEM WORK OR Non-flow Work:

To obtain the closed system work, the area under P-V should be projected on Volume axis and the mathematical expression for closed system work is

$$W = \int P dv$$

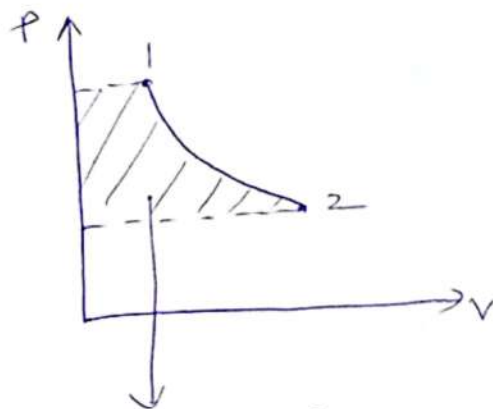


$$W_{\text{closed}} = \int_1^2 P dv.$$

(2) OPEN SYSTEM WORK OR Steady flow Work:-

To obtain the open system work, area under P-V should be projected on pressure axis and the mathematical expressions

$$W = - \int V dp$$



$$W_{\text{open}} = - \int V dp.$$

Expression of Closed System Work for Different Processes:

Various thermodynamic processes used given below.

These processes may undergo either compression or expansion processes.

In compression process, Volume decreases while pressure and temperature increases.

In expansion process, Volume increases while pressure and temperature decreases.

- (1) Constant Volume Process ($V=c$)
- (2) Constant Pressure Process ($P=c$)
- (3) Constant temperature or Isothermal process ($PV=c$) or ($T=c$)
- (4) Adiabatic Process ($PV^\gamma=c$)
- (5) Polytropic process ($PV^n=c$)

CONSTANT-VOLUME PROCESS - OR ISOCHORIC PROCESS OR ISOMETRIC PROCESS

If any system of gas undergoes a process in such a way that during the process, the volume of the system remains constant, the process is called constant volume process or Isochoric Process.

ex. processes taking place in pressure cooker, gas cylinder etc.

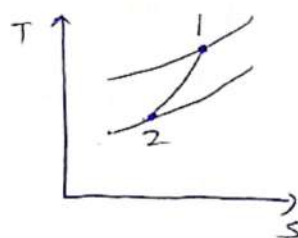
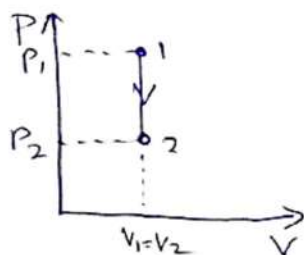
(i) Properties Relationship-

The properties relationship for any system undergoing a process between two states is expressed as:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

For a const - Volume process $V_1 = V_2$

Then the above relation reduces to $\frac{P_1}{T_1} = \frac{P_2}{T_2}$



const Volume cooling process on P-V and T-S diagram.

WORK DONE DURING THE PROCESS

For a non-flow system, the workdone can be obtained either from the area under the curve or mathematically as

$$W_{1-2} = \int_1^2 p dV$$

For a const volume process

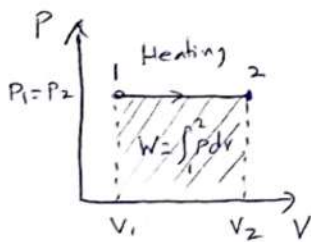
$$dV = 0$$

$$\therefore W_{1-2} = 0$$

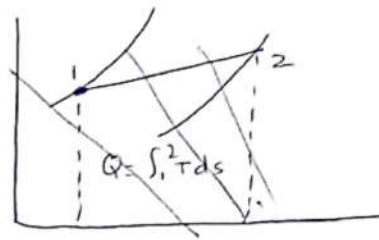
It is also shown from a p-v diagram, as there is no area under the vertical line.

(2) CONSTANT PRESSURE OR ISOBARIC PROCESS OR ISOPIESTIC PROCESS -

If any system of gas undergoes a process in such a way that during the process, the pressure of the gas remains const. then such process is called a const. pressure or isobaric process.



const. pressure



(1) Properties Relationship

In general, properties are related between two states as:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

At const pressure $P_1 = P_2$

$$\therefore \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

(1) WORK DONE - The $\int p dV$ work done during the process can be evaluated from an area under the curve on a p-v diagram or can be calculated, $W_{1-2} = \int_1^2 p dV = p (V_2 - V_1)$ KJ
Where p is expressed in kPa (KN/m²) and V is m³

WORK DONE DURING THE PROCESS

For a non-flow system, the workdone can be obtained either from the area under the curve or mathematically as

$$W_{1-2} = \int_1^2 p dV$$

For a const volume process

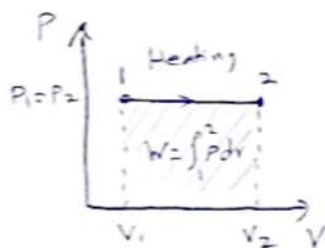
$$dV = 0$$

$$\therefore W_{1-2} = 0$$

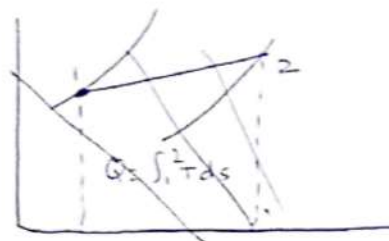
It is also shown from a p-v diagram, as there is no area under the vertical line.

(2) CONSTANT PRESSURE OR ISOBARIC PROCESS OR ISOPRESTIC PROCESS -

If any system of gas undergoes a process in such a way that during the process, the pressure of the gas remains const. then such process is called a const. pressure or isobaric process.



Const. pressure



(1) Properties Relationship

In general, properties are related between two states as:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

At const pressure $P_1 = P_2$

$$\therefore \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

(11) WORK DONE - The $\int p dV$ work done ~~at~~ during the process can be evaluated from an area under the curve on a p-v diagram or can be calculated. $W_{1-2} = \int_1^2 p dV = p (V_2 - V_1)$ KJ
Where p is expressed in kPa (KN/m²) and V is m³

(3) Isothermal Process or Constant Temperature Process or Hyperbolic process

If a system undergoes a process in such a way that during the process, the temperature of the system remains constant, such a process is called an isothermal process or constant temperature process.

(1) Relation between P, V and T is

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

If Temperature is const. ($T_1 = T_2$)

then $P_1 V_1 = P_2 V_2$

or $PV = C$

It is the equation of hyperbola and hence an isothermal process is also called a hyperbolic process.

(ii) WORK DONE -

The workdone during a process is expressed as,

$$W_{1-2} = \int_1^2 P dv$$

For an isothermal process,

$$PV = C \quad T = C$$

$$P = \frac{C}{V} \quad PV = mRT \quad PV = C$$

$$\text{Then } W_{1-2} = \int_1^2 \frac{C}{V} dv = C \int_1^2 \frac{dv}{V}$$

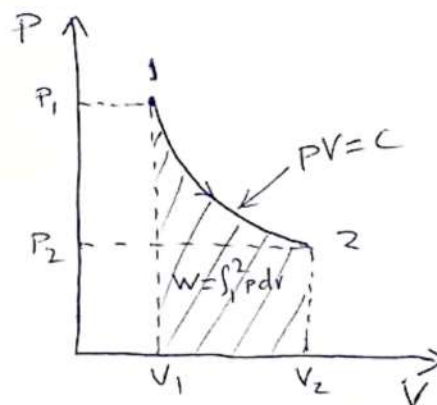
$$W_{1-2} = C \ln\left(\frac{V_2}{V_1}\right)$$

Using $C = P_1 V_1$

we get $W_{1-2} = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$

or $W_{1-2} = mRT_1 \ln\left(\frac{V_2}{V_1}\right)$

or $W_{1-2} = P_2 V_2 \ln\left(\frac{V_2}{V_1}\right) = mRT_2 \ln\left(\frac{V_2}{V_1}\right)$



From properties relation, we have

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}$$

Then $W_{1-2} = mRT_1 \ln\left(\frac{P_1}{P_2}\right)$

or $W_{1-2} = P_1 V_1 \ln\left(\frac{P_1}{P_2}\right)$
 $W_{1-2} = P_2 V_2 \ln\left(\frac{P_1}{P_2}\right)$

$W_{1-2} = mRT_1 \ln\left(\frac{P_1}{P_2}\right)$
 $W_{1-2} = mRT_2 \ln\left(\frac{P_1}{P_2}\right)$

REVERSIBLE ADIABATIC OR ISENTROPIC PROCESS

If any process of expansion or compression is carried out without exchange of heat between system and surrounding i.e., operation in an insulated cylinder, the process is called adiabatic process. During this process, the system neither receives nor rejects any amount of heat.

When an adiabatic process is reversible, i.e., frictionless, etc., then this process is called isentropic or reversible adiabatic or constant entropy process.

It will follow a law $PV^\gamma = C$ where γ is the adiabatic index. This is defined as the ratio of specific heat at constant pressure (C_p) to the specific heat at constant volume (C_v).

$$PV^\gamma = C$$

$$\gamma = C_p / C_v$$

For air

$$C_p = 1.005 \quad C_v = 0.718 \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{KJ/kgK}$$

$$R = C_p - C_v = 0.287 \text{ (KJ/kgK)}$$

$$\gamma = \frac{C_p}{C_v} = 1.4$$

(1) Relation between P , V and T

The thermodynamic properties for a perfect gas are related as:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{T_2}{T_1} = \frac{P_2 V_2}{P_1 V_1} \quad \dots \text{--- (1)}$$

For an isentropic or adiabatic process

$$PV^\gamma = C$$

$$\text{or } P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\text{or } \frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^\gamma = \left(\frac{V_2}{V_1} \right)^{-\gamma} = \left(\frac{V_2}{V_1} \right)^{-\gamma} \quad \dots \text{--- (2)}$$

$$\text{or } \frac{V_2}{V_1} = \frac{V_2}{V_1} = \left(\frac{P_2}{P_1} \right)^{-1/\gamma} \quad \dots (3)$$

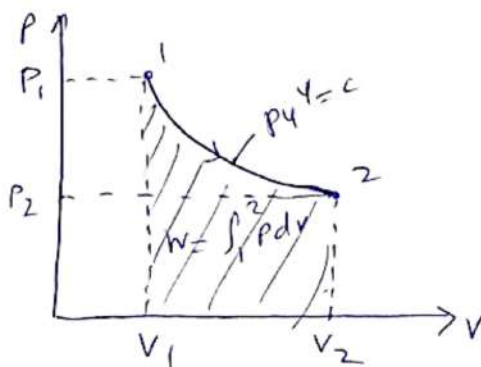
Substituting equation (3) in eq (1)

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1} \right)^{-\gamma} \left(\frac{V_2}{V_1} \right) = \left(\frac{V_2}{V_1} \right)^{1-\gamma} = \left(\frac{P_2}{P_1} \right)^{\gamma-1} \quad \dots (4)$$

Using eq. (3) in Eq. (1)

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right) \left(\frac{P_2}{P_1} \right)^{-1/\gamma} = \left(\frac{P_2}{P_1} \right)^{1-1/\gamma} = \left(\frac{P_2}{P_1} \right)^{\gamma-1/\gamma} \quad \dots (5)$$

WORK DONE



$$P_1 V_1^\gamma = P_2 V_2^\gamma = C$$

$$\Delta Q = 0$$

The work done during a non-flow process is expressed as

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

For an isentropic process or adiabatic process

$$P V^\gamma = C \quad \text{or} \quad P = \frac{C}{V^\gamma}$$

$$\text{Then } W_{1-2} = \int_1^2 \frac{C}{V^\gamma} dV = C \int_{V_1}^{V_2} V^{-\gamma} dV$$

$$W_{1-2} = C \left[\frac{V^{-\gamma+1}}{-\gamma+1} \right]_{V_1}^{V_2} = C \left[\frac{V_2^{-\gamma+1} - V_1^{-\gamma+1}}{1-\gamma} \right]$$

Substituting for C as $P_1 V_1^\gamma$ and $P_2 V_2^\gamma$

$$W_{1-2} = \frac{P_2 V_2^{-\gamma+1} - P_1 V_1^{-\gamma+1}}{1-\gamma}$$

We get

$$\boxed{W_{1-2} = \frac{P_2 V_2 - P_1 V_1}{1-\gamma} = \frac{mR(T_2 - T_1)}{1-\gamma}} \quad \text{or } W_{1-2} = \left[\frac{P_1 V_1 - P_2 V_2}{\gamma-1} \right]$$

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

If we put $R = C_p - C_v$ and $\gamma = \frac{C_p}{C_v}$, we get

$$R = C_v \gamma - C_v = C_v (\gamma - 1)$$

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

$$W_{1-2} = -m C_v (T_2 - T_1) = -\Delta U$$

This expression explains that during an isentropic expansion process, the work done is always equal to decrease in internal energy during the process.

⑤ POLYTROPIC PROCESS -

It is exactly similar to adiabatic process except the heat interaction is not equal to 0. It will follow a law $PV^n = C$ where n is ~~poly~~ polytropic index.

(I) Determination of Polytropic Index (n) -

If a polytropic process is taking place from an initial state P_1, V_1 to a final state P_2, V_2 , then

$$P_1 V_1^n = P_2 V_2^n$$

Taking log on both sides, we get

$$\ln P_1 + n \ln V_1 = \ln P_2 + n \ln V_2$$

$$\text{or } n(\ln V_1 - \ln V_2) = \ln P_2 - \ln P_1$$

$$n = \frac{\ln(P_2/P_1)}{\ln(V_1/V_2)}$$

(II) P, V, T Relationship -

If the adiabatic index γ is replaced by polytropic index n in eq. (2)

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

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

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

$$\text{and } \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right) \left(\frac{P_2}{P_1}\right)^{-1/n} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

(III) WORK DONE

For a non-flow process, the polytropic work transfer is calculated as:

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

$$\text{We know } PV^n = C \quad \text{or } P = \frac{C}{V^n} = CV^{-n}$$

$$\begin{aligned} \text{Hence } W_{1-2} &= \int_1^2 CV^{-n} dV = C \int_1^2 V^{-n} dV \\ &= C \left[\frac{V_2^{-n+1} - V_1^{-n+1}}{-n+1} \right] \end{aligned}$$

$$\text{Using } C = P_1 V_1^n = P_2 V_2^n$$

$$\text{we get } W_{1-2} = \frac{P_2 V_2^n V_2^{-n+1} - P_1 V_1^n V_1^{-n+1}}{-n+1}$$

$$W_{1-2} = \frac{P_2 V_2 - P_1 V_1}{1-n}$$

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

Q. Calculate the non-flow workdone for a gas which expands from initial pressure 5 bar and volume 4 m^3 to final volume 20 m^3 under the following reversible processes.
Show the process on p-v diagram.

(a) $P=c$ (b) $V=c$ (c) $PV=c$ (d) $PV^\gamma=c$ where $\gamma=1.4$

(e) $PV^n=c$ when $n=1.25$. Comment on the results.

(May 2018)

(a) When pressure is const.:

$$P=c \text{ i.e. } P_1=P_2 \text{ (Isobaric process)}$$

$$\begin{aligned} W_{1-2} &= \int_1^2 P dv = P(V_2 - V_1) = 5 \times 10^5 \frac{\text{N}}{\text{m}^2} (20 - 4) \text{ m}^3 \\ &= 80 \times 10^5 \text{ J} = 80 \times 10^2 \text{ KJ} \\ &= 8 \times 10^3 \text{ KJ} = 8 \text{ MJ} \end{aligned}$$

(b) When Volume is const.:

$$V=c, \text{ i.e. } dV=0 \text{ (Isobaric process)}$$

$$W_{1-2} = \int_1^2 P dv = 0$$

(c) When $PV=c$ i.e. $P_1V_1 = P_2V_2$ (Isothermal process)

$$\begin{aligned} W_{1-2} &= \int_1^2 P dv = \int_1^2 \frac{c}{v} dv = c \int_1^2 \frac{dv}{v} = c \ln \frac{V_2}{V_1} \\ &= P_1 V_1 \ln \frac{V_2}{V_1} \\ &= 5 \times 10^5 \frac{\text{N}}{\text{m}^2} \times 4 \text{ m}^3 \ln \frac{20}{4} \\ &= 20 \times 10^5 \times \ln 5 \text{ J} \\ &= 3216.8 \text{ KJ} = 3.2188 \text{ MJ} \end{aligned}$$

$$\text{Here } P_2 = P_1 \frac{V_1}{V_2} = 5 \times \frac{4}{20} = 1 \text{ bar}$$

(d) When $PV^\gamma=c$ (adiabatic process)

$$W_{1-2} = \int_1^2 P dv = \int_1^2 \frac{c}{v^\gamma} dv = c \left[\frac{v^{-\gamma+1}}{-\gamma+1} \right]_1^2 = c \left[\frac{V_2^{-\gamma+1} - V_1^{-\gamma+1}}{1-\gamma} \right]$$

$$\begin{aligned} \text{Put } P_1 V_1^\gamma &= P_2 V_2^\gamma = c \\ &= \frac{P_2 V_2^\gamma V_2^{-\gamma+1} - P_1 V_1^\gamma V_1^{-\gamma+1}}{1-\gamma} = \left[\frac{P_2 V_2 - P_1 V_1}{1-\gamma} \right] \end{aligned}$$

$$\text{Hence } P_2 = P_1 \left(\frac{V_1}{V_2} \right)^\gamma = 5 \left(\frac{4}{20} \right)^{1.4} = 0.525 \text{ bar}$$

$$\therefore W_{1-2} = \frac{5 \times 10^5 \times 4 - 0.525 \times 10^5 \times 20}{0.4} = 2375 \text{ kJ} = 2.375 \text{ MJ}$$

(e) When $PV^n = C$ when $n = 1.25$ (Polytropic Process)

$$W_{1-2} = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

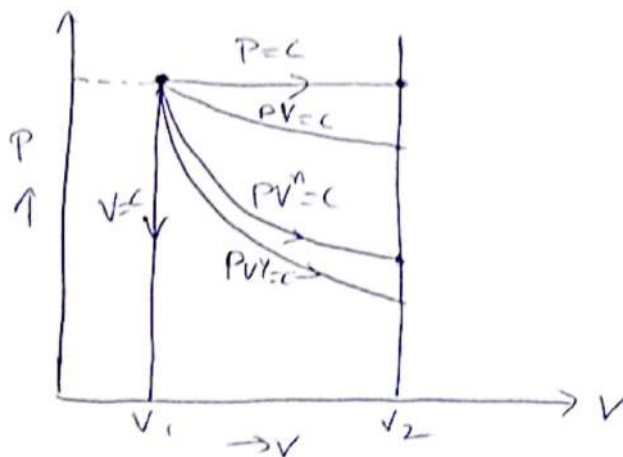
$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^{1.25} = 0.668 \text{ bar}$$

$$W_{1-2} = \frac{5 \times 10^5 \times 4 - 0.668 \times 10^5 \times 20}{1.25 - 1}$$

$$= 2656 \text{ kJ} = 2.656 \text{ MJ}$$

The workdone is the maximum when $p=c$ but practically it is not possible, The workdone is zero in the case of $V=c$.

Therefore, Workable processes are $PV^\gamma = C$ and $PV^n = C$.



(without scale)

HEAT

Heat is an energy which appears at the boundary when a system changes its state due to a difference in temperature between the system and its surroundings.

OR

Heat is an energy interaction between the system and surrounding without transfer of mass, across the boundary of system because of temperature difference between system and surrounding.

There would be no heat transfer if they are at same temperature. The amount of heat transferred from the state 1 to the state 2 is designated Q_{1-2} or Q and its unit in SI is Joule and in MKS, calories.

Heat, like work, is a transient quantity which only appears at the boundary while a change is taking place within the system. It is path function and ~~is~~ inexact differential.

Therefore it is denoted by δQ .

Heat transfer per unit mass of system is denoted by q and expressed as

$$q = \frac{Q}{m} \text{ (KJ/kg)}$$

SIGN CONVENTION -

If the heat flows into a system from the surroundings, the quantity is said to be positive.

If the heat flows from the system to the surroundings it is said to be negative.

In other words:

Heat received by the system = $+Q$

Heat rejected by the system = $-Q$

Expression for heat

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

Where c is specific heat, m is mass and ΔT is temp. difference either in $^{\circ}\text{C}$ or K .

SIMILARITIES AND DISSIMILARITIES BETWEEN HEAT AND WORK

SIMILARITIES BETWEEN HEAT AND WORK

- 1) Both are recognized at the boundary of the system as they cross it, therefore both heat and work are boundary phenomena.
- (2) Both are functions. They are represented by a path followed during the process.
- (3) Both have inexact differentials. are represented by δQ and δW .
- (4) Both are associated with a process, not a state. Therefore, unlike properties heat or work has no meaning at a state.
- 5) A system may have energy, but not heat or work, because heat and work are transient phenomena.

Dissimilarities between Heat and Work

- 1) Heat is low-grade energy, whereas the work is high-grade energy.
- 2) Heat transfer takes place due to temperature difference only, while work transfer may take place due to any potential difference in pressure, voltage, height, velocity, temperature etc.
3. A stationary system cannot do work, while such a restriction is not imposed on heat transfer.
4. The entire quantity of work can be converted into heat or any other form of energy, while conversion of the entire quantity of heat into work is not possible.
- 5) All the forms of energy interaction are work interaction except energy interaction due to temperature difference.
- 6) Area under P-V provides work ~~interaction~~ interaction and area under T-S provides heat interaction.

FIRST LAW OF THERMODYNAMICS

LAWS OF THERMODYNAMICS

The laws of thermodynamics are as follows:-

- (1) Zeroth Law of Thermodynamics
- (2) FIRST Law of thermodynamics
- (3) Second Law of thermodynamics
- (4) Third Law of thermodynamics

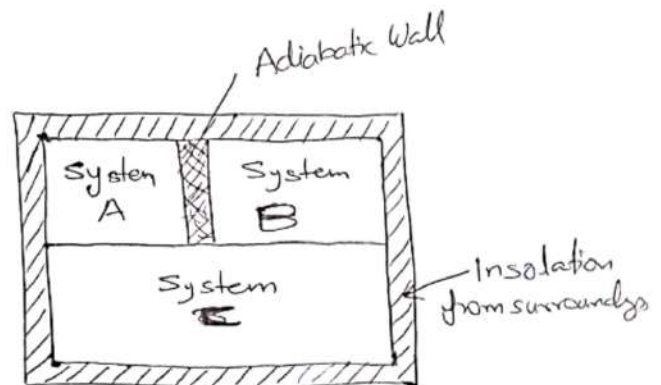
Zeroth Law of Thermodynamics

Zeroth law states that if two system are each in thermal equilibrium with a third system, they are also in thermal equilibrium with each other.

This statement is known as the Zeroth Law of Thermodynamics and is the basis of concept of temperature as well as the basis of all temperature measurement. The third body is called the thermometer.

ex

Consider two System A and B which are separated by an adiabatic wall and a third System C is in communication with both the systems as shown in fig.



If system A and B are individually in thermal equilibrium with third system C, then Systems A and B will also be in thermal equilibrium with each other, even though they are not in contact.

Three System in thermal Equilibrium

The zeroth law serves a basis for the validity of temperature measurement, by replacing the third system by a thermometer.

* SIGN CONVENTION:→

① Heat supplied to the system

$$Q_{\text{supplied}} = +ve$$

② Heat Rejected from the system

$$Q_{\text{Rejected}} = -ve$$

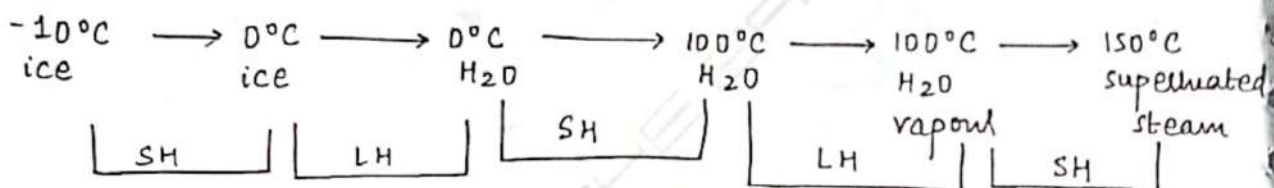
* TYPES OF HEAT:→

① Sensible heat → It is a form of energy interaction by the virtue of temperature difference.

② Latent heat → It is the amount of heat required to cause the phase change.

$$\text{Sensible heat} = mc\Delta T$$

$$\text{Latent heat} = m(LH)_{S/V/F}$$



* Ist LAW OF THERMODYNAMICS:→

OR

LAW OF CONSERVATION OF ENERGY:→

OR

JOULES LAW:→

OR

QUANTITATIVE LAW:→

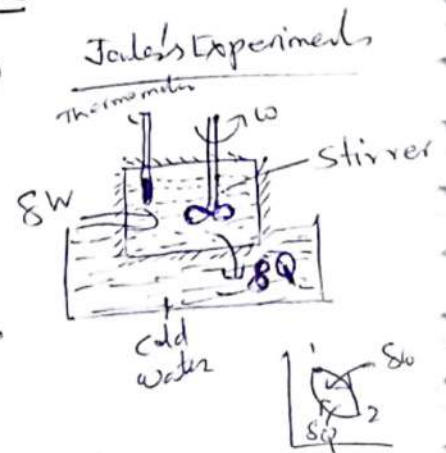
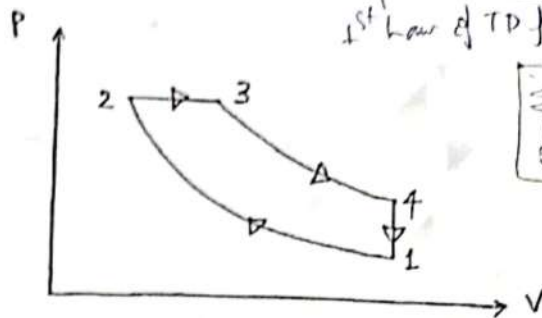
Statement $\rightarrow$ "Energy can neither be created nor be destroyed" (33)
 rather it converts from one form of energy to another form"
 OR $E_{\text{input}} = E_{\text{output}}$

"for a Closed System undergoing a cyclic process, the net heat interaction is equal to net work interaction when they are expressed in their own units"

$$\oint \delta Q = \oint \delta W \quad \text{--- (1)}$$

1st law of TD for a cycle

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



$$Q_{1-2} + Q_{2-3} + Q_{3-4} + Q_{4-1} = W_{1-2} + W_{2-3} + W_{3-4} + W_{4-1}$$

The equation no. (1) is applicable for both reversible process and irreversible process and cyclic process.

For power producing cycle, both net work interaction & net heat interaction are +ve and for power consuming cycles both net work interaction & net heat interaction are negative.

Q $\rightarrow$ What is the problem with eqn. 1?

Ans $\rightarrow$ The equation no. 1 is applicable only for a cycle or not applicable for a single process (like $1 \rightarrow 2$)

* CONSEQUENCES OF FIRST LAW OF THERMODYNAMICS $\rightarrow$

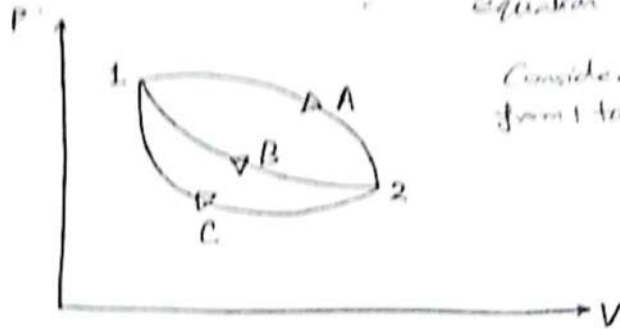
- (1) Heat interaction is a path function
- (2) Energy of the system is the property of [N.P.] the system
- (3) Energy of an isolated system is const.

- (4) Perpetual motion machine of first kind (PMM-1) is impossible.
- Perpetual - Continuous.

MOHIT CHOUKSEY

Scanned by CamScanner

① Heat transfer is a path function. In a cyclic process, the first law of thermodynamics is given by equation $\oint \delta W = \oint \delta Q$



Consider a system undergoing a change of state from 1 to 2, along a path A and

$$1-A-2-B-1 \rightarrow Q_{1-A-2} + Q_{2-B-1} = W_{1-A-2} + W_{2-B-1} \quad \text{--- (A)}$$

$$1-A-2-C-1 \rightarrow Q_{1-A-2} + Q_{2-C-1} = W_{1-A-2} + W_{2-C-1} \quad \text{--- (B)}$$

$$Q_{2-B-1} - Q_{2-C-1} = W_{2-B-1} - W_{2-C-1} \quad \text{--- (C)}$$

$$W_{2-B-1} - W_{2-C-1} \neq 0$$

$$Q_{2-B-1} - Q_{2-C-1} \neq 0$$

$$Q_{2-B-1} \neq Q_{2-C-1}$$

.....-hence, heat transfer is a path function, proved.....

② Energy is a PROPERTY

using above eqn. no. (C)

$$Q_{2-B-1} - Q_{2-C-1} = W_{2-B-1} - W_{2-C-1} \quad \text{--- (C)}$$

$$Q_{2-3} - W_{2-3} = Q_{2-C} - W_{2-C}$$

$$= Q_{2-D} - W_{2-D}$$

$$\delta Q - \delta W = dE \quad (\because \text{Point fn} \rightarrow \text{exact diff})$$

$$\boxed{\delta Q = dE + \delta W} \quad (2)$$

$$\boxed{\delta Q = dE + \delta W}$$

$$dE = d(\underbrace{KE + PE}_{\text{macroscopic form}} + \underbrace{U}_{\text{microscopic form}})$$

$U \rightarrow$  all forms of energy of molecule at m

$$\boxed{dE = dU}$$

$$\boxed{\delta Q = dU + \delta W} \quad (3) \quad (\text{Assumption :- Neglect KE, PE})$$

* Condition for Applying PdV work :-

- ① It should cross the Boundary.
- ② It should be a closed system.
- ③ It should be a reversible process.

$$\boxed{\delta Q = dU + PdV} \quad (4)$$

The eqn. (4) is applicable for a reversible process and closed system.

③ Energy of a isolated system is CONSTANT

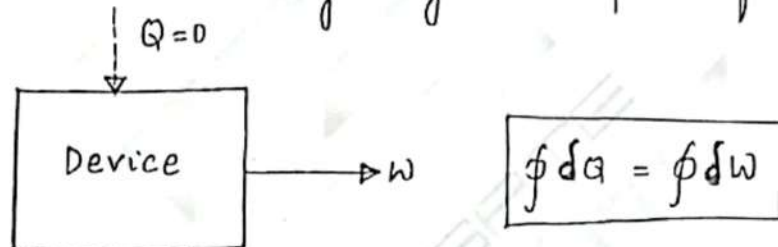
$$\delta Q = dE + \delta W$$

$$\boxed{dE = 0} \rightarrow \text{change in energy}$$

$$E_f - E_i = 0$$

$$\boxed{E_f = E_i} \rightarrow \text{energy constant}$$

④ PMM-1 $\Rightarrow$ Perpetual motion machine of 1st kind is impossible because it violates 1st law of thermodynamics. It is impossible to construct a device which produces work continuously without consuming any other form of energy.



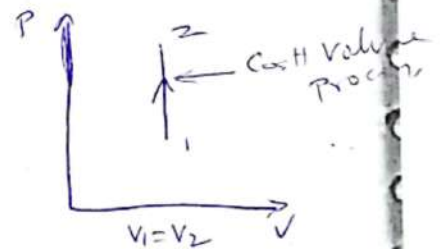
* EXPRESSION OF HEAT FOR DIFFERENT PROCESSES $\Rightarrow$

① Constant Volume Process ($V=c$) $\Rightarrow$

Apply first law to the process

$$dQ = dU + PdV$$

$$W = \int_1^2 PdV = 0 \Rightarrow dV = 0$$



$$V = c$$

$$dV = 0$$

$$\boxed{dQ = dU} \quad \text{①} \quad U_2 - U_1 = mC_v(T_2 - T_1)$$

$$\boxed{dQ = mC_v \Delta T} \quad \text{②} \quad Q = (U_2 - U_1) = mC_v(T_2 - T_1)$$

Compare eqn. ① & ②

$$\boxed{dU = mC_v \Delta T} \quad \leftarrow mC_v(T_2 - T_1) = (U_2 - U_1)$$

MOHIT CHOUKSEY

Scanned by CamScanner

① The expression $[dU = m C_v \Delta T]$ is applicable for all processes because it contains all point functions. (27)

② Internal Energy is a function of temperature only for ideal gas.

* **ENTHALPY** $\rightarrow$ It represents the total heat content of the system and the mathematical expression for the enthalpy is Imp. $H = U + PV$

Unit $\rightarrow$ Joule $\rightarrow$ Nm
 $M L^2 T^{-2}$

* **Specific Enthalpy** $\rightarrow$ It is a summation of specific internal energy and flow work.

$$h = \frac{H}{m} = \frac{U}{m} + P \left(\frac{V}{m} \right)$$

$$h = u + P v$$

flow work

* **Flow Work** $\rightarrow$ It is the amount of work which is required to displace a infinitely small fluid element into or out of the control volume is known as Flow work.

NOTE: ^a **Control Volume** is also known as Open system and the Boundary of Control Volume is known as Control surface.

MOHIT CHOUKSEY

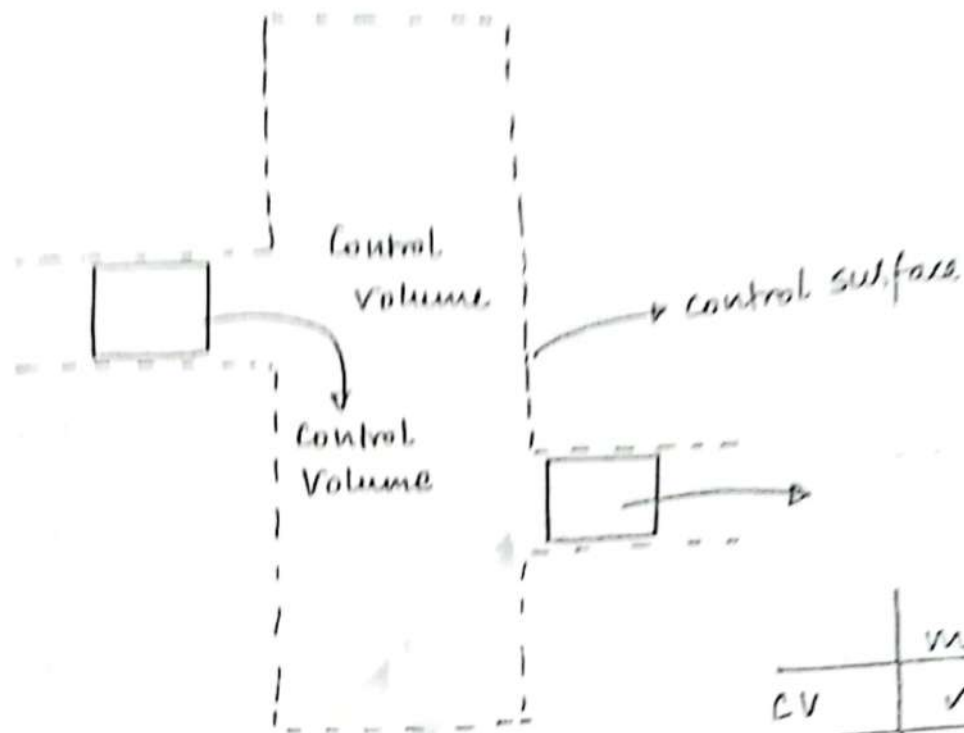
This PDF was downloaded from www.thegatehunt.com

Scanned by CamScanner



Scanned with OKEN Scanner

(b) Control mass is also known as close system.



	CV	CM
V, Z	✓	✓
E, Z	✓	✓



(a) Constant Pressure Process ($P=c$)

$P=c, dp=0$
Apply first law of thermodynamics

$$\delta Q = du + Pdv$$

$$P=c$$

$$H = U + PV$$

$$dh = du + Pdv + vdp$$

$$= dv + Pdv$$

$$dv = dh - Pdv$$

$$\delta Q = du + Pdv$$

$$\delta Q = dh - Pdv + Pdv$$

$$\delta Q = d(u + Pv) = dh$$

$$\boxed{\delta Q = dh} \quad \text{--- (1)}$$

$$\boxed{dQ = mC_p \Delta T} \quad \text{--- (2)}$$

on comp. (1) & (2) eqn $\Rightarrow$

$$\boxed{dH = mC_p \Delta T}$$

$$Q = (U_2 - U_1) + W$$

The work done

$$W = \int_1^2 Pdv = P(V_2 - V_1)$$

$$\therefore Q = (U_2 + U_1) + P(V_2 - V_1)$$

$$= U_2 - U_1 + PV_2 - PV_1$$

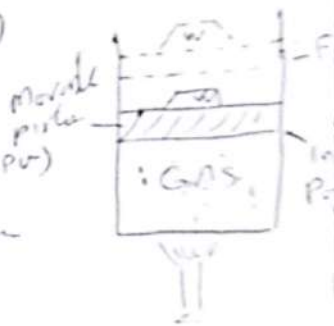
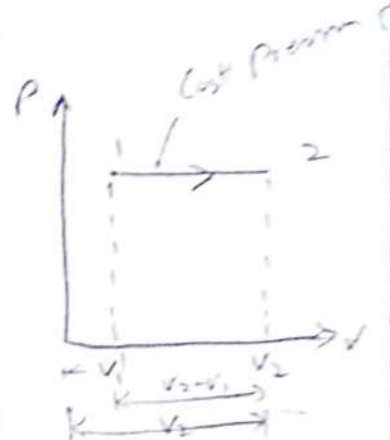
$$= (U_2 + PV_2) - (U_1 + PV_1)$$

$$= h_2 - h_1$$

$$Q = C_p(T_2 - T_1) \quad (h = u + Pv)$$

For mass m of working substance

$$Q = H_2 - H_1 = mC_p(T_2 - T_1)$$

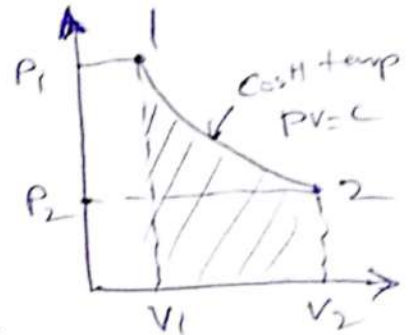


$$\boxed{Q = H = mC_p(T_2 - T_1)}$$

Note: → ① Enthalpy is a function of temperature only for C_v^* ideal gas

② The expression for $dH = mC_p dT$ is applicable for all processes because it contains all properties and all properties are point function.

③ **ISOTHERMAL PROCESS ($T = C$)** →



$T = C$ Applies First Law of Thermodynamics
 $U = f(T); dT = 0, du = 0$
 $\delta Q = du + Pdv \rightarrow 0$
 $\delta Q = Pdv = \delta W$
 $T = C$
 $dT = 0$
 $mC_v dT = 0$
 $du = 0$

$\delta Q = \delta W = C \ln \frac{V_2}{V_1}$
 $\propto \ln \frac{P_1}{P_2}$
 $Q = W = C \ln \frac{V_2}{V_1} = C \ln \frac{P_1}{P_2}$
 $Q = W = P_1 V_1 \ln \frac{V_2}{V_1}$
 $\text{or } Q = W = P_2 V_2 \ln \frac{V_2}{V_1}$

OBJ

$$dQ = dW = C \ln \frac{V_F}{V_I} \text{ or } C \ln \frac{P_I}{P_F}$$

$$C = P_I V_I = P_F V_F = mRT_I = mRT_F$$

④ **Adiabatic Process ($PV^\gamma = C$)** → It is a process in which there is no heat interaction between system and surrounding.

Example :- Insulated Tank. $\delta Q = 0$

Q → Prove that there is no heat interaction in adiabatic process?

Sol → $PV^\gamma = C$

* Relationship between C_p , C_v , R and γ :->

$$\frac{C_p}{C_v} = \gamma$$

$$C_p = \gamma C_v$$

$$R = C_p - C_v$$

$$R = \gamma C_v - C_v$$

$$R = (\gamma - 1) C_v$$

$$C_v (\gamma - 1) = R$$

OBJ

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

Previous Qn Proof :-> $dQ = dU + PdV$

$$dQ = m C_v dT + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$dQ = m C_v (T_F - T_I) + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$PV = mRT$$

$$\neq m C_v T$$

$$dQ = m \frac{R}{\gamma - 1} (T_F - T_I) + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$= \frac{P_F V_F - P_I V_I}{\gamma - 1} + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

MOHIT CHOUKSEY = Zero (0) www.thegatehunt.com

Scanned by CamScanner



Scanned with OKEN Scanner

Q. Prove that $[PV]^\gamma = c$ for a reversible adiabatic process.

Sol. $dU = nC_v dT$
 $dH = nC_p dT$

$$dQ = dU + PdV$$

$$dQ = nC_v dT + PdV$$

Rev. Adiabatic $\therefore dQ = 0$

$$nC_v dT + PdV = 0$$

$$nC_v dT = -PdV \quad \text{--- (1)}$$

$$H = U + PV$$

Diff.:-

$$dH = (dU + PdV) + VdP$$

$$dQ = dU + PdV$$

$$dH = dQ + VdP$$

imp $dQ = dH - VdP$

Rev. adiabatic $\therefore dQ = 0$

$$dH - VdP = 0$$

$$dH = VdP$$

$$nC_p dT = VdP \quad \text{--- (2)}$$

$$\frac{(2)}{(1)} \quad \frac{nC_p dT}{nC_v dT} = \frac{-VdP}{PdV}$$

$$\frac{C_p}{C_v} = \gamma = -\left(\frac{V}{dV}\right)\left(\frac{dP}{P}\right)$$

$$\frac{C_p}{C_v} = \gamma = -\left(\frac{V}{dV}\right)\left(\frac{dP}{P}\right)$$

$$\gamma \frac{dV}{V} = -\frac{dP}{P}$$

$$\int \frac{dP}{P} + \gamma \int \frac{dV}{V} = \int 0$$

$$\ln P + (\ln V)^\gamma = \ln C$$

$$\ln P + \gamma \ln V = \ln C$$

$$\ln P + \ln V^\gamma = \ln C$$

$$\ln PV^\gamma = \ln C$$

$$[PV]^\gamma = C$$

... HP. ...

⑤ POLYTROPIC PROCESS :→

$$dQ = dU + PdV$$

$$dQ = mC_v dT + \frac{P_I V_I - P_F V_F}{n-1}$$

$$= m \frac{R}{\gamma-1} dT + \frac{P_I V_I - P_F V_F}{n-1}$$

$$= m \frac{R}{\gamma-1} (T_F - T_I) + \frac{P_I V_I - P_F V_F}{n-1}$$

$$= \frac{P_F V_F - P_I V_I}{\gamma-1} + \frac{P_I V_I - P_F V_F}{n-1}$$

$$dQ = \frac{P_I V_I - P_F V_F}{n-1} - \frac{P_I V_I - P_F V_F}{\gamma-1}$$

$$= (P_I V_I - P_F V_F) \left[\frac{1}{n-1} - \frac{1}{\gamma-1} \right]$$

$$= (P_I V_I - P_F V_F) \left[\frac{\gamma - \gamma - n + 1}{(n-1)(\gamma-1)} \right]$$

$$= \left[\left(\frac{P_I V_I - P_F V_F}{n-1} \right) \right] \frac{(\gamma-n)}{(\gamma-1)}$$

OBJ

$$dQ = \left(\frac{\gamma-n}{\gamma-1} \right) W_{\text{CLOSED}}$$

$$\frac{P_I}{V_I^n} = \frac{P_F}{V_F^n}$$

Polytropic
 $dQ =$

$$dQ =$$

II ND LAW OF THERMODYNAMICS :-

(99)

OR

QUALITATIVE LAW :-

OR LAW OF DEGRADATION OF ENERGY :-

OR DIRECTIONAL LAW :-

Ist law of thermodynamics simply says that Total Energy is conserved. It does not provide any information regarding the direction of possible energy conversion. It is the second law of thermodynamics which provides the feasibility or direction of possible energy conversion through the concept of Entropy. and second law of thermodynamics defines the concept of energy on quality basis. Therefore, it is the II nd law of thermodynamics which is applied first in the numericals to find out the direction and then apply Ist law of Thermodynamics.

NOTE :- ① Heat is a low grade energy and work is a high grade energy.

Joule's statement

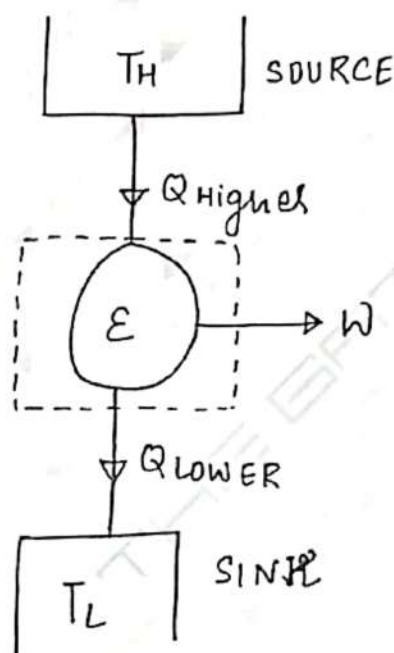
② Complete conversion of low grade Energy into high grade is not possible. But the complete conversion of high grade energy into low grade is possible.

99) * **THERMAL ENERGY RESERVOIR** :-

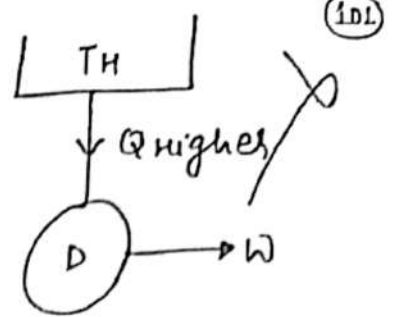
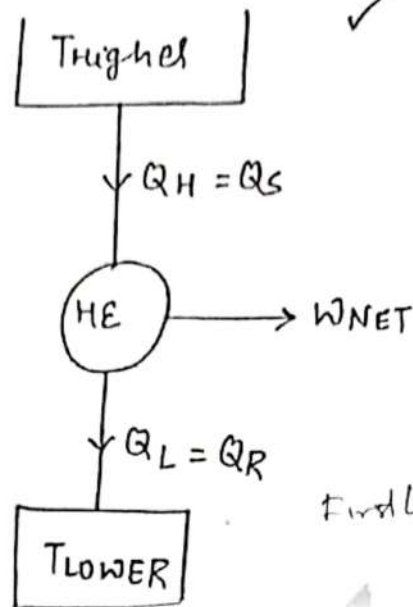
It is a reservoir of infinite heat capacity.

✓ **SOURCE** :- It is a supplier of Heat Energy without affecting its temperature.

✓ **SINK** :- absorber of Heat Energy without any change in its temperature.



* **Kelvin Planck's statement** → It is impossible to construct a device which operate in a cycle produces work continuously while interacting with single thermal Reservoir.



$$Q = W$$

$$\eta = \frac{W}{Q} \times 100 = 100\%$$

First Law $E_{in} = E_{out}$

$$Q_h = W + Q_L$$

$$W = Q_h - Q_L$$

$$\eta = \frac{O/P}{I/P} = \frac{W_{NET}}{Q_S} = \frac{Q_{NET}}{Q_S} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_S} = 1 - \frac{Q_L}{Q_H}$$

$$\% \eta = \left(1 - \frac{Q_L}{Q_H}\right) \times 100$$

Heat engine $\eta = 1 - \frac{Q_R}{Q_H}$
 valid for both reversible as well as irreversible process.

Thermodynamic Temp. scale of kelvin Temp. scale :- $Q \propto T$

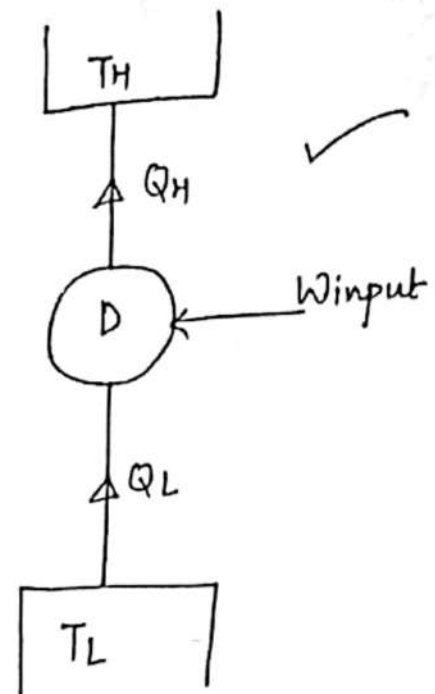
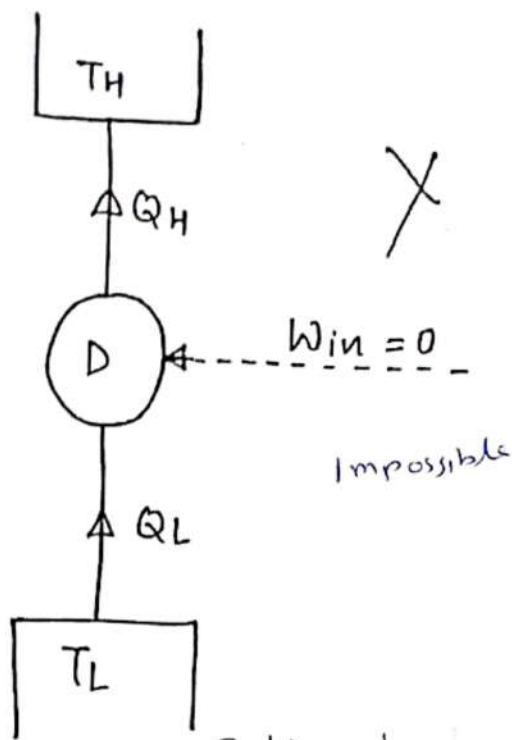
$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$

Valid only for reversible cycle.

IMP

$$\therefore \eta = 1 - \frac{T_L}{T_H}$$

* **Clausius statement** :- It is impossible to construct a device which operate in a cycle transfer heat from low temp. Reservoir to High Temp. Reservoir without consuming any other form of energy (work input = 0)



Refrigerator:

The amount of heat which must be extracted from a storage space in order to maintain lower temperature than surrounding.

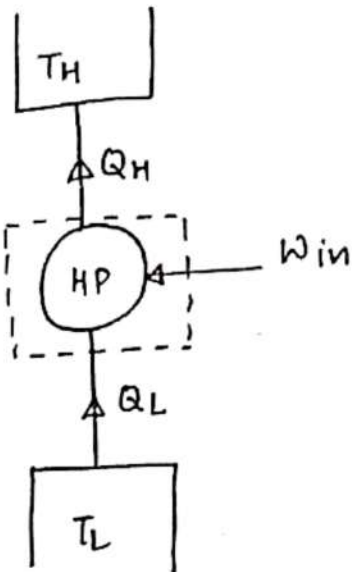
6/9/2016

COP (Coefficient of Performance) :-

OR

Heat Pump

EPR (Energy Performance Ratio) :- It is defined as the ratio of the desired effect to the work input.



$$COP_{HP} = \frac{DE}{W_{in}} = \frac{Q_H}{W_{in}}$$

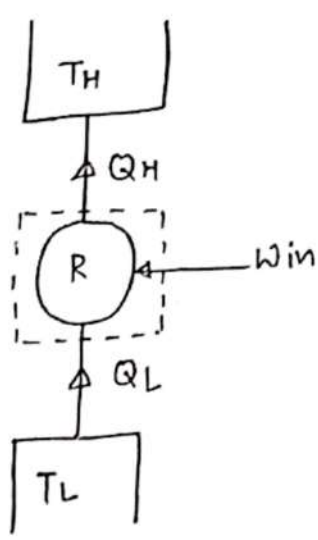
$$Q_L + W_{in} = Q_H$$

$$W_{in} = Q_H - Q_L$$

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L}$$

OBJ

$$COP_{HP} = \frac{T_H}{T_H - T_L}$$



$$\text{COP}_R = \frac{DE}{W_{in}} = \frac{Q_L}{W_{in}} = \frac{Q_L}{Q_H - Q_L}$$
$$= \frac{T_L}{T_H - T_L}$$

OBJ

$$\text{COP}_R = \frac{T_L}{T_H - T_L}$$

NOTE :- (a) Kelvin-Planck's statement provides the concept of work producing devices that is heat engine and clausius statement provides the concept of work absorbing devices that is Heat pump and Refrigerator.

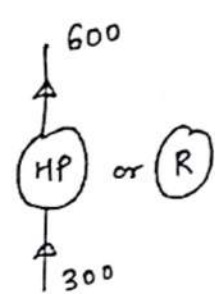
* Relationship between COP of Heat Pump and cop of Refrigeration:-

$$1 + \text{COP}_R = \frac{T_L}{T_H - T_L} + 1$$
$$= \frac{T_L + T_H - T_L}{T_H - T_L}$$

$$1 + \text{COP}_R = \frac{T_H}{T_H - T_L} = \text{COP}_{HP}$$

OBJ

$$(\text{COP})_{HP} = 1 + \text{COP}_R$$



Boiler

The function of a boiler is to generate steam at a desired pressure and temperature by transferring of heat produced by burning of fuel to water to change in steam.

Steam used in following works:

Power generation, Processing units, Heating purpose.

Fuel used: ^{Pulverised} Coal, oil, and gas

Water is supplied by centrifugal pump at a pressure slightly higher than desired pressure of steam to overcome pressure losses. Only phase is changed in the boiler. The heating in the boiler is done at const. pressure.

Good Boiler:

- It should be capable of generating the maximum quantity of steam at a required pressure and temp. and quality with minimum fuel consumption.
- It should be light in weight and should not occupy much space.
- It should be safe in working.
- Conform to the safety regulation laid down in the Boiler Act.
- All parts are easily accessible for inspection and repair.
- The design and construction of the component parts should be such that they can be easily dismantled and transported.
- To make the best use of the heat supplied, the boiler should have proper arrangement of circulation of water and hot gases.

Classification of Boiler

- | | |
|------------------------------------|----------------------------------|
| (1) Tube Content | (6) Position and number of drums |
| (2) Method of firing | (7) Nature of service |
| (3) Pressure of steam | (8) Fluid used |
| (4) Method of Circulation of Water | (9) Boiler shell material |
| (5) Nature of Draft | |

Tube Content

(1) Fire tube boiler - In the fire tube boiler the hot gases (flue gas) pass through the tubes and water surround them. (60% to 80% efficiency)

(1) Cochran (2) Lancashire (3) Cornish (4) Locomotive Boiler

(2) Water Tube Boiler: (80% - 95% efficiency)

In water tube boiler, water flows inside the tube and the hot flue gases flow outside the tubes.

(1) Babcock and Wilcox Boiler (2) Stirling boiler
(3) La Mont Boiler (high pressure) (4) Benson Boiler (5) Velox

(3) Low Pressure Boiler - below 80 bar
Lancashire, locomotive, Cochran, Cornish

(4) High Pressure Boiler - Above 80 bar
Babcock & Wilcox, La Mont, Velox, Benson power boilers.

Sub critical - below 220 bar, Super critical above 220 bar.

Boiler Material

Cast Iron - suitable for low pressure

Steel boiler - suitable for high pressure

Copper and Stainless steel - miniature type boiler.

Efficiency

Boiler Mountings: Boiler mountings are those machine components which are mounted over the body of the boiler itself for the safety of the boiler and for complete control of the process of steam generation.

(1) Two Safety Valve (2) Two water level indicator (3) Pressure gauge
(IV) Fusible plug (V) Steam stop valve (VI) Feed check Valve
(VII) Blow-off cock (VIII) Inspector's test gauge (IX) Min and Max Water

Ques (II) Method of Firing -

On the basis of method of firing, boilers are classified as

(a) Internally fired boiler -

In this boiler, the furnace region is provided inside the boiler shell and is completely surrounded by water cooled surface.
ex. Lancashire, Locomotive and Scotch boilers.

(b) Externally fired boiler -

In this boiler, the furnace region is provided outside the boiler. Its furnace region is simple and easy to construct.

ex - Babcock and Wilcox Boiler.

(III) PRESSURE OF STEAM - (a) Low Pressure Boiler

A boiler which generates steam at a pressure below 80 bar is called a low pressure boiler.

Example: Cochran, Cornish, Lancashire and Locomotive boiler.

(b) High Pressure Boiler :

A boiler which generates steam at a pressure higher than 80 bar is called a high pressure boiler.

Example: Babcock and Wilcox, Lamont, Velox, Benson etc.

(IV) METHOD OF CIRCULATION OF BOILER

(a) Natural Circulation - In natural circulation type of boilers, the circulation of water in the boiler takes place by natural convection current produced by the application of heat. Ex. Lancashire, Locomotive, Babcock and Wilcox Boiler etc.

(b) FORCED CIRCULATION → In the forced circulation type of boilers, the circulation in the boiler is not left to natural circulation alone but mechanical means (pumps) are used to increase the circulation. Ex: Lamont, Velox, etc.

(V) Nature of Service :-

- (a) Stationary Boilers - Boilers that are used for stationary plants are called stationary or land Boilers.
- (b) Portable Boilers - Boilers which can easily dismantled and transported from one place to another are called portable boilers.
- (c) Mobile Boilers - The boilers which are mobile on some carrier such as locomotive are called mobile boilers.

(VI) POSITION AND NUMBER OF DRUMS -

According to position, the boiler may be classified as (a) horizontal (b) Inclined (c) Vertical.

According to number of drums boilers may be classified as single or multi-drums.

(VII) NATURE OF DRAUGHT -

- (a) Natural Draught Boiler - In this, the draught is produced by natural circulation of air or gas.
- (b) Forced Draught boilers - The draught is produced by mechanical means such as fan etc.

(VIII) Heat Source :-

The heat source may be any of the following -

- (a) Combustion of solid, liquid or gaseous fossil fuels.
- (b) Electrical or nuclear energy
- (c) Hot waste gases which are by-products of other chemical processes.

(IX) Boiler Shell Material -

On the basis of materials used for shell, boilers are classified as follows:-

- (a) Cast iron
- (b) Steel boilers
- (c) Copper and Stainless steel boilers

(A) BOILER MOUNTINGS -

~~The~~

(I) SAFETY VALVE -

The function of the safety valve is to blow-off the steam from the boiler to the atmosphere when the pressure of the steam in the boiler exceeds the working pressure.

The principle of operation of safety valve depends on the fact that a valve depends on the fact that a valve is pressed against the seat through some agency such as spring, screw or strut by force or external weight.

When the ~~steam~~ steam force corresponding to boiler pressure acting under the valve exceeds the external force, the valve gets lifted off on its seat allowing some of the steam to escape until pressure is restored again.

There are four types of safety valves are -

- (i) Dead weight Safety Valve (iii) Lever Safety Valve
- (ii) Spring loaded Safety Valve (iv) High steam and low water safety valve.

(II) WATER LEVEL INDICATOR -

The function of the water level indicator is to show the level of water in the boiler.

Its upper end is connected to the steam space while the lower end is connected to the water space for pressure balance. It is mounted in front of the boiler from where it is visible to the attendant. Generally, two water level indicators are used in the boiler.

(III) PRESSURE GAUGE :

The function of a pressure gauge is to indicate the steam pressure of the boiler in bar gauge. It is fitted in front of the boiler such that the attendant can read it conveniently. A pipe is connected to the ~~space~~ steam space.

(IV) FUSIBLE PLUG -

~~The~~ The function of the fusible plug is to stop the fire in the furnace of the boiler when the water level in the boiler falls below the safe limit thereby preventing the boiler from explosion as a result of overheating of the fire-box crown-plate of fire tubes.

(extinguish)

(V) STEAM STOP VALVE

The function of the steam stop valve is to stop or allow the flow of steam from the boiler to the steam pipe or from the steam pipe to the turbine (or engine).

(VI) FEED CHECK VALVE -

The function of the feed check valve is to allow the feed water under pressure to pass into the boiler and to prevent any water ~~or~~ escaping back from the boiler in the ~~case~~ event of failure of the feed pump.

It is fitted to the boiler slightly below the working level of the water.

(VII) BLOW-OFF COCK

The function of Blow off cock is -

- (i) to remove periodically the sediments (mud, scale or other impurities) collected at the bottom of the boiler while the boiler is ~~work~~ working.
- (ii) to empty the boiler when it is to be cleaned or emptied.
- (iii) to lower the water level rapidly in case the level becomes too high.

(VIII) MAN HOLE

The function of manhole is to provide an opening through which a man can enter a boiler for cleaning and inspection purposes. The manhole is provided on the boiler shell at a convenient place. Generally it is oval in shape and cover is provided.

BOILER ACCESSORIES -

These are those boiler components which are installed either inside or outside the boiler to increase the efficiency of the plant and or to help in the proper working of the plant.

These are :-

- | | | |
|-------------------------------|-----------------|-------------------|
| (I) Air Preheater | (II) Economiser | (III) Superheater |
| (IV) Feed pump | (V) Injector | (VI) Steam trap |
| (VII) Pressure reducing Valve | | |

BOILER ACCESSORIES -

(I) AIR PRE HEATER -

Air preheater is the waste heat recovery device which is placed in the path of the waste flue gases going to the chimney thereby abstracting heat from the flue gases and transferring it to the air before its use for economical combustion and therefore it is called pre heater. It is placed near the chimney and above the economiser.

(II) ECONOMISER -

The function of economiser is to recover some of the heat from the heat carried away in the flue gases up the chimney or stack and to utilise it for heating the feed water supplied to the boiler.

It is placed in the path of the flue passes in between the exit from the boiler and entry into the chimney. Therefore the temperature of feed water is raised with the use of an economiser.

(III) SUPERHEATER -

It is used to heat up ~~feed~~ the steam above saturation temperature or desired temperature. It is a surface heat exchanger located in the passage of hot flue gases.

By this way the wet steam takes heat from the flue gases and first get dried at the same temperature and pressure and then, its temperature at the same pressure. In a large installation, the super heater may be placed in an independent fire furnace.

(1) Convective Superheater (2) Radiant Superheater (3) Combination Superheater.

(IV) ECONOMISER -

Used to heat up feed water by utilizing the heat of waste flue gases. It recovers some of the heat from the heat carried away in the flue gases up the chimney and to utilise it for heating the feed water supplied to the boiler.

It is placed in the path of the flue passes in between the exit from the boiler and entry into the chimney.

(V) FEED PUMP -

Used to force the water into boiler.

The function of the feed pump is to pump the feed water to the boiler at pressure slightly higher than required steam pressure to overcome pressure losses (about 10 to 15%).

Three types of feed pumps commonly used are (1) reciprocating pump (2) Rotary pump (3) Injector.

STEAM TRAP -

The function of Steam trap is to drain off water resultly from steam to ~~ess~~ escape through it. It is fixed in the steam pipe near the engine or turbine.

It is of two types:

(1) Bucket or float type (11) Thermal Expansion type.

STEAM SEPARATOR -

The function of Steam separator is to separate suspended water particles carried by steam on its way from the boiler to the engine or turbine.

In steam separator, the steam from the boiler enters the steam separator, through a flange and courses down. During its passage down it strikes the baffles causes the particles having greater density and hence greater inertia to fall to the bottom of the separator. Water is collected at the bottom which is drained out through out by the drain cock and the drain pipe.

PRESSURE REDUCING VALVE -

The function of a pressure reducing valve is to maintain constant pressure on its delivery side of the valve irrespective of fluctuating demand of steam from the boiler.

This is achieved by throttling of steam while passing through the pressure reducing valve. It is generally used in low steaming capacity boilers, where it is difficult to maintain constant delivery pressure, with fluctuating demand. In such boilers, steam is generated at a higher rated pressure, ~~with fluctuating demand~~ than required by the prime movers.

- (1) Dead weight safety valve (2) Spring loaded " " (3) High steam and

DRAUGHT

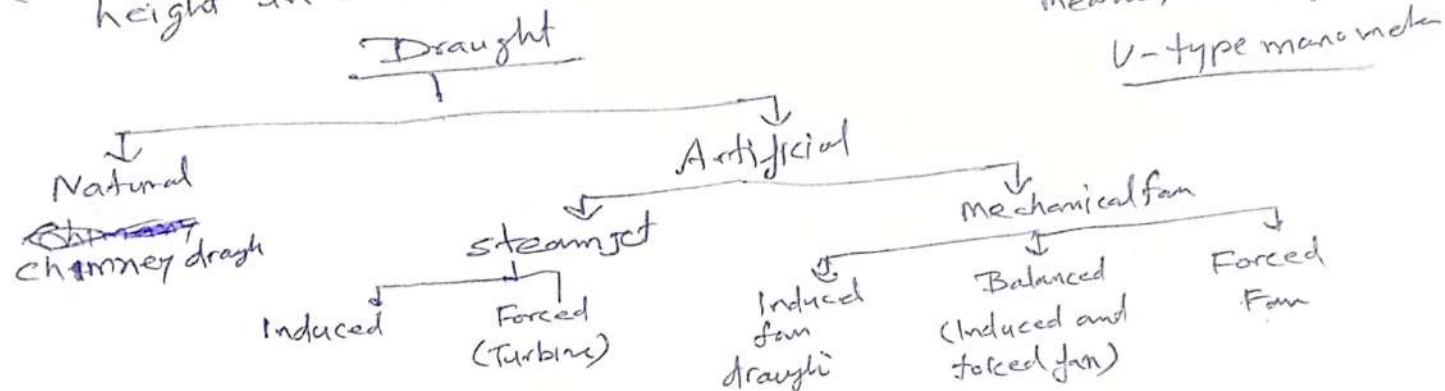
Draught is defined as small pressure difference causing flow of air and gases (in and out) through boiler.

It is essential to supply a sufficient quantity of air to support combustion in boiler and to remove the products of combustion.

This is done by producing a draught.

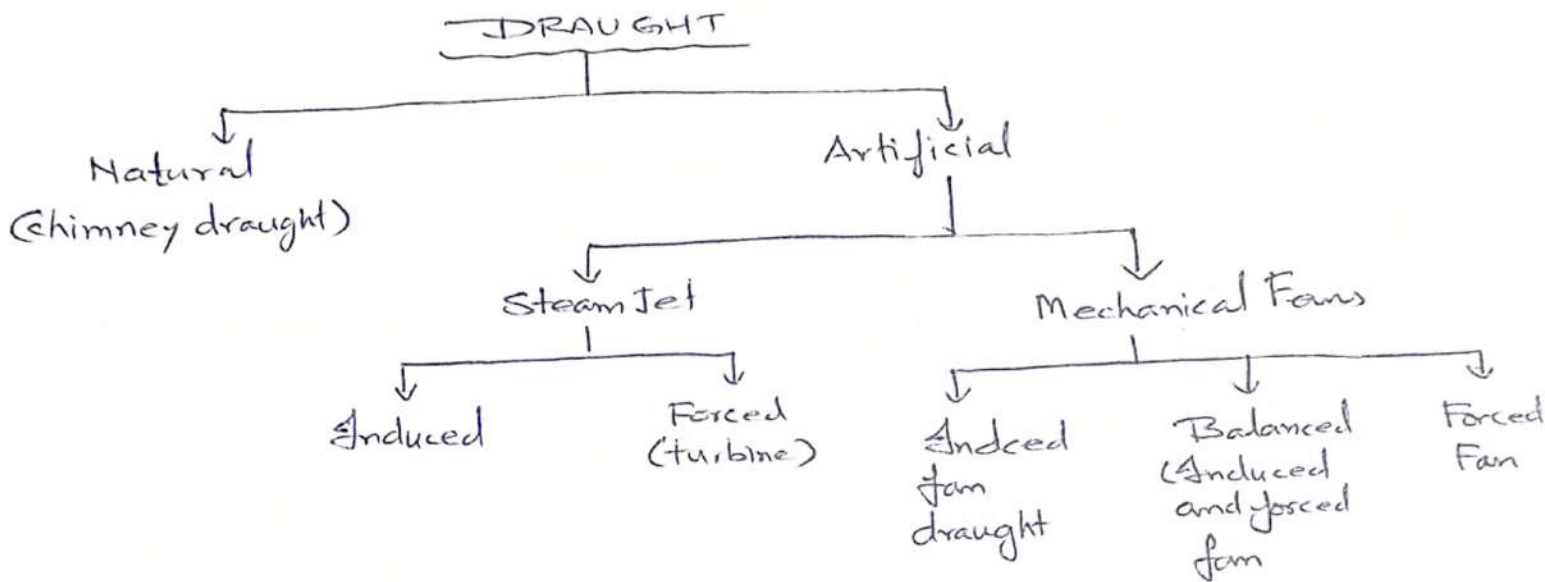
Draught producing equipment is designed to:

- (1) create a ~~different~~ differential pressure sufficient to allow the desired volume of air flow into the furnace at the required velocity.
- (2) to overcome the resistance of passages in the boiler
- (3) To discharge gases (products of combustion) at a sufficient height in order to avoid pollution to ~~atmosphere~~ atmosphere.



TYPES OF DRAUGHT-

There are mainly two types of draught commonly in use. Their classification and sub-classification are given below:-



1) NATURAL DRAUGHT (CHIMNEY DRAUGHT)

It is defined as the difference between the pressure of a column of hot gases in the chimney or stack and an equal column of cold outside air.

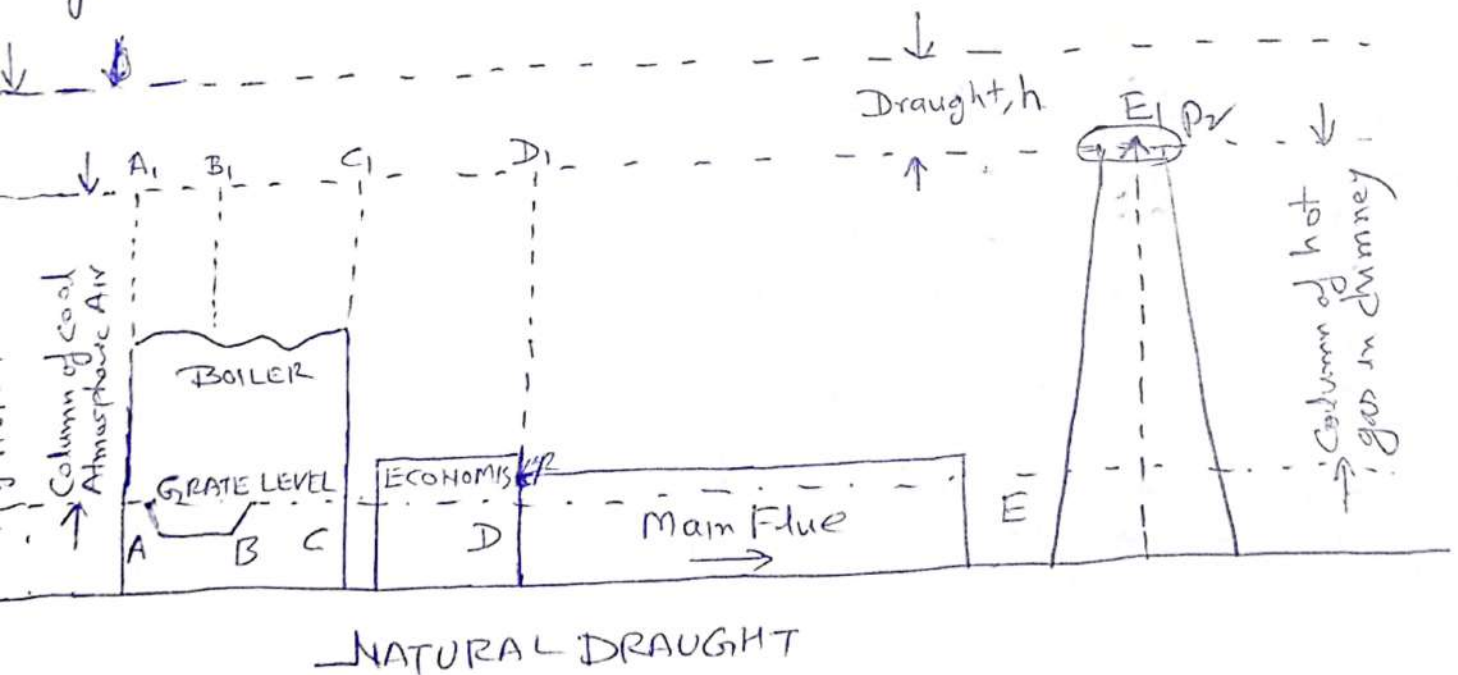


Figure shows Natural Draught. First consider the case when the fire is not lighted in the boiler. At the grate level the atmospheric pressure, say P_1 , at all points as A, B, C, D and E is the same. Let H be the Height of the chimney. The atmospheric pressure is also same, hence pressure P_2 at the top of chimney is lower than pressure P_1 at the grate because of difference in altitude due to the height of chimney.

Now consider the case when the fire is lighted and the chimney is filled with hot gases due to combustion. In this case also, the atmospheric P_1 at the grate level, outside the boiler, in the ash pit and P_2 at the top of the chimney do not alter. But at the base of the chimney, the pressure P_3 is the sum of pressure P_2 at the chimney and the pressure due to hot column H of gases. It is to be noted that the pressure P_1 is the sum of pressure P_2 and the pressure due to cold column of air H . Thus $P_2 + \text{pressure due to cold column } H > P_2 + \text{pressure due to hot column, } H$. In other words, we can say that pressure at the grate due to cold column H is greater than pressure at the chimney base due to hot column H .

The above analysis shows that there exists a difference in static pressure between the ash pit at the grate and at the chimney base, even though they are at the same height. This difference in pressure is called static draught.

It is equivalent to height h of the hot gas column expressed in mm of H_2O as shown in fig.

This draught enables air to rush from the ash pit through the grate via the economiser and the flue to the chimney base and removes product of combustion. This static pressure difference decreases along the height of the chimney and is zero at the top of the chimney because of gases (product of combustion) diffuse in the atmospheric air.

LIMITATIONS OF CHIMNEY DRAUGHT

- (1) Chimney draught is not suitable when the rate of fuel burning required is to be very high.
- (2) It is costlier than artificial draught
- (3) It cannot be controlled because it depends upon the atmospheric temperature.

9. (iv) The flow of air through the grate and furnace is not uniform.
(v) It produces comparatively less draught.
(vi) Rate of combustion is low.
(vii) Air flow cannot be regulated according to the ~~following~~ changing requirements.
(viii) Fuel consumption is more, About 15% more fuel is consumed for the same amount of work.

SELECTION OF BOILER -

While selecting a boiler the following factors should be considered:

- 1) The working pressure and quality of steam required. (~~also~~ whether wet or dry or superheated)
- 2) Steam generation rate
- 3) Floor area available
- 4) Accessibility for repair and inspection.
- 5) Comparative initial cost.
- 6) Erection facilities
- 7) The fuel and water available.
- 8) Operating and maintenance cost.

ARTIFICIAL DRAUGHT -

When we create natural draught, it is dependent of climatic conditions. In order to obtain a draught which is independent of climatic conditions and which at the same time requires a chimney of lower height, we use Artificial Draught.

Large steam generators which need to handle, a tremendous volume of gas cannot run on natural draught, they require artificial draught.

Various methods of Artificial Draughts are.

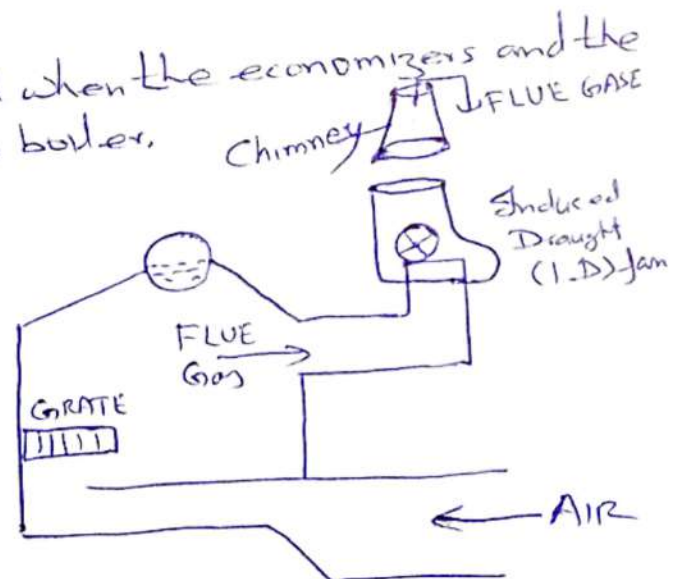
- (1) Induced ~~Dr~~ Draught (Fan type)
- (2) Forced Draught (Fan type)
- (3) Balanced Draught
- (4) Steam Jet Draught

(1) INDUCED DRAUGHT (Fan Type)

In the induced draught system, a fan is located at or near the base of the chimney as shown in fig. The fan may have either steam or electricity drive. The function of fan is to reduce the pressure over the fuel bed rather than that of atmospheric and, thus create a partial vacuum on its suction side. This partial vacuum created in the furnace and flues draw the products of combustion from the body of the flue and they pass up to the chimney.

This draught is generally used when the economizers and the air preheaters are used in the boiler.

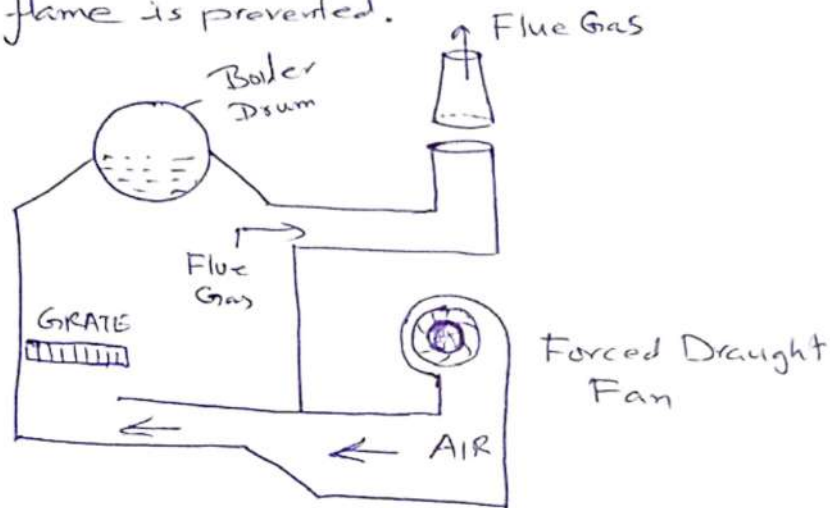
The fan should be positioned such that the temperature of the gas handled is at its lowest. The best place to locate it is after preheater.



FORCED DRAUGHT (FAN TYPE)

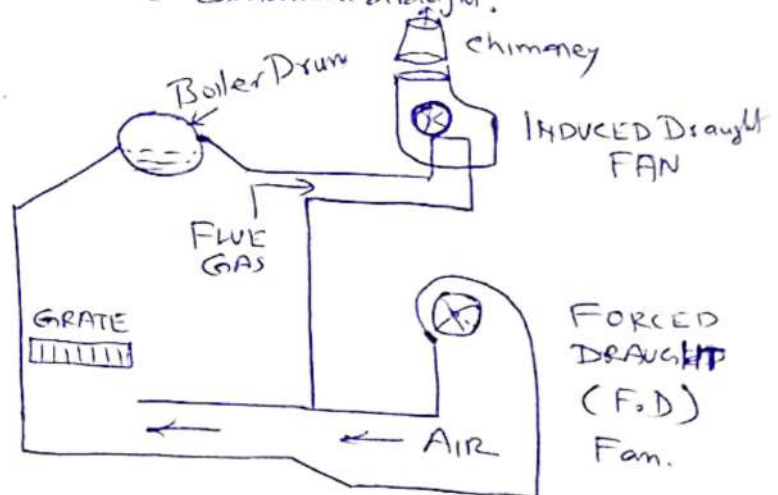
In this system, a fan or a blower is installed near the base of the boiler to force the air, under pressure, through the coal bed and other passages, like furnace, flues, air heater etc. to the chimney.

The furnace enclosure is securely sealed to prevent leakage of smoke and flames since the air inside is above atmospheric pressure. In order to shut off the draught automatic dampers are also fitted, so that when the door is opened, the outward rush of smoke and flame is prevented.



BALANCED DRAUGHT -

The balanced draught is a combination of the induced and forced draught system. The forced draught fan forces air at a sufficient pressure to pass through the fuel bed either direct or through the air heater where the induced draught fan draws the flue gases through the boiler flues, economiser and preheater and, then discharges them to the top of the chimney. The pressure in the furnace is balanced, hence the name balanced draught.



STEAM JET DRAUGHT -

In this system, the steam passes through a jet to ~~produce~~ produce a draught, thus the name steam jet draught.

It may be induced or forced draught depending upon where the steam jet is located to produce the draught. When the steam jet is directed into the smoke box near the ^{exhausting} stack, the air is induced through the flues, the grate and ash pit to the smoke box. But when the jet is installed before the grate, the draught becomes the forced draught and the air is forced through the fuel bed, furnace and flues to the chimney.

The steam jet draught has following advantages:-

- 1) Very Simple and economical
- 2) Occupies minimum space.
- 3) Requires very little attention.
- 4) Several ~~or~~ classes of low grade fuels can be used with this system.

DIFFERENCE BETWEEN FIRE-TUBE & WATER TUBE BOILER

FIRE-TUBE

- 1) Hot-gases inside the tubes and water is outside the tubes.
- 2) Generally internally fired.
- 3) Rate of steam production is lower.
- 4) Not suitable for large power plant.
- 5) Lesser risk on explosion due to lower pressure.
- 6) For a given power it occupies more floor area.
- 7) Construction is difficult.
- 8) Transportation is difficult.
- 9) Treatment of water not necessary.
- 10) Various parts not so easily accessible for cleaning, repair and inspection.
- 11) Require less skill for efficient and economic working.

WATER-TUBE

- 1) Water is inside the tubes and hot gases on the tubes.
- 2) Generally externally fired.
- 3) Rate of Steam production is higher.
- 4) Suitable for large power plants.
- 5) More risk on bursting due to high pressure.
- 6) For a given power it occupies less floor area.
- 7) Construction is simple.
- 8) Transportation is simple.
- 9) Treatment of water more necessary.
- 10) Various parts are more accessible.
- 11) Require more skill and ~~a~~ careful attention for working.

BOILER PERFORMANCE

Boiler performance can not be defined by single parameter is not sufficient to describe the complete performance of boiler. Steam production rate and its quality (wet, saturated or superheated) varies with ~~the~~ different feed water temperature, different boiler pressure, different saturation temperature. Under such ~~conditions~~ different conditions, it is very difficult to compare two boilers. Common basis for comparing the performance of two or more boilers, the standard conditions adopted are as

- (I) Feed water is supplied at the boiler at 100°C
- (II) Evaporation of steam takes place at 100°C
- (III) The steam generated is just dry and saturated.

Depending upon the operating conditions any one of the following terms or combination of them may be used to describe the performance of the boiler —

- (I) Equivalent evaporation
- (II) Boiler Efficiency
- (III) Overall Efficiency
- (IV) Combustion Rate
- (V) Combustion Space
- (VI) Heat liberated.

Equivalent Evaporation —

It is defined as the amount of dry saturated steam that could be generated by the boiler per unit time from ~~1~~ One kg of water at 100°C to ~~steam at~~ dry and saturated steam at 100°C at std. atmospheric pressure of 1.013 bar. (i.e. latent heat of steam at atmospheric pressure)

It is usually, written as "from and at 100°C ".
The quantity of heat supplied by the boiler to each kg of steam is 2257 KJ under the above mentioned condition.

Consider a boiler generating M_{as} Kg of steam per hour at a pressure P and temperature T from water with enthalpy h .

Let M_{as} = Actual evaporation, Kg of steam per hour or Kg of steam / Kg of fuel.

M_{es} = Equivalent Evaporation, Kg of steam per Kg of fuel or $\frac{\text{Kg of steam per hour}}{\text{Kg of fuel}}$.

h = enthalpy of steam at the working pressure, KJ/Kg

h_f = ~~the~~ enthalpy of feed water KJ/Kg

h_{fg} = latent heat of steam at 1.013 bar = 2257 KJ/Kg

F = Factor of evaporation.

Let h_{fi} = Specific enthalpy of water at given feed water temperature.
 Then heat absorbed by water at actual working pressure
 is given by $= m_{as} (h - h_{fi})$ KJ

The equivalent evaporation from the definition is obtained by

$$m_{es} = \frac{m_{as}(h - h_{fi})}{2257} \quad \frac{\text{Kg}}{\text{kg of coal burnt}}$$

Where $h = h_f + x h_{fg}$ for wet steam at pressure (p) and dryness (x).

$h_g = h_f + h_{fg}$ for dry saturated steam at pressure (P)

$h = h_f + h_{fg} + C_p (T_{sup} - T_s)$ for steam at pressure P and dryness (x).

The term $\left[\frac{h - h_{fi}}{2257} \right] = F$ is termed as the factor of evaporation and it is always greater than unity.

This equation is a fair indication of performance but it suffers from the defect that quality of the fuel is not taken into consideration.

BOILER EFFICIENCY -

It is defined as the ratio of heat energy utilised by the feed water for its conversion into steam to the generation of the heat energy supplied by the fuel during the same period. Boiler efficiency is also a tool to know the performance of a boiler.

$$\eta_{\text{boiler}} = \frac{\text{Heat utilised by feed water, KJ/hour}}{\text{Heat supplied by fuel, KJ/hour}}$$

$$= \frac{m_{as}(h - h_{fi})}{M_f \times C.V}$$

Where,
 m_{as} = Actual mass flow rate of steam, (Kg/h)
 h = final enthalpy of steam, (KJ/Kg)
 h_{fi} = Initial enthalpy of feed water, (KJ/Kg)
 M_f = mass of fuel consumed, (Kg/h)
 $C.V$ = Calorific value of fuel (KJ/Kg of fuel)

Boiler efficiency of modern boiler varies from 80% to 95%.
 It is the measure of various heat losses in boiler.

Loss of heat of boiler-

It is defined as the portion of heat generated by the combustion of fuel which is not utilised in the production of steam. The source of this losses depends on the following factors:-

- (a) Hot flue gases discarded through chimney
- (b) Radiation from the furnace to the outside
- (c) Incomplete combustion
- (d) Presence of moisture in the fuel
- (e) Unburnt fuel going to ashpit
- (f) Boiler design
- (g) Properties of characteristics of fuel burnt

EVAPORATIVE CAPACITY-

Evaporative capacity of boiler is measured in terms of steam generated per unit time i.e. in an hour or mass of steam generated per unit grate area or mass of steam generated per unit furnace volume.

$$\begin{aligned}\text{Evaporative Capacity} &= \frac{m_s}{\text{Area of grate}} \quad \text{Kg/m}^2 \text{ of per unit grate area/hr} \\ &= \frac{m_s}{\text{Volume of furnace}}\end{aligned}$$

UNIT-V

UNIT - 5

Definition related to Internal Combustion engine. In this a piston that reciprocates within a cylinder fitted with two valves and a spark plug or fuel injector.

The figures are labelled with some special terms, defined below :-

1. BORE - It is the internal diameter of the cylinder of the reciprocating engine. It is denoted by (d) and expressed in mm.
2. STROKE - It is the linear distance through which the piston travels between the top dead centre (TDC) and the bottom dead centre (BDC) in the cylinder. It is also called stroke length. It is denoted by L and expressed in mm.
3. SWEEP VOLUME - It is also called piston displacement volume or stroke volume. It is the volume created or displaced by the piston during its one stroke travel i.e., travel of the piston from one dead centre to other dead centre. It is denoted by V_s and calculated for one cycle as,

$$V_s = \left(\frac{\pi}{4}\right) d^2 L$$

(4). Cubic Capacity, or Engine Capacity:

It is the product of swept volume of a cylinder and the number of cylinder in an engine, i.e. total volume displaced in each cycle of an engine. For K number of cylinders.

$$\text{Cubic Capacity} = K V_s$$

- 5) CLEARANCE VOLUME - It is the volume left in the cylinder when the piston reaches the top dead centre. It is denoted by V_c .

- 6) TOTAL VOLUME - It is the maximum volume in the cylinder and is the sum of swept volume and clearance volume. It is denoted by V_1 .

$$V_1 = V_s + V_c$$

7) COMPRESSION RATIO -

It is the ratio of maximum possible volume to clearance (minimum volume in the cylinder). It is denoted by (r) and expressed as

$$r = \frac{V_{\max}}{V_{\min}} = \frac{V_s + V_c}{V_c} = \frac{\text{Full Cylinder Volume}}{\text{Clearance Volume}}$$

8) Clearance Ratio -

It is the ratio of clearance volume to swept volume. It is usually kept 3-5% of the swept volume. It is denoted by C and expressed as,

$$C = \frac{V_c}{V_s}$$

9) Cut-off Ratio - It is the ratio of cut-off volume to swept volume. It is denoted by ρ . This term is used in Diesel cycle and dual-cycle engines.

10) Expansion Ratio - It is the ratio of maximum volume to minimum volume during expansion in the cylinder. It is denoted by r_e .

11) Dead Centres - There are two fixed positions in the cylinder between which the piston reciprocates. The uppermost position is called top Dead centre (TDC), while the bottom-most position is called the bottom dead centre (BDC).

12) CHARGE - It is air-petrol mixture for petrol engines and only air for Diesel engines, which is introduced during suction stroke of the engine.

13) MEAN EFFECTIVE PRESSURE - (P_m)

It is a hypothetical average pressure, which if acted on the piston during the entire power stroke, will produce the same power output as produced during the actual cycle.

Net work done in a Cycle

$$W_{\text{net}} = P_m \times (\text{piston area}) \times (\text{stroke}) \\ = P_m \times A \cdot L = P_m \times V_s \quad \text{KJ}$$

$$\therefore P_m = \frac{W_{\text{net}}}{V_s} = \frac{\text{workdone per cycle}}{\text{Stroke Volume}}$$

$$\text{Workdone per minute} = P_m \cdot L \cdot A \cdot n$$

(n is the number of cycle per minute)

③

$$\text{Indicated Power} = \dot{W}_p = \frac{P_m L A n}{60} \text{ kW} \quad \text{where } P_m \text{ is in } \text{KN/m}^2 \text{ or kPa.}$$

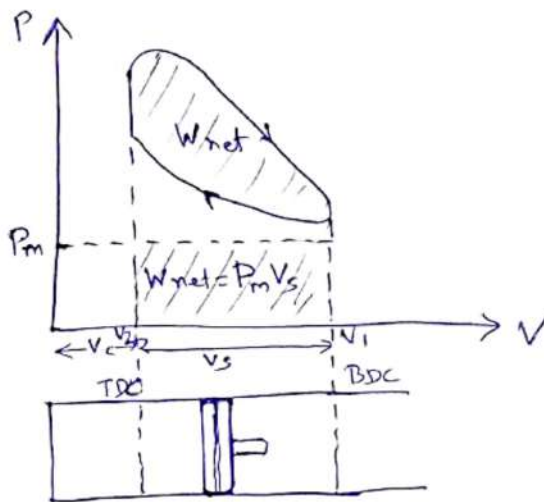
$$\text{Indicated Power} = \dot{W}_p = \frac{100 P_m L A n}{60} \text{ kW}$$

Where P_m is in bar, $n =$ number of cycle per minute,

$n = \frac{N}{2}$ for four strokes engines,

$n = N$ for two strokes engines, $N =$ revolution per minute.

The mean effective pressure is used to compare the output of similar engines of different sizes.



The net work of a cycle is a product of the mean effective pressure and swept volume.

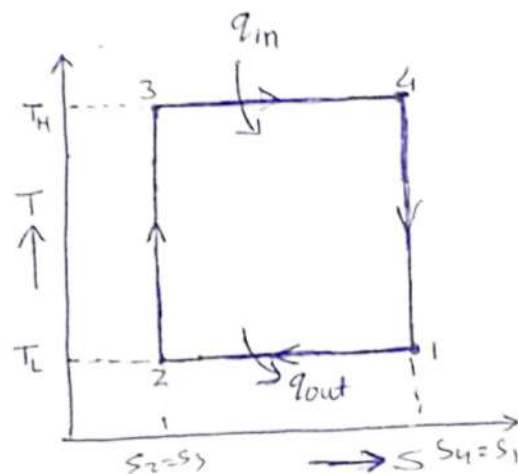
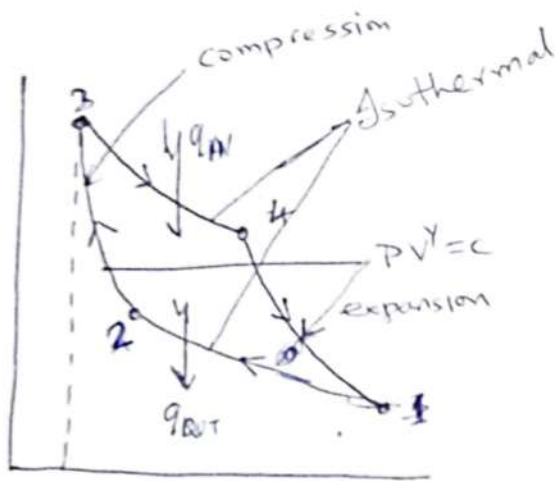
CARNOT CYCLE

Carnot cycle is an ideal cycle, which is not possible in practice and has the maximum efficiency compared to other cycle.

Through the analysis of Carnot cycle does not give the performance of actual cycle, it however permits the designer to arrive at the maximum possible efficiency that can be ~~attain~~ obtained in any heat engine under given conditions.

The cycle is represented on $p-v$ and $T-s$ diagram shown in fig. It consists of ~~simple~~ four simple operations ~~namely~~ namely:

- (a) Isothermal Expansion
- (b) Adiabatic Expansion
- (c) Isothermal compression
- (d) ~~Isothermal~~ Adiabatic compression.



It consists of four reversible processes -

- 1) Isothermal heat addition
- 2) Isentropic expansion
- 3) Isothermal heat rejection
- 4) Isentropic compression

From fig.

Heat supplied per Kg of air during isothermal process - (3-4)

$$q_{in} = T_H (S_4 - S_3)$$

Heat rejected per Kg of air during isothermal process 1-2

$$q_{out} = T_L (S_1 - S_2)$$

Process 2-3 and 4-1 are isentropic processes

$$\therefore q_{2-3} = 0 \text{ and } q_{4-1} = 0$$

$$\text{and } s_1 = s_4 \text{ and } s_2 = s_3$$

The network done per kg of air in the cycle

$$W_{\text{net}} = \Sigma q = q_{\text{in}} - q_{\text{out}}$$

$$= T_H (s_1 - s_2) - T_L (s_1 - s_2)$$

$$= (T_H - T_L) (s_1 - s_2)$$

$\therefore$ Thermal efficiency of Carnot Cycle -

$$\eta_{\text{Carnot}} = \frac{W_{\text{net}}}{q_{\text{in}}} = \frac{(T_H - T_L)(s_1 - s_2)}{T_H (s_1 - s_2)}$$

$$= \frac{T_H - T_L}{T_H}$$

$$\boxed{\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H}}$$

In actual practice, the transfer of heat energy at constant pressure is very difficult to achieve, because it would require very large heat exchangers and the heat would be transfer with extremely slow rate to be isothermal.

Further, the isentropic processes are very fast processes, therefore it is impractical to design an engine which would operate with very fast and extremely slow processes in succession thus no thermodynamic cycle closely approximate Carnot Cycle.

~~Thermal efficiency of Carnot~~

From the equation, ~~states~~ that if temperature T_L decreases, efficiency increases and it becomes 100% if T_L becomes absolute zero which, of course is impossible to attain.

Further, it is not possible to produce an engine that should work on Carnot's cycle as it would necessitate the piston to travel very slowly during first portion of the forward stroke (isothermal expansion) and to travel more quickly during the remainder of the stroke (adiabatic expansion) which however is not practicable.

Q A Carnot engine working between 400°C and 40°C produces 130 kJ of work. Determine

- (i) The engine thermal ~~efficiency~~ efficiency
- (ii) The heat added
- (iii) The entropy changes during heat rejection process.

Solution-

Given that,

$$\text{Temperature } T_1 = T_2 \\ = 400 + 273 = 673 \text{ K}$$

$$\text{Temperature } T_3 = T_4 = 40 + 273 = 313 \text{ K}$$

$$\text{Work produced } W = 130 \text{ kJ}$$

(i) Engine thermal efficiency, η_{th}

$$\eta_{th} = \frac{673 - 313}{673} = 0.535 \text{ or } 53.5\%$$

(ii) Heat added

$$\eta_{th} = \frac{\text{Work done}}{\text{Heat added}}$$

$$0.535 = \frac{130}{\text{Heat added}}$$

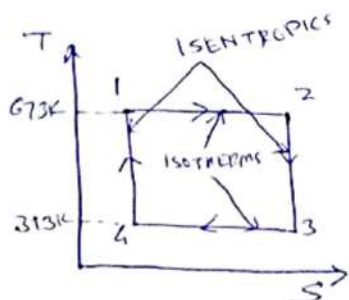
$$\therefore \text{Heat added} = \frac{130}{0.535} = 243 \text{ kJ}$$

(iii) Entropy change during the heat rejection process ($S_3 - S_4$)

$$\text{Heat rejected} = \text{Heat added} - \text{Work done} \\ = 243 - 130 = 113 \text{ kJ}$$

$$\text{Heat rejected} = T_3(S_3 - S_4) = 113$$

$$S_3 - S_4 = \frac{113}{T_3} = \frac{113}{313} = 0.361 \text{ kJ/K}$$



OTTO CYCLE

The Otto cycle is an ideal air standard cycle for the gasoline (petrol) engine, gas engines and ~~sp~~ high speed engines. It is the standard of comparison for internal combustion engines.

The operations of the Otto cycle is shown in fig. and the p-v and T-s diagrams are shown in fig. The Otto cycle consists of four processes:

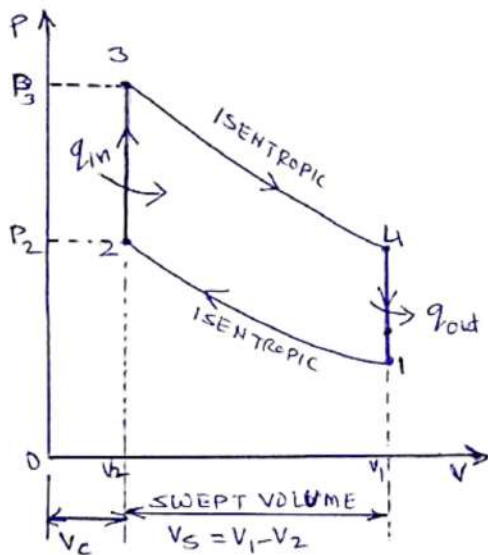
Process 1-2 Isentropic Compression

Process 2-3 Reversible const. Volume heat addition

Process 3-4 Isentropic expansion

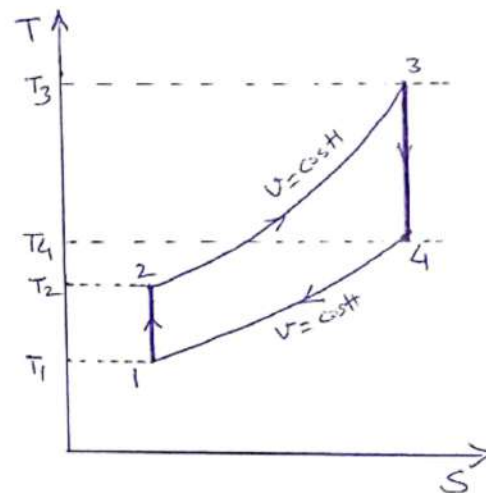
Process 4-1 Reversible const. volume heat rejection

In an actual engine, the working substance becomes the air-fuel mixture and heat transfer processes are replaced by combustion process and exhaust process.

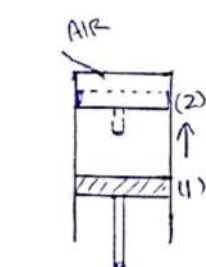


CLEARANCE VOLUME

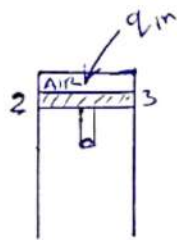
p-v diagram



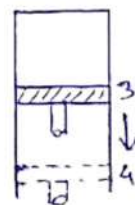
T-S diagram for air standard Otto Cycle



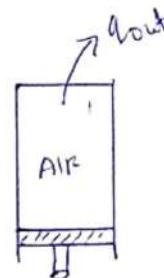
ISENTROPIC COMPRESSION



$V = \text{const.}$ heat addition



ISENTROPIC EXPANSION



$V = \text{const.}$ heat rejection

For Otto Cycle, per unit mass of air

$$\text{Heat supplied, } q_{in} = q_{2-3} = C_v(T_3 - T_2) \quad (\text{a positive quantity})$$

$$\text{Heat rejected } q_{out} = q_{4-1} = C_v(T_4 - T_1) \quad (\text{a negative quantity})$$

Net work done = Σq for a cycle

$$W_{net} = q_{in} - q_{out} \\ = C_v(T_3 - T_2) - C_v(T_4 - T_1)$$

The thermal efficiency of the cycle

$$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{q_{in} - q_{out}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} \\ = 1 - \frac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \\ = 1 - \frac{T_1 \left(\frac{T_4}{T_1} - 1 \right)}{T_2 \left(\frac{T_3}{T_2} - 1 \right)} \quad \dots (i)$$

Considering the isentropic process - (1-2)

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

Where $\left| r = \frac{V_1}{V_2} \right|$ is called compression ratio

For the isentropic process 3-4

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3} \right)^{\gamma-1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1} = r^{\gamma-1} \quad \dots (iii)$$

Equation Equating Equation (ii) and (iii) we get,

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \quad \text{or} \quad \frac{T_4}{T_1} = \frac{T_3}{T_2}$$

Using in Eq. (i), we get

$$\eta_{otto} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{\left(\frac{T_2}{T_1} \right)} = 1 - \frac{1}{(r)^{\gamma-1}} \quad \text{or} \quad \boxed{\eta_{otto} = 1 - \frac{1}{(r)^{\gamma-1}}} \quad \dots (4)$$

For air, the ratio of specific heats γ (gamma) is assumed to be const., and thus the efficiency of the Otto cycle given by ~~eq (iv)~~ eq (iv) is the function of compression ratio only. The efficiency of the Otto cycle increases with increase in compression ratio, but due to practical difficulties its value is limited to about 8.

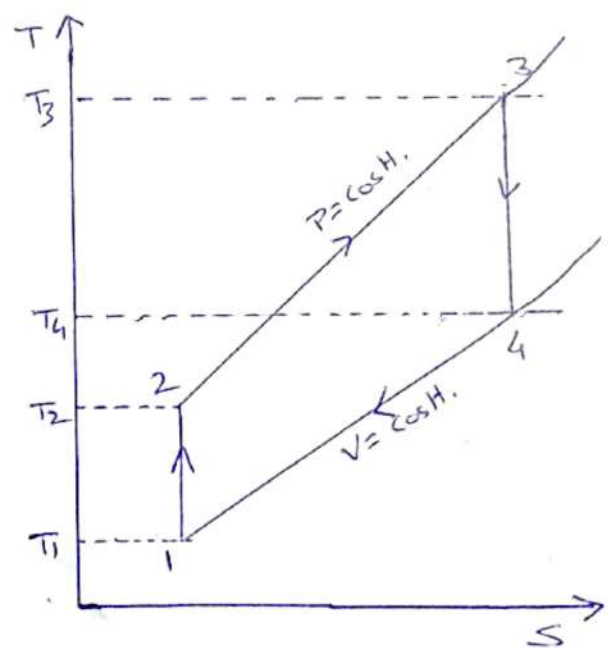
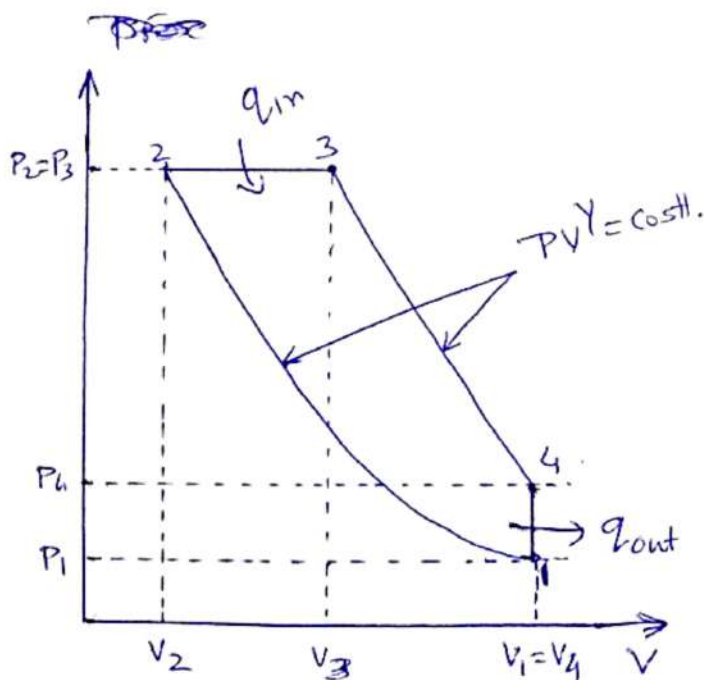
DIESEL CYCLE (Constant pressure cycle)

The Diesel cycle is an ideal cycle for reciprocating compression ignition (CI) engine. It was proposed by Rudolph Diesel in 1892.

In gasoline engine, a mixture of air and fuel is compressed during the compression stroke, and thus the compression ratio is limited by engine knock (auto-ignition of charge). In a Diesel engine, only air is compressed during the compression stroke, thus eliminating the possibility of auto-ignition.

Therefore, Diesel engines are designed to operate at a very high compression ratio, typically between 12 and 14.

In the air-standard Diesel Cycle (as shown in fig) the combustion process is approximated as a constant-pressure, heat addition process. The remaining three processes are same for both Otto and Diesel Cycle.



Air-Standard Diesel Cycle

Process 1-2 Isentropic Compression

Process 2-3 Reversible const pressure heat addition

Process 3-4 Isentropic expansion

Process 4-1 Reversible const. volume heat rejection

Analysis -

For 1 Kg of air undergoing a Diesel Cycle,

Heat supplied $q_{in} = q_{2-3} = C_p(T_3 - T_2)$

Heat rejected $q_{out} = q_{4-1} = C_v(T_4 - T_1)$

The efficiency of the Cycle.

$$\begin{aligned}\eta &= 1 - \frac{q_{out}}{q_{in}} = \frac{q_{in} - q_{out}}{q_{in}} \\ &= \frac{C_p(T_3 - T_2) - C_v(T_4 - T_1)}{C_p(T_3 - T_2)} \\ &= 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}\end{aligned}$$

$$\boxed{\eta_{\text{Diesel}} = 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)}} \quad \dots \textcircled{1} \quad (C_p/C_v = \gamma)$$

The efficiency of the Diesel cycle may be expressed in the following terms -

Compression Ratio -

$$r = \frac{V_1}{V_2} = \frac{V_1}{V_2} = \frac{\text{Volume before compression}}{\text{Volume after compression}}$$

Cut-off Ratio -

$$\rho = \frac{V_3}{V_2} = \frac{V_3}{V_2} = \frac{\text{Volume after heat supply (or Volume at Cut)}}{\text{Volume after compression (or Clearance Volume)}}$$

Expansion Ratio

$$r_e = \frac{V_4}{V_3} = \frac{V_4}{V_3} = \frac{\text{Volume after expansion}}{\text{Volume before expansion}}$$

It can be proved that

$$r = r_e \rho \Rightarrow \left[\frac{V_4}{V_3} \times \frac{V_3}{V_2} = \frac{V_4}{V_2} = r \right] \quad \dots \textcircled{2}$$

Now for Isentropic process (or adiabatic compression 1-2)

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

or $\boxed{T_2 = T_1 r^{\gamma-1}} \quad \dots \dots (3)$

For the const-pressure heat-addition process 2-3

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = e$$

or $\boxed{T_3 = e T_2 = e r^{\gamma-1} T_1} \quad \dots \dots (4)$

For the Isentropic Process 3-4

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4} \right)^{\gamma-1} = \left(\frac{V_3}{V_1} \right)^{\gamma-1} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_1} \right)^{\gamma-1}$$

or $T_4 = \left(\frac{e}{r} \right)^{\gamma-1} T_3 = \left(\frac{e}{r} \right)^{\gamma-1} e r^{\gamma-1} T_1 = \frac{e^{\gamma-1}}{r^{\gamma-1}} \times e r^{\gamma-1} T_1$

$$\boxed{T_4 = e^{\gamma} T_1} \quad \dots \dots (5)$$

Using the values of T_2, T_3 and T_4 from Eq (3) (4) and (5) respectively in Eq. (1), we get

$$\eta_{\text{Diesel}} = 1 - \frac{(e^{\gamma}-1) T_1}{\gamma}$$

$$\eta_{\text{Diesel}} = 1 - \left(\frac{T_4 - T_1}{\gamma (T_3 - T_2)} \right) = 1 - \frac{(e^{\gamma} T_1 - T_1)}{\gamma (e r^{\gamma-1} T_1 - r^{\gamma-1} T_1)}$$

$$= 1 - \frac{(e^{\gamma}-1) T_1}{\gamma [r^{\gamma-1} T_1 (e-1)]}$$

$$= 1 - \left[\frac{e^{\gamma}-1}{\gamma (e-1)} \right] \frac{1}{r^{\gamma-1}}$$

$$\boxed{\eta_{\text{Diesel}} = 1 - \frac{1}{r^{\gamma-1}} \left[\frac{e^{\gamma}-1}{\gamma (e-1)} \right]}$$

It may be observed that equation shows for efficiency of Diesel cycle is different from that of the Otto Cycle only in bracketed factor. This factor is always greater than unity because $\epsilon > 1$.

Hence, for a given ^{same} compression ratio, the Otto Cycle is more efficient.

Therefore, since Diesel ~~engines~~ engines employed much higher compression ratio, thus their thermal efficiency is higher.

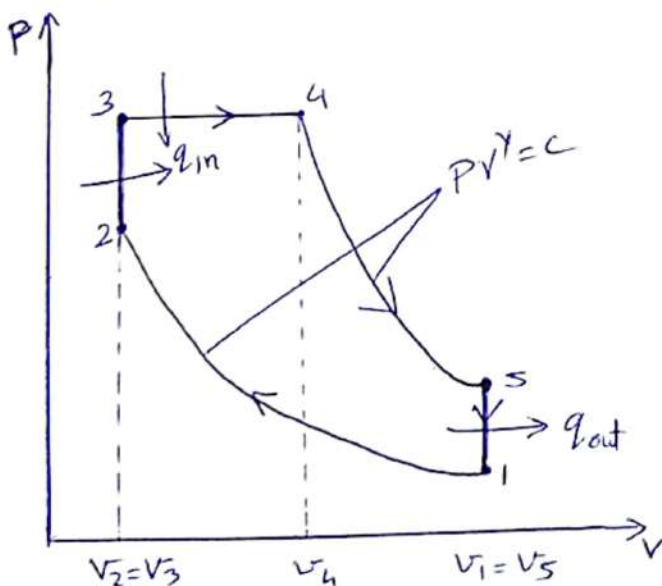
DUAL CYCLE

~~In the Otto cycle, the~~

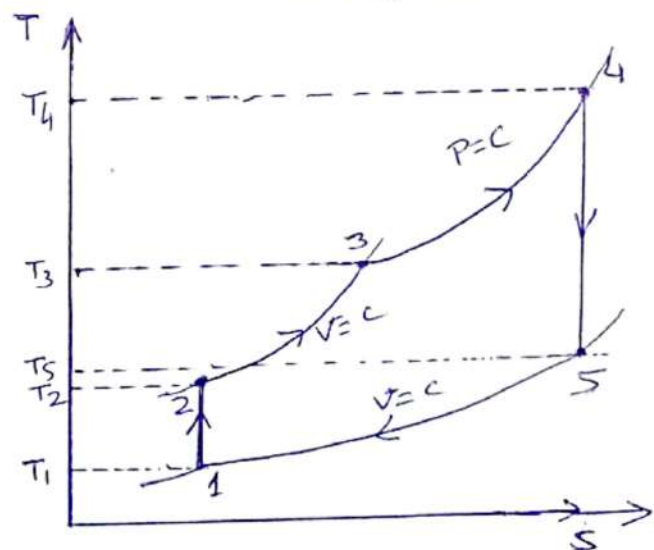
This cycle (also called the limited pressure cycle or mixed cycle) is a combination of Otto and Diesel cycles. In the Otto cycle, the combustion is assumed at constant volume, while in the Diesel cycle, the combustion is at constt pressure.

In actual Diesel engine, the fuel injection starts before the end of compression stroke and thus a part of heat is added at constt volume and rest at constt. pressure as shown in fig. The advantage of which is that more time is available to fuel (which is injected into the engine cylinder before the end of compression stroke). Such cycle is referred as air standard dual cycle or mixed cycle or limited pressure cycle.

↳ For combustion, Because of lagging characteristics of fuel this cycle is invariably used for diesel and hot spot ignition engines.



P-V Diagram



T-S Diagram

The dual combustion cycle consists of the following operations:

- (i) 1-2 - Adiabatic compression.
- (ii) 2-3 - Addition of heat at constant volume.
- (iii) 3-4 - Addition of heat at constant pressure.
- (iv) 4-5 - Adiabatic expansion.
- (v) 5-1 - Rejection of heat at constant volume.

Analysis.

Consider 1 kg of Air.

$$\begin{aligned}\text{Total heat supplied} &= \text{Heat supplied during the Operation 2-3} \\ &\quad + \text{heat supplied during the operation 3-4} \\ &= C_v(T_3 - T_2) + C_p(T_4 - T_3)\end{aligned}$$

$$\text{Heat rejected during operation 5-1} = C_v(T_5 - T_1)$$

$$\begin{aligned}\text{Work Done} &= \text{Heat Supplied} - \text{heat Rejected} \\ &= C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)\end{aligned}$$

$$\begin{aligned}\eta_{\text{DUAL}} &= \frac{C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)} \\ &= 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)} \\ &= 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} \quad \text{--- (1)} \quad \left(\gamma = \frac{C_p}{C_v}\right)\end{aligned}$$

Considering the following ratio to express the efficiency of Dual Cycle.

$$\text{Compression ratio } \gamma = \frac{V_1}{V_2}$$

$$\text{Cut-off ratio } \rho = \frac{V_4}{V_3}$$

$$\text{Pressure Ratio } r_p = \frac{P_3}{P_2}$$

$$\text{Expansion Ratio } r_e = \frac{V_5}{V_4}$$

For isentropic compression process 1-2

$$T_2 = T_1 \gamma^{\gamma-1}$$

For constant volume process 2-3

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = r_p$$

$$\text{or } T_3 = r_p \gamma^{\gamma-1} T_1$$

For constant pressure process 3-4

$$\frac{V_4}{T_4} = \frac{V_3}{T_3}$$

$$\begin{aligned} \text{or } T_4 &= \frac{V_4}{V_3} T_3 = e T_3 \\ &= e r_p \gamma^{\gamma-1} T_1 \end{aligned}$$

For isentropic expansion process 4-5

$$\begin{aligned} \frac{T_5}{T_4} &= \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} = \left(\frac{V_4}{V_3} \times \frac{V_3}{V_2} \times \frac{V_2}{V_1}\right)^{\gamma-1} \\ &= \left(\frac{e}{r}\right)^{\gamma-1} \quad (\because V_3 = V_2) \end{aligned}$$

$$\text{or } T_5 = \left(\frac{e}{r}\right)^{\gamma-1} T_4 = \left(\frac{e}{r}\right)^{\gamma-1} e r_p \gamma^{\gamma-1} T_1 = e^{\gamma} r_p T_1$$

Using the values for T_2, T_3, T_4 and T_5 in eq (1) we get.

$$\eta_{\text{Dual}} = 1 - \frac{T_1 (e^{\gamma} r_p - 1)}{T_1 (r_p \gamma^{\gamma-1} - \gamma^{\gamma-1}) + \gamma T_1 (e r_p \gamma^{\gamma-1} - r_p \gamma^{\gamma-1})}$$

$$\boxed{\eta_{\text{Dual}} = 1 - \frac{1}{r^{\gamma-1}} \left[\frac{r_p e^{\gamma} - 1}{(r_p - 1) + \gamma r_p (e - 1)} \right]} \quad \dots (2)$$

Therefore, the efficiency of Dual Cycle given by Eq (2) is function of γ, e, r_p and γ . When

(i) $r_p = 1$, then $\eta_{\text{Dual}} = \eta_{\text{Diesel}}$

(ii) $e = 1, r_p = 1$ $\eta_{\text{Dual}} = \eta_{\text{Otto}}$

(iii) For same compression ratio and cut-off ratio as pressure r_p increases, thermal efficiency of Dual cycle increases.

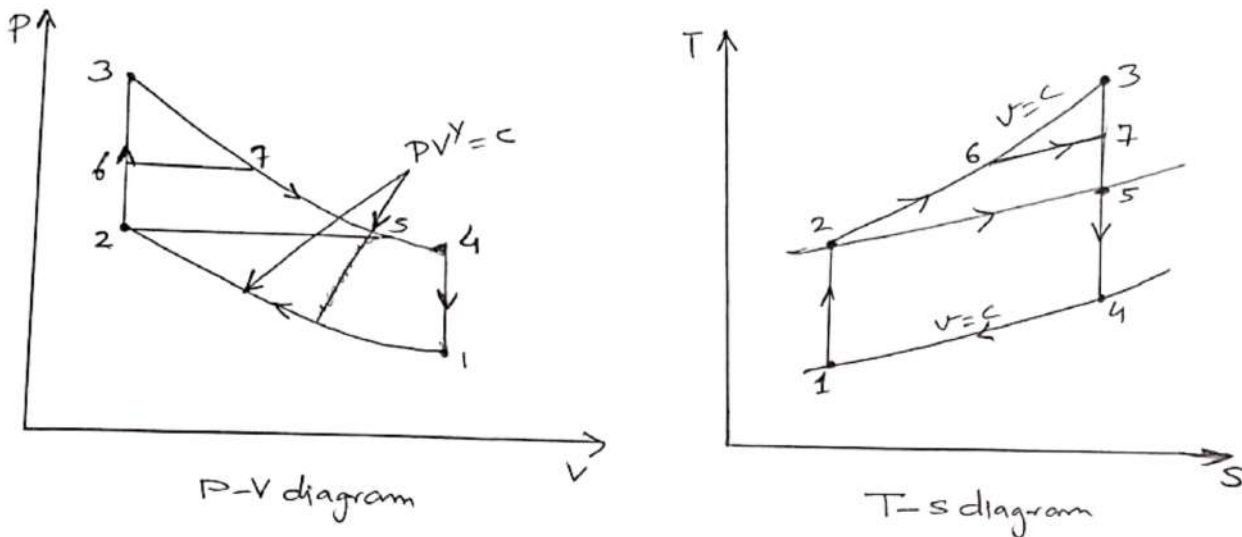
Hence, modern Diesel Engines are designed to operate more closely to Dual cycle.

COMPARISON OF OTTO, DIESEL AND DUAL CYCLES

The three cycles can be compared on the basis of either the same compression ratio or the same maximum pressure and temperature.

(1) FOR SAME COMPRESSION RATIO -

Fig shows the comparison of three cycles on p-v and T-s diagrams



Here, cycle 1-2-3-4-1 is Otto cycle
cycle 1-2-5-4-1 is Diesel cycle
cycle 1-2-6-7-5-4-1 is Dual cycle

It is evident from p-v and T-s diagrams, that the heat rejection process 4-1 for Otto, Diesel and Dual cycles is same, but heat supply (area under 2-3 on the T-s diagram) and work done (area under 3-4 on the p-v diagram) are highest for Otto cycle. Thus, it is the most efficient cycle. Heat supply (process 2-5) and work done (process 2-5-4) for Diesel cycle are least, and thus it is the least efficient among the three cycles.

Therefore,

$$\eta_{\text{Otto}} > \eta_{\text{Dual}} > \eta_{\text{Diesel}}$$

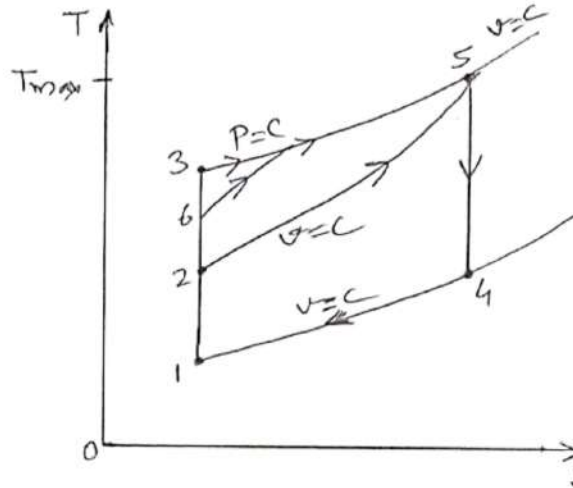
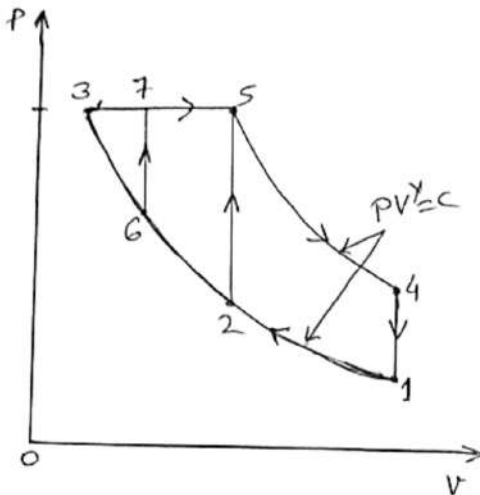
For Same Maximum Pressure and Temperature

Fig. shows the Otto cycle and Diesel Cycle on $p-v$ and $T-s$ diagrams.

Cycle 1-2-5-4-1 is Otto Cycle

cycle 1-2-3-5-4-1 is Diesel cycle

cycle 1-2-6-7-5-4-1 is Dual Cycle



COMPARISON OF OTTO AND DIESEL CYCLES FOR SAME MAX pressure and temp

The ~~peak~~ peak pressure ($P_3 = P_5$), peak temperature T_5 and heat rejection (area under the curve 4-1 on the $T-s$ diagram) are same for the three cycles.

The heat input for the Diesel cycle is the area under curve 3-5, for Dual cycle, area under 6-7-5 and for the Otto cycle, it is the area under the curve 2-5 on the $T-s$ diagram. It is evident that the heat supply in a Diesel cycle is more, and hence, it is the most efficient. The Otto cycle receives the least heat supply, and thus is the least efficient for same maximum pressure and temperature.

Therefore, $\eta_{\text{Diesel}} > \eta_{\text{Dual}} > \eta_{\text{Otto}}$