RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

B. Tech. First Year

Branch- Common to All Disciplines

BT203	**Basic Mechanical Engineering**	**3L-0T-2P**	**4 Credits**

Course Contents:

Unit I :

Materials : Classification of engineering material, Composition of Cast iron and Carbon steels, Iron Carbon diagram. Alloy steels their applications. Mechanical properties like strength, hardness, toughness , ductility, brittleness , malleability etc. of materials , Tensile test- Stress-strain diagram of ductile and brittle materials ,Hooks law and modulus of elasticity, Hardness and Impact testing of materials, BHN etc.

Unit II:

Measurement: Concept of measurements, errors in measurement, Temperature, Pressure, Velocity, Flow strain, Force and torque measurement, Vernier caliper, Micrometer, Dial gauge, Slip gauge, Sine-bar and Combination set.

Production Engineering: Elementary theoretical aspects of production processes like casting, carpentry, welding etc Introduction to Lathe and Drilling machines and their various operations.

Unit III :

Fluids : 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 .

Unit IV:

Thermodynamics : Thermodynamic system, properties, state, process, Zeroth, First and second law of thermodynamics, thermodynamic processes at constant pressure, volume, enthalpy & entropy.

Steam Engineering : Classification and working of boilers, mountings and accessories of boilers, Efficiency and performance analysis, natural and artificial draught, steam properties, use of steam tables.

Unit V:

Reciprocating Machines :

Working principle of steam Engine, Carnot, Otto, Diesel and Dual cycles P-V & T-S diagrams and its efficiency, working of Two stroke & Four stroke Petrol & Diesel engines. Working principle of compressor.

Reference Books:

1- Kothandaraman & Rudramoorthy, Fluid Mechanics & Machinery, New Age .
2- Nakra & Chaudhary , Instrumentation and Measurements, TMH.
3- Nag P.K, Engineering Thermodynamics , TMH .
4- Ganesan , Internal Combustion Engines, TMH .
5- Agrawal C M, Basic Mechanical Engineering ,Wiley Publication.
6- Achuthan M , , Engineering Thermodynamics ,PHI.

List of Suggestive Core Experiments:

Theory related Eight to Ten experiments including core experiments as follows:

1- Study of Universal Testing machines.
2- Linear and Angular measurement using, Micrometer, Slip Gauges, Dial Gauge and Sine-bar.
3- Study of Lathe Machine.
4- Study of Drilling Machines.
5- Verification of Bernoulli's Theorem.
6- Study of various types of Boilers.
7- Study of different IC Engines.
8- Study of different types of Boilers Mountings and accessories.

w.e.f. July 2018

UNIT I

Materials- Engineering material classification, Cast iron and Carbon steel composition, Fe-C diagram. Steel alloys and applications. Mechanical properties of materials, Tensile testing, Stress-strain curve for ductile and brittle materials, hooks law, modulus of elasticity, Hardness and Impact testing.

Classification of Materials

Most engineering materials are classified into following categories.

(a) Metals

(i) Ferrous (ii) Non-ferrous

(b) Ceramics

(c) Organics

(d) Composites

(e) Semiconductors

Metals

Metals are composed of elements who shares electrons to form metallic bonds. In ferrous metals iron is present and Non-ferrous are free from iron.

Ceramics

Ceramics are any non metallic, inorganic solids used for high temp resistance.

Organics

These are polymeric materials composed of carbon compounds.

Composites

These materials consist of more than one material in structure to show the best characteristics of each compound in combination.

Semiconductors

These have electrical properties that are in-between the conductors and insulators.

Cast-Iron and Carbon-Steel Composition

Steels are alloys of iron, carbon and other alloying elements. Alloying is necessary for many reasons like improving properties, corrosion resistance, etc.

Mechanical properties of steels are dependent on carbon content. Hence steel classification is based on their carbon content. Thus steels are basically of three types,

Low-carbon steel (% wt of C < 0.3)

Medium carbon steel (0.3 <% wt of C < 0.6)

High-carbon steel (% wt of C > 0.6)

1. **Low carbon steel:** Carbon in these alloys is limited, and is not enough to give strength to these materials during heat treatment; hence by cold working strength is improved. Their microstructure consists of ferrite and pearlite; these alloys are relatively soft and ductile. Hence these materials are easily machinable and weld-able.
2. **Medium carbon steels:** These are stronger than low carbon steel. These are less ductile than low carbon steel. These can be heat treated to improve their strength. Typical applications include: railway tracks and wheels, gears etc.
3. **High carbon steels:** These are strongest and hardest of carbon steel, so ductility is very limited. These possess very high wear resistance, and capable of holding sharp edges. So these are used for tool making application like knives, razors, hacksaw blades, etc.
4. **Stainless steel:** These are high resistance to corrosion i.e. they are rust-less (stain-less). For making highly

corrosion resistant addition of special alloying elements is required, especially a minimum of 12% Cr along with Ni and Mo.

Cast iron

Alloys with more than 2.14 wt. % C are designated as cast irons, commercially cast irons contain about 3.0-4.5% C along with some alloying additions. Alloys with this carbon content melt at lower temperatures than steels. Cast irons are categorized as gray, white, nodular and malleable cast irons.

1. **Gray cast iron:** These alloys consists carbon in graphite flakes form, which are surrounded by either ferrite or pearlite. Due to graphite flakes, gray cast irons are weak and brittle. However they possess good damping properties and thus typical applications are base structures, bed for heavy machines, etc.
2. **White cast iron:** In this Si content is low (< 1%) in combination with faster cooling rates, there is no time left for cementite to get decomposed. Because of presence of cementite, fractured surface appear white, which is the main reason of its name. These are very brittle and extremely difficult to machine. So their use is limited to wear resistant applications such as rollers in rolling mills.
3. **Nodular cast iron:** Small additions of Mg / Ce to the gray cast iron before casting can result in graphite to form nodules or sphere-like particles. These are stronger and ductile than gray cast iron. Typical applications are like pump bodies, crank shafts, automotive components, etc.
4. **Malleable cast iron:** It is formed by heat treating white cast iron. High temperature incubation causes cementite to decompose and form ferrite and graphite. Thus these materials are stronger with appreciable amount of ductility. Having applications like railroad, connecting rods, marine and other heavy-duty services

Iron - Carbon Diagram:-

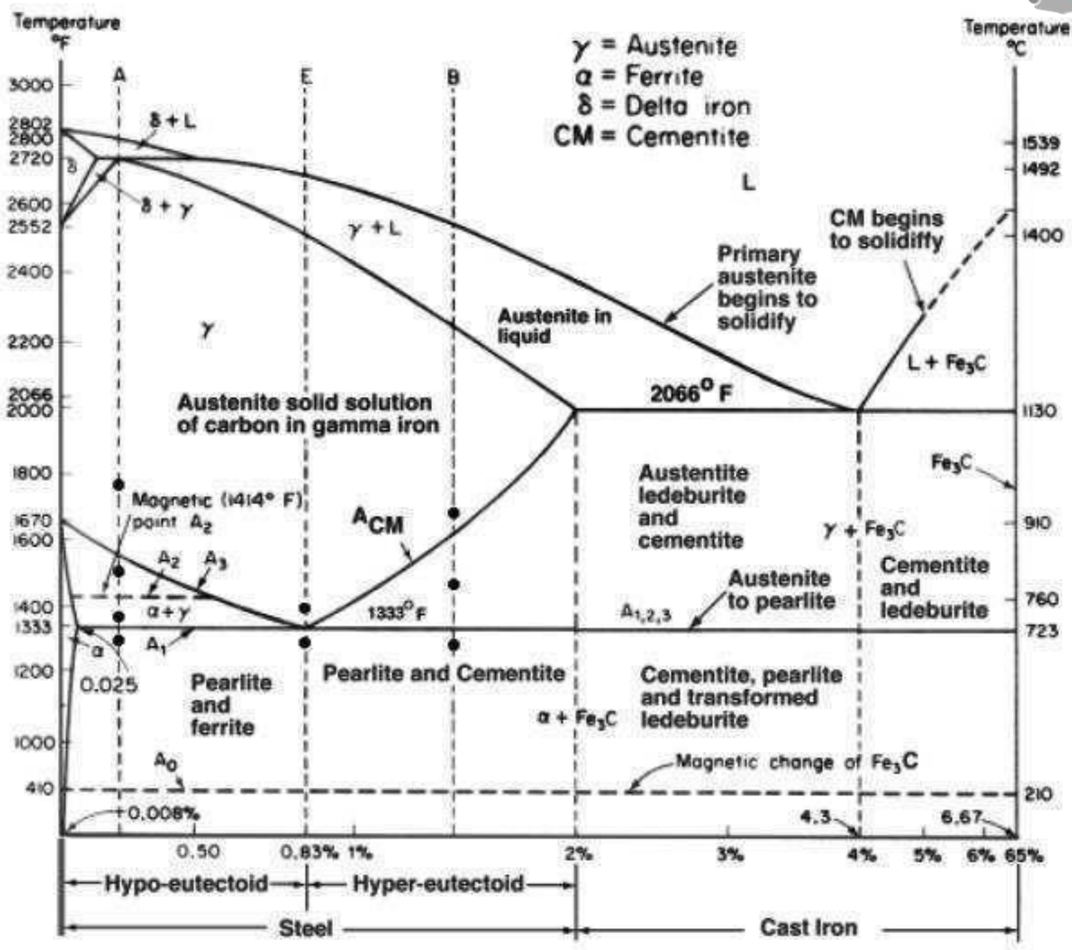

Fig. 1.1 Iron-Carbon Diagram

1. Ferrite – It is BCC in structure with magnetic properties.
2. Austenite – A non magnetic solid solution of ferri-carbide used in making corrosion resistant steel.
3. Cementite (Fe_3C) – Also known as Iron carbide and is hard and brittle material.
4. Bainite – These are needle like crystals.

Phase transformation in Fe-C system

Peritectic reaction at 1495 °C

L (0.53% C) + (0.09% C) → (0.17% C)

Eutectic reaction at 1146 °C

L (4.3% C) → (2.1 % C) + Fe3C (6.67% C)

The eutectic mixture of austenite (γ) and cementite (Fe3C) is called Ledeburite. Compositions right and left of 4.3% are called hyper and hypoeutectic steels (Cast iron) respectively.

Eutectoid reaction at 727 °C

(0.8 % C) → (0.025% C) + Fe3C (6.67% C)

The eutectoid mixture of ferrite (α) and cementite (Fe3C) is called Pearlite. Compositions right and left of 0.8% are called hyper and hypoeutectoid steels respectively. Compositions up to 2.1% C are steels and beyond this it is considered as cast iron.

Steel alloying Elements

1. Manganese (Mn) – It improves hardenability, ductility and wear resistance. It eliminates formation of harmful iron sulphides, increasing strength at high temperatures.

2. Nickel (Ni) – It increases strength, impact strength and toughness.

3. Chromium (Cr) – This improves harden ability, strength and wear resistance, sharply increases corrosion

resistance at high concentrations (> 12%).
4. Tungsten (W) – This increases hardness particularly at elevated temperatures due to stable carbides and refines grain size.
5. Vanadium (V) – Vanadium increases strength, hardness, creep resistance and impact resistance due to formation of hard vanadium carbides.
6. Molybdenum (Mo) – Molybdenum increases harden ability and strength particularly at high temperatures and under dynamic conditions.
7. Silicon (Si) – Silicon improves strength, elasticity, acid resistance and promotes large grain sizes.
8. Titanium (Ti) –It improves strength and corrosion resistance, limits austenite grain size.
9. Cobalt (Co) – It improves strength at high temperatures.
10. Zirconium (Zr) – It increases strength and limits grain sizes.
11. Boron (B) – This is highly effective harden ability agent, improves deformability and machinability.
12. Copper (Cu) – It improves corrosion resistance.
13. Aluminium (Al) – It acts as deoxidizer, limits austenite grains growth.

Mechanical Properties of Engineering Materials: -
1. Elasticity: - The ability of a material by virtue of which it recover its original shape on the removal of distorting load.

Elasticity E = Stress / strain

2. Plasticity: - It is the ability of material by virtue of which the material undergoes permanent deformation after removal of distorting load.
3. Tensile Strength: - The ratio of the maximum load to the original cross-section area is known as tensile strength or the ability to sustain force needed to fracture the material is known as tensile strength.
4. Ductility: - Ability of a material to undergo deformation under tension without rupture.
5. Brittleness: - It's the tendency of material to fracture without appreciable deformation i.e. less than 5% for a 50 mm gauge.
6. Malleability: - The capacity to withstand deformation y the material under compression without rupture is known as malleability.
7. Toughness: - Ability of material to absorb energy during plastic deformation up-to fracture.
8. Creep: - It is the time dependent permanent deformation that occurs under constant stress.
9. Hardness: - It is the resistance of material to plastic deformation by indentation.
10. Fatigue: -The fatigue is the failure of material, when it is subjected to cyclic loads in which the value of developed stress is less than the tensile strength of material.
11. Resilience: - It is the capacity of a material to absorb energy when elastically deformed then on unloading to have this energy recovered.
12. Yield strength: - Ability of material to oppose the plastic deformation is known as yield strength.
13. Impact Strength: - Capacity of material to absorb shock energy before it fractures is called its impact strength.

Tensile Test
In this test ends of work piece are fixed into grips connected to a straining device with a load measuring system. For the small load, the deformation of work piece is entirely elastic, in which the material will return to its original form as soon as load is removed. If the load is too large, the material can be deformed permanently. The starting part of the tension curve which is recoverable immediately after unloading known as elastic and the rest of the curve represents the manner in which solid undergoes plastic deformation known as plastic. The stress below in which the deformations is entirely elastic known as the yield strength, Point known as ultimate strength point where the ratio of the load on the test piece to original cross-sectional area, reaches a maximum value. Further loading will eventually cause 'neck' formation and rupture.
Procedure for testing
1) Measure the original length and diameter of the specimen.
2) Insert the specimen into grips on the test machine and attach strain-measuring device to it.

3) Start applying load and record load v/s elongation data.
4) Take readings frequently as yield point is appeared.
5) Measure elongation values with the help of a ruler.
6) Continue the test till Fracture occurs.
7) In the end joining the two broken pieces of the specimen together to measure the final length and dia. of specimen.

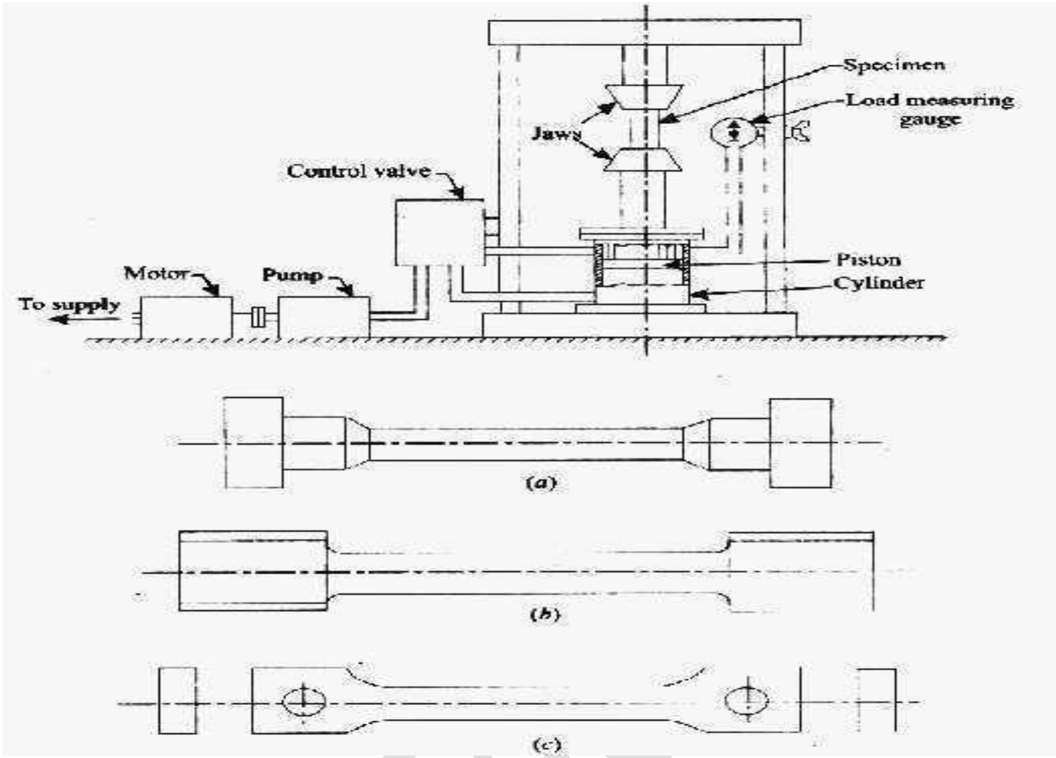

Fig. 1.2 Tensile Test

Stress - Strain Curve

The stress and strain curve for ductile material is as below which shows the behaviour of material under loading and its different strengths before fracture. Here part I show two points A and B up-to which applied load is known as proportional limit where load does not changes the shape of work piece beyond A and on point B applied load is in elastic limit and material will regain its original shape. Beyond point B and up to point C in II phase of the curve load will be resist by the material for its plastic deformation and known as yield strength but after point C and till point D applied load causes permanent deformation in the test piece. Load sustained by the work piece up to point D shows the tensile strength of the material. Beyond point D applied load changes the shape of the test piece and area of cross section decreases in this, at point E material fails and point knows as rupture point.

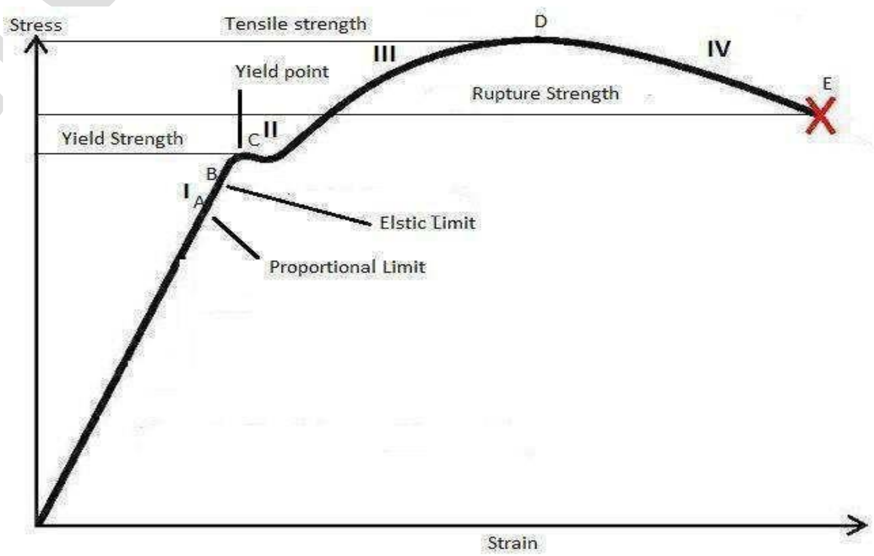

Fig. 1.3 stress - Strain Curve for Ductile Material

Stress strain curve for brittle material is shown below in which it is clearly shown that like ductile materials brittle materials does not shows yield point load applied up-to that limit results fracture of test piece.

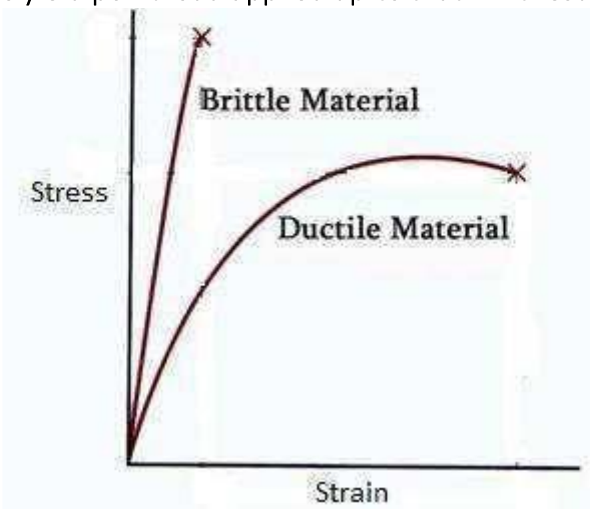

Fig. 1.4 stress - Strain Curve for Brittle Material

Hooke's Law

The Law stated that stress is proportional to strain within elastic limits.

Stress α strain

Modulus of Elasticity: The ratio of stress to the strain is known as modulus of elasticity.

Y or E = Stress / Strain

$= \sigma / \varepsilon$

Hardness Test

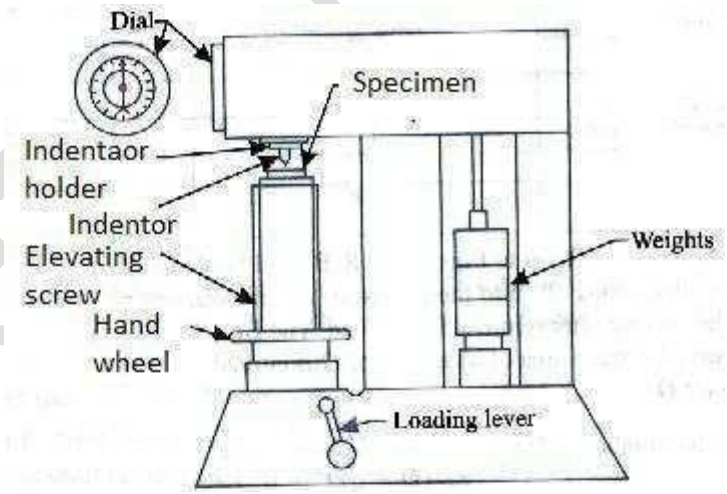

Fig. 1.5 Hardness Test

Hardness is the resistance of a material to plastic deformation or abrasion. This test gives an accurate, fast and economical way of find the resistance of materials to deformation. There are three types of hardness measurement procedures:

i. Scratch hardness measurement,

ii. Rebound hardness measurement

iii. Indention hardness measurement

In scratch hardness test the materials are rated on their ability to scratch the other and it is usually used by mineralogists only.

In rebound hardness test, a standard body is usually dropped on to the material surface and the hardness is measured in terms of the height of its rebound.
In indentation test, the indenter is usually a ball cone or pyramid of a material much harder than the test specimen. A load is applied by pressing the indenter at right angles to the surface being tested and hardness of the material depends on the resistance which it exerts during a small amount of yielding.

Impact Test

The purpose of impact testing is to measure the ability of material to resist sudden applied loads, or to test the behaviour of two objects striking each other at high relative speeds or one is in steady state and another is moving. To resist impact often is one of the determining factors in the service life of a part, or in the suitability of a designated for a particular application.
The Charpy, Charpy V notch, Izod Tests and other Impact testing determines the material toughness or impact strength in the presence of a flaw or notch and fast loading conditions.

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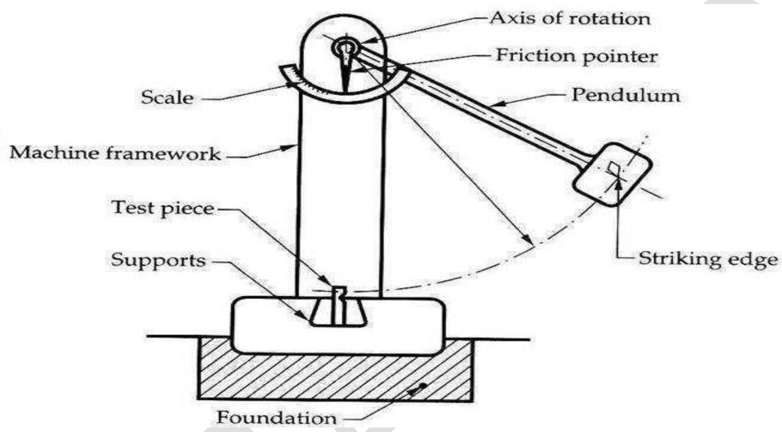


Fig. 1.6 Impact Test

UNIT II

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

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

Measurement Types

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

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

Weight = Length x Breadth x Height x Density

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

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

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

Precision & Accuracy for Measurement

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

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

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

Factors affecting the accuracy of measuring system

a) Factors affecting the standard of measurement:

Co-efficient of thermal expansion
Elastic properties
Stability with time
Geometric compatibility

b) Factors affecting the work piece to be measured:

Co-efficient of thermal expansion
Elastic properties
Arrangement of supporting work piece
Hidden geometry
Surface defects such as scratches, waviness, etc.

c) Factors affecting the inherent characteristics of instrument:

Repeatability & readability
Calibration errors

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

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

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

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

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

Types of Errors

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

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

C) Error of observation

1) Reading error: It is the error of observation resulting from wrong reading of the indication by the observer for the instrument.
2) Parallax error: It is the reading error which is produced, when the index at a certain distance from the surface of scale, and reading is not in the correct direction.
3) Interpolation error: It is the reading error which is the result of the inexact evaluation of the position of the index

D) Based on nature of errors

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

E) Based on control

1) Controllable errors: The source of error is known and it is possible to have a control on these sources.
2) Calibration errors: This is caused due to variation in the calibrated scale from its normal value.
3) Environmental Errors: International agreement has been reached on ambient condition which is at 20^0C temperature, 760 mm of Hg pressure and 10 mm of Hg humidity. Instruments are calibrated at these conditions. If there is any variation in the ambient condition, errors may creep into final results, of the three, temperature effect is most considerable.
4) Stylus pressure errors: Excess pressure during measurement is the cause of this error.
5) Avoidable errors: These errors may occur due to parallax in the reading of measuring instruments.

Causes of Errors

1) Errors due to deflection: When long bars get deformed or deflected. This elastic deformation occurs under their weight. The amount of deflection depends up-on the positions of the supports.
2) Errors due to misalignment: According to Abbes' principle, "the axis or line of measurement of the measured part should coincide with the line of measuring scale or the axis of measurement of the measuring instrument".
3) Error due to contact pressure: The variations in contact pressure, is the main cause of this error. The deformation of the work piece and the anvils of instrument depend upon the contact pressure and the shape of the contact surfaces.
4) Error due to vibrations: This could be because of moving body or part.
5) Error due to dirt: Because of improper maintenance dirty instruments gives wrong values.
6) Error due to poor contact: Because of improper handling the instrument gives the wrong value.
7) Error due to wear in gauges: Wear of measuring surfaces of instrument occurs due to repeated use.
8) Error due to looseness: This happens because of improper contact between the measuring part and the measuring device.

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

Temperature Measurement

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

Thermocouple

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

RTDs and thermostats

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

Infrared radiators

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

Bimetallic devices

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

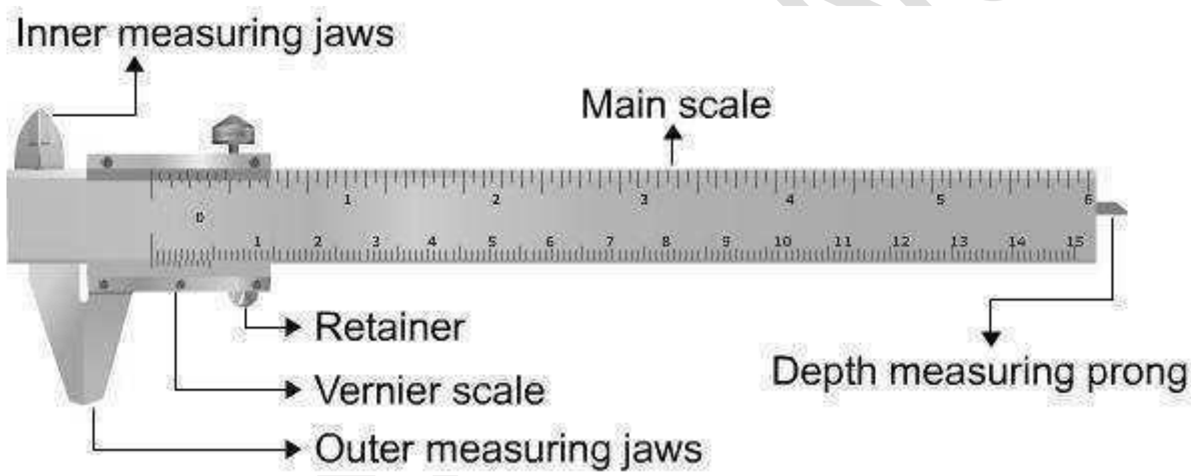
Change-of-state devices

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

Vernier caliper, Micrometer, Dial gauge:

Vernier caliper

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



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

Least Count

It is the smallest reading which the instrument can calculated,

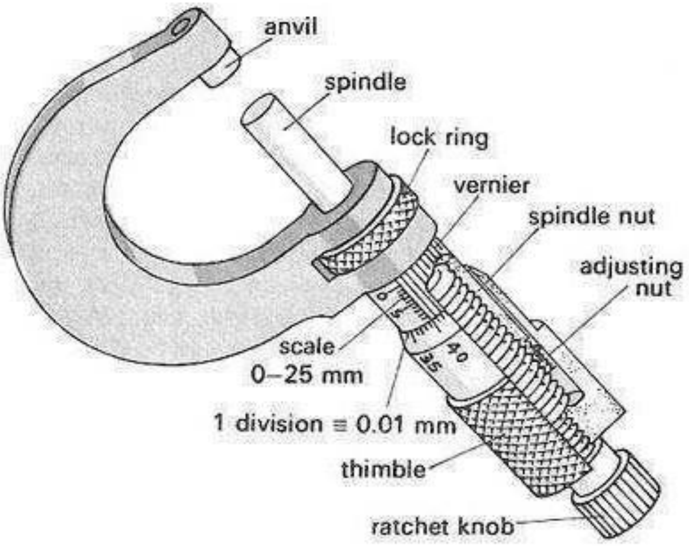
Least count = One Main scale division / Number of divisions in Vernier scale

Micrometer

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

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

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



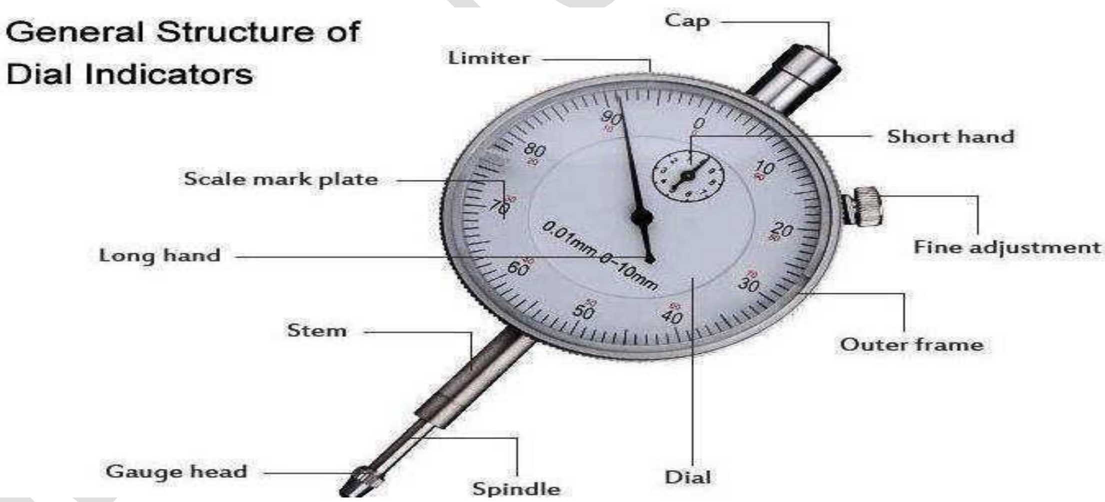
Dial gauge

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

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

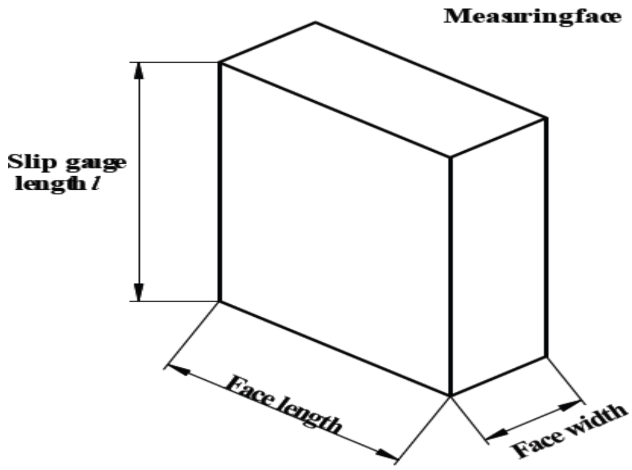
Embedded clock face and needle- These are smaller than the graduated dial and needle and are used for recording the number of needle rotations in the main dial.

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



Slip gauges

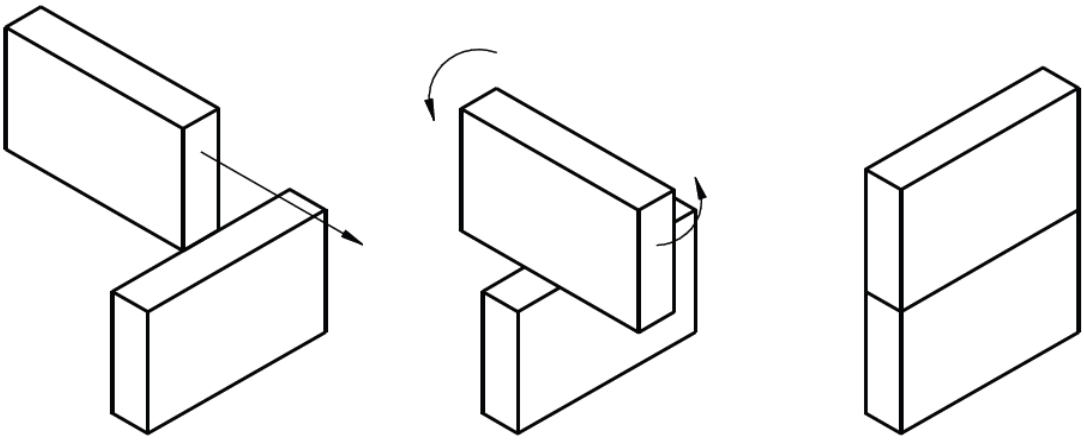
These are the rectangular blocks of steel having cross section of 30 mm face length & 10 mm face width



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

Wringing of Gauges:

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

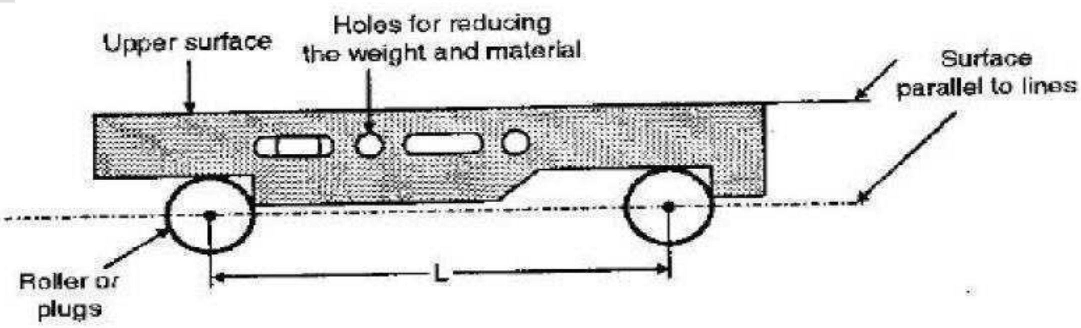


Wringing of Slip Gauges

Sine Bar:

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

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



Sine bar working principle:

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

Advantages of sine bar:

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

Disadvantages:

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

Combination Set :

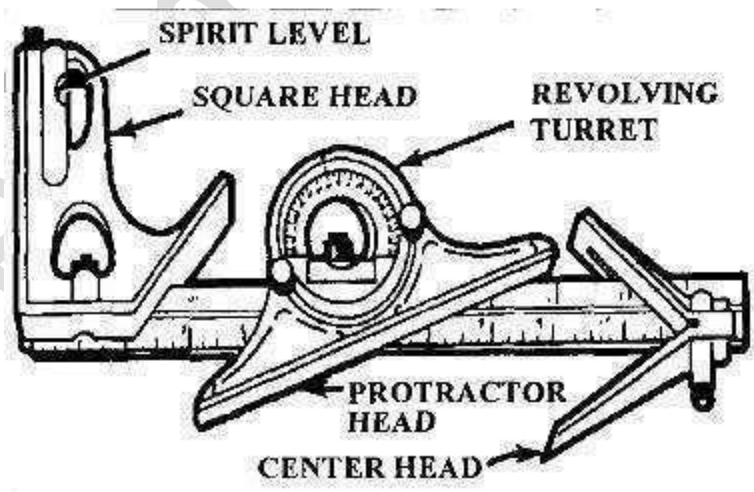
This is the most commonly used non-precision instrument in layout and inspection work.

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

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

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

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



Production Engineering

Theoretical aspects of production processes like casting, carpentry, welding:

Casting

Casting is one of the oldest manufacturing processes. It is the first step in making most of the products. Followed by the following steps for casting

Steps: -

Making mould cavity

Material is first liquefied by properly heating it in a suitable furnace

Liquid is poured into a prepared mould cavity

Allowed to solidify

Product is taken out of the mould cavity,

Trimmed and made to shape

Advantages

Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized. Possible to cast practically any material like ferrous or non-ferrous, the necessary tools required for casting moulds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process. There are certain parts (like turbine blades) made from metals and alloys that can only be processed this way. Size and weight of the product is not a limitation for the casting process.

Carpentry

Carpentry is the skill or work of making or fixing wooden objects or wooden parts of buildings it's a trade in which the primary work is the cutting, shaping and installation of building materials during the construction of buildings, concrete formwork, ships, timber bridges, etc.

For the carpentry work following tools are used

Carpentry Hand Tools:

- Hammer
- Tape Measure
- Chalk Line
- Carpenter's Pencil
- Utility Knife
- Tin Snips
- Nail Puller
- Speed Square
- Framing Square
- Levels
- Wood Chisel (1 inch)

Essential Power Tools:

- Circular Saw
- Drill (3/8" to 1/2" chuck)
- Reciprocating Saw

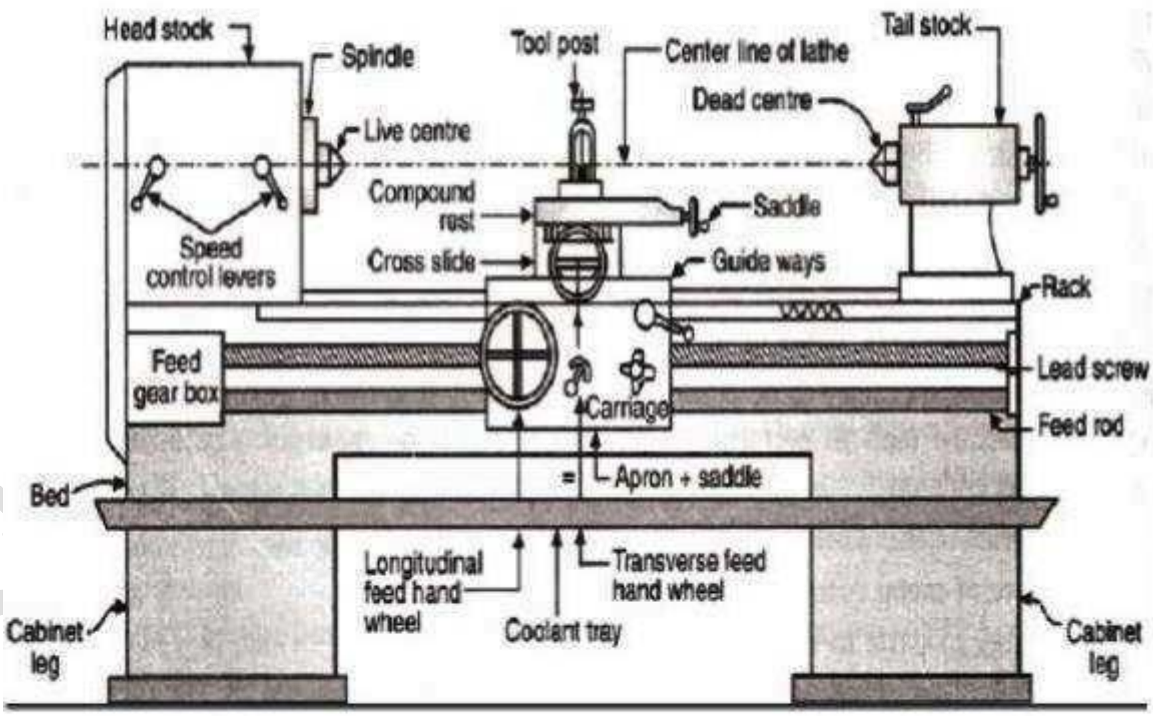
Welding

It's the process of joining two or more, similar or dissimilar metals by heating them to a suitable temperature, with or without application of pressure, filler material and flux. The heat may be supplied by electric are, combustion of gas, or electrical resistance etc.

Some of the welding methods are:
Gas welding – Also known as oxyacetylene welding
Electric Arc welding – Types are MIG and TIG, Submerged arc welding.
Resistance Welding – Spot welding, Seam welding are the types.
Solid State Welding – Cold welding, Friction welding are the types.
Radiant Energy Welding – Laser and electronic beam welding.
Low Temperature Welding – Soldering and Brazing are of the types.

Lathe and Drilling machines and their operations
Lathe
Principle of operation
In the lathe machine the work piece to be machined is held firmly and rotated above its axis, while the cutting tool is moved relative to work piece. Because of this reason the lathe machine is also known as Turning Machine.
The cutting tool which is made of harder material then that of work piece is feed against the work piece. It removes undesirable material from work piece.

Basic elements or Parts
Bed
Head Stock
Tail stock
Carriage
Lead Screw
Feed drive



Specification of Lathe
1. Overall Length of Bed- It is the total length of the lathe bed.
2. Swing length- It is the maximum diameter of work piece that can revolve between the centers without touching the bag. It is also the maximum diameter work piece that can be machined.
3. Distance between Centers- It is the distance between head centre and tail centre. It is also the maximum length of work piece that can be mounted between the centers.
4. Max. And Min. Spindle Speed- It gives the maximum and minimum speed at which the spindle rotates.

Types of Operations

Turning
Eccentric Turning
Taper Turning
Facing
Chamfering
Grooving
Parting
Knurling
Drilling
Boring

Drilling

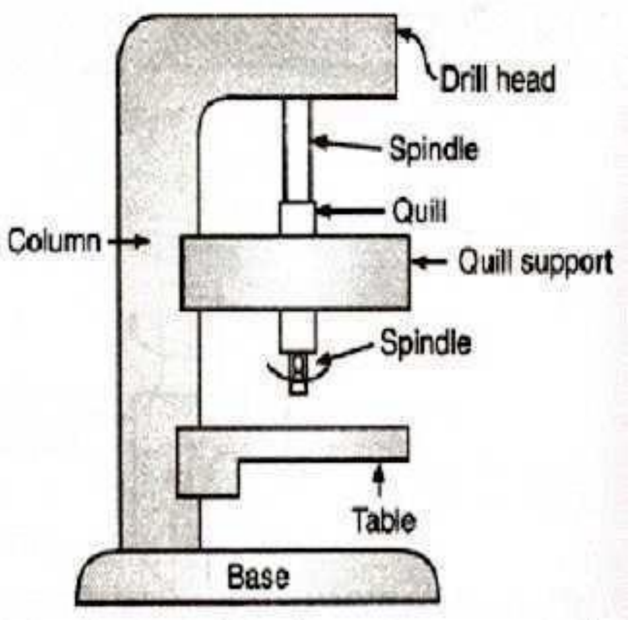
The process of making cylindrical hole in work piece is called drilling .The machine tool used for making the hole in work piece by forcing the rotating tool into stationary work piece is called as Drilling Machine.

Principle of operation

In a drilling machine the work piece is firmly kept on worktable. The work piece is stationary .The cutting tool called drill is press fitted into the spindle of drilling machine.

Basic elements or Parts

Base
Column
Work Table
Drilling Head
Spindle



Types of Operations

Drilling
Reaming
Boring
Counter boring
Spot facing
Counter Sinking
Tapping
Trepanning

UNIT III

Fluids: 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 is a substance that continually deforms under an applied load. Fluids are liquids, gases, plasmas, and to some extent, plastic solids. Fluids are substances that have zero shear modulus, or, in simpler terms, a fluid is a substance which cannot resist any shear force applied to it.

Branches of Fluid Mechanics:-

1. Fluid Statics: - The study of mechanics of fluids at rest is called Fluid Statics. The fluid statics is also study of incompressible fluid under static conditions.

2. Fluid Dynamics: - The study of mechanics of fluid in motion under the influence of forces is called Fluid Dynamics.

3. Fluid Kinematics: - The fluid kinematics deals with translational, rotation and deformation of fluid without considering the forces. The study of fluid in motion due to its energy without considering forces is called Fluid Kinematics.

4. Fluid Kinetics: - Fluid Kinetics deals with the relation between velocities, acceleration and the forces which are exerted by or upon the moving fluid.

5. Hydraulics: - Hydraulics is the branch of Fluid Mechanics which deals with behavior of water (incompressible fluid) either in motion or at rest.

6. Pneumatics: - Pneumatics is the branch of Fluid Mechanics, which deals with behavior of compressible fluid either at rest or in motion.

Types of Fluid:-

1. Ideal Fluid: - An Ideal Fluid is one which has no properties other than its density. Such type of fluids is theoretical fluids and doesn't exist in nature. These fluids are based on assumptions for simplification of calculations, or we can say that "The fluid which is having zero viscosity is known as Ideal Fluid."

2. Real Fluid: - All fluids are Real Fluids. They have viscosity, surface tension, compressibility and density. Means "The Fluid which has some viscosity, it is known as Real Fluid"

3. Newtonian Fluid: - The Fluid which obeys the Newton's Law of Viscosity is known as Newtonian Fluid. If for a fluid the shear stress is directly proportional to the rate of shear strain than such fluids are known as Newtonian Fluid.

4. Non - Newtonian Fluid: - The fluids which doesn't obeys Newton's Law of Viscosity, is known as Non – Newtonian Fluid.

5. Ideal Plastic Fluid:- A fluid, in which shear stress is more than the yield value and the shear stress is directly proportional to the rate of shear strain is known as Ideal Plastic Fluid.

Properties of Fluids:-

1. Density: - It is also known as Specific Mass or Mass Density of Fluid. Density or Mass Density of Fluid is defined as the ratio of mass and its volume. Thus Mass per unit Volume is called Density. It is denoted by symbol **'ρ'** (Rho).

$$\rho = \text{Mass} / \text{Volume}\ (kg/m^3)$$

2. Specific Weight or Weight Density: - Specific Weight or Weight Density of a fluid is the ratio between the Weight of the fluid and its volume. Thus Weight per unit Volume of a fluid is known as the Weight Density. It is denoted by **'ϒ'** (Gamma).

Thus,

Υ = (Mass of Fluid X Acceleration due to Gravity) / Volume of Fluid
$\Upsilon = (m \times g) / V$ N/m^3

3. Specific Gravity: - The specific Gravity is defined as the ratio of density of a substance (ρ) to the density of water at 4° C (ρ_{water} = 1000 kg/m3). It is denoted by S and it is a dimensionless quantity.
$S = \rho / \rho_{water}$
So the density of fluid, $\rho = S \times \rho_{water} = S \times 1000$ (kg/m^3)
The weight density of a fluid $\Upsilon = (S \times \rho_{water}) \times g = S \times 1000 \times 9.81$ (N/m^3)

4. Dynamic Viscosity: - The dynamic viscosity or simply viscosity is defined as the property of fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid. It is denoted by mu,

$$\mu = \tau / (du/dy)$$

The viscosity is measured in poise, or in centi-poise.
1 Poise = 1000 centi-poise
1 N-s/m^2 = 10 Poise
The viscosity of water at 20° C is 0.01 poise or centi-poise.

5. Kinematic Viscosity: - It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by the Greek symbol 'v' (called nu). Thus,

$$v = \text{Viscosity} / \text{Density} = \mu / \rho$$

The kinematic viscosity is measured in m^2/sec; In C.G.S. units it is measured in stoke (cm^2/sec).
1 Stoke = 10^{-4} m^2/sec

Newton's Law of Viscosity:-
It states that the Shear Stress is directly proportional to the rate of Shear strain or Velocity Gradient. i. e.

$$\tau \propto du / dy$$

$$\text{Or, } \tau = \mu (du / dy)$$

Whereμ is the constant of proportionality, called Coefficient of Viscosity or Dynamic Viscosity.

Pressure:-
The pressure or intensity of pressure is defined as normal force exerted by a fluid per unit area. Pressure is considered only in case of Liquid and Gases, while in case of Solid it is Stress.

$$P = F / A \ (N / m^2)$$

Where, Force, F = mass (m) X Acceleration due to gravity (g)
Mass, m = Volume X Density = Area (A) X Depth (h) X Density (ρ)
So, $F = A \times h \times \rho \times g$
And Now Pressure, $P = (A \times h \times \rho \times g) / A = \rho \times g \times h$ (N / m^2)

Units of Pressure: - The pressure is measured in N/m^2, which is called Pascal (Pa).

$$1 \text{ kPa} = 10^3 \text{ Pa}$$
$$1 \text{ MPa} = 10^6 \text{ Pa} = 10^3 \text{ kPa}$$
$$1 \text{ bar} = 100 \text{ kPa} = 10^5 \text{ Pa}$$
$$1 \text{ atm} = 101325 \text{ Pa} = 101.325 \text{ kPa}$$

Pascal's Law:-
Pascal's law (also Pascal's principle or the principle of transmission of fluid-pressure) is a principle in fluid mechanics which states that a pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid with the same intensity in all directions.
Or Pascal's law states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container.

This principle is stated mathematically as:

$$\Delta P = h \times \rho \times \Delta h$$

Where

ΔP = hydrostatic pressure

Δh = the height of fluid above the point of measurement

Bernoulli equation

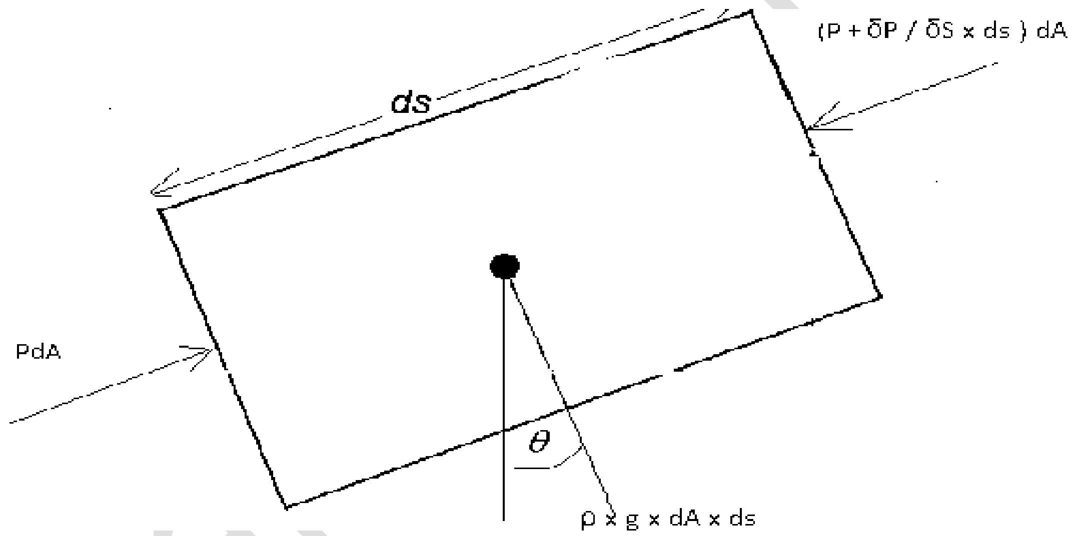
Euler's Equation of Motion

This is the equation of motion in which forces due to gravity and pressure are taken in to consideration. Considering a stream line flow in which flow is in s–direction, Consider a cylindrical element of cross sectional area dA and length ds

The forces acting on the cylindrical element are

1. Pressure force PdA in the direction of flow
2. Pressure force $(P + \delta P/ \delta S)$ dA opposite to the direction of flow
3. Weight of element $\rho \times g \times dA \times ds$

Let θ is the angle between the direction of flow and line of action of the weight of element.



The resultant force on the fluid element in the direction of flow must be equal to the mass of fluid element multiplied wit acceleration in the direction.

$$PdA - (P + \delta P/ \delta S \times ds)\, dA - \rho \times g \times dA \times ds \times \cos\theta = \rho \times dA \times ds \times a_s \text{-----------}(1)$$

Where term a_s is the acceleration in the direction of flow

Now $a_s = dv / dt$ where v is the function of s and t. ------------------------------ (2)

So $a_s = (\delta v/\delta s) \times (\delta v/\delta t) + \delta v/\delta t$

If the flow is steady,

$$\delta v / \delta t = 0$$

Now equation no (2) will be

$$a_s = v\,(\delta v/\delta s)$$

Putting the values in equation no (1)

$$-(\delta P/ \delta S \times ds)\, dA - \rho \times g \times dA \times ds \times \cos\theta = \rho \times dA \times ds \times v\,(\delta v/\delta s)$$

On dividing by $\rho \times dA \times ds$ to the above equation

$$-\quad (\delta P/\rho\, ds) - g \times \cos\theta = v\,(\delta v/\delta s)$$

$$(\delta P/\rho\, \delta s) + g \times \cos\theta + v\,(\delta v/\delta s) = 0$$

$$(1/\rho) \times (\delta P/\delta s) + g\,(dz/ds) + v\,(\delta v/\delta s) = 0$$

$$(dP/\rho) + g\,dz + v\,dv = 0$$

This equation is known as Euler's equation of motion.

Bernoulli Theorem:-

It states that in a steady, ideal flow of an incompressible fluid, the total energy at any point of the fluid is constant. The total energy consists of pressure energy, kinetic energy, and Potential Energy.

Assumptions of Theorem:-

1. Flow is steady
2. The fluid is ideal
3. The flow is incompressible
4. The flow is along a stream line

Now on integration of Euler's equation

$$\int (dP/\rho) + \int (g\,dz) + \int v\,dv = \text{Constant}$$

If flow is incompressible then ρ is constant and equation will be

$$(P/\rho g) +) + (V^2/2g) = \text{constant}$$

The above equation is known as Bernoulli equation.

Hydraulic Machines

The basic rule of hydraulic machines is Pascal's Principle.

Pascal's Principle: pressure exerted on a fluid is distributed equally throughout the fluid. Hydraulics uses incompressible liquids so the applied pressure from one end is equal to the desired pressure on the other end.

Pump:-

A fluid or hydraulic pump is a machine that transfers energy from its moving parts to the fluid passing through the pump. The energy transferred from the pump to the fluid appears as the pressure and velocity of the fluid. Or a hydraulic pump is a mechanical source of power that converts mechanical power into hydraulic energy.

When a hydraulic pump operates, it creates a vacuum at the pump inlet, which forces liquid from the reservoir into the inlet line to the pump and by mechanical action delivers this liquid to the pump outlet and forces it into the hydraulic system.

Hydraulic pump types
1.1 Gear pumps
1.2 Rotary vane pumps
1.3 Screw pumps

TURBINES

Turbines are used to convert freely available energy from rivers and wind into useful mechanical work, usually through a rotating shaft. The **hydraulic turbine** is a mechanical device that converts the potential energy contained in an elevated body of water (a river or reservoir) into rotational mechanical energy. Which can be further used to generate electricity.

Classification of Hydraulic Turbines: Based on flow path

Water can pass through the Hydraulic Turbines in different flow paths. Based on the flow path of the liquid Hydraulic Turbines can be categorized into three types.

1. Axial Flow Hydraulic Turbines: This category of Hydraulic Turbines has the flow path of the liquid mainly parallel to the axis of rotation. Kaplan Turbines has liquid flow mainly in axial direction.

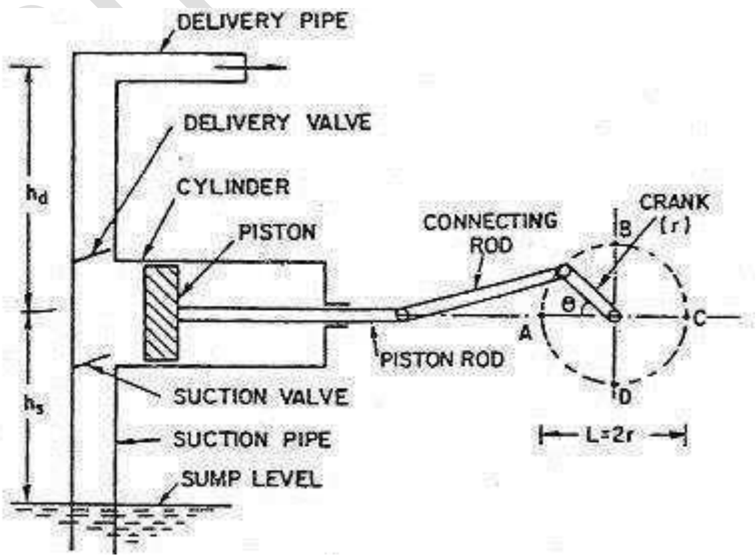
2. Radial Flow Hydraulic Turbines: Such Hydraulic Turbines has the liquid flowing mainly in a plane perpendicular to the axis of rotation.

3. Mixed Flow Hydraulic Turbines: Most of the Hydraulic Turbines used there is a significant component of both axial and radial flows. Such types of Hydraulic Turbines are called as Mixed Flow Turbines. Francis Turbine is an example of mixed flow type, in Francis Turbine water enters in radial direction and exits in axial direction.

None of the Hydraulic Turbines are purely axial flow or purely radial flow. There is always a component of radial flow in axial flow turbines and of axial flow in radial flow turbines.

Reciprocating Pump

A reciprocating pump is a class of pump which includes the piston, plunger and diaphragm. It is often used where a relatively small quantity of liquid is to be handled and where delivery pressure is quite large. In reciprocating pumps, the chamber in which the liquid is trapped, is a stationary cylinder that contains the piston or plunger.



The Main Parts of Reciprocating Pump are:

1. CYLINDER- It is made of cast iron or steel alloy. The piston reciprocates inside the cylinder. The movement of piston is obtained by a connecting rod which connects piston and rotating crank.

2. SUCTION PIPE- It connects the source of water and cylinder, the water is sucked.

3. DELIVERY PIPE- Water sucked by pump is discharged into delivery pipe.

4. SUCTION VALVE- It adjusts the flow from the suction pipe into delivery pipe.
5. DELIVERY VALVE- It admits the flow from the cylinder in to delivery pipe.
6. AIR VESSEL- It is a cast iron closed chamber having an opening at its pass through which the water flows into vessel.

WORKING:
During the suction stroke the piston moves left thus creating vacuum in the Cylinder. This vacuum causes the suction valve to open and water enters the Cylinder. During the delivery stroke the piston moves towards right. This increasing pressure in the cylinder causes the suction valve to close and delivery to open and water is forced in the delivery pipe. The air vessel is used to get uniform discharge.

Describe the construction and working of Pelton turbine. [RGPV Dec 2010]

Or

Draw a neat sketch of Pelton turbine and explain its working. [RGPV Dec 2014]

Or

Describe the construction and working of any one hydraulic turbine. [RGPV June 2011]

Or

Write a short note on hydraulic turbine and fluid coupling explaining their working with the help of neat sketches. [RGPV Dec 2011]

Construction of the Pelton turbine are as follows :

1. **Nozzle and flow regulating arrangement :** The amount of water striking the buckets (vanes) of the runner is controlled by providing a spear in the nozzle.

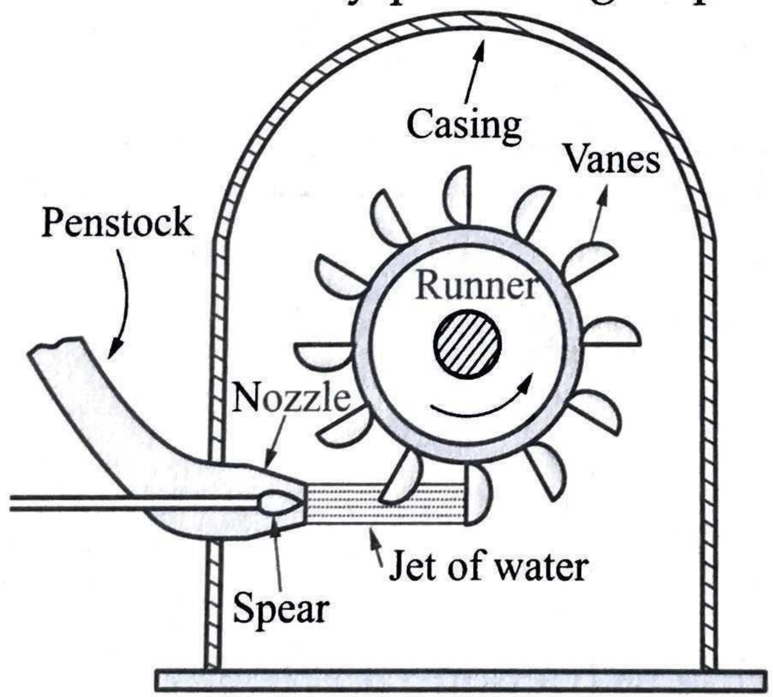


Fig. Pelton turbine

2. **Runner with buckets :** It consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed. The shape of the buckets is of a double hemispherical cup or bowl.
3. **Casing :** The function of the casing is to prevent the splashing of the water and to discharge water to tail race.
4. **Breaking jet :** To stop the runner in a short time, a small nozzle is provided which directs the jet of water on the back of the vanes. This jet of water is called breaking jet.

The working principle of Pelton turbine are as follows :

- A Pelton turbine is a tangential flow impulse turbine.
- When water is transferred from a high head source through a penstock which is fitted with a nozzle. Through the nozzle, the water flows out as a high speed jet.
- A needle spear moving inside the nozzle controls the flow of water through the nozzle and at the same time provides a smooth flow with a negligible energy loss.
- The available potential energy of water is thus converted into kinetic energy before the jet strikes the buckets.
- The pressure of wheel is atmospheric and constant so that energy transfer occurs due to purely impulse action. Thus the wheel rotates in the direction of jet producing mechanical work.
- Speed of the turbine is kept constant by a governing mechanism that automatically regulate the quantity of water flowing through the runner in accordance with any variation of load.

Explain the construction and working of a radial flow reaction turbine or Francis turbine.

Radial flow reaction turbine : This type of turbines in which the water flows in the radi direction and at the same time water at the inlet of the turbine possesses kinetic energy well as pressure energy.

Construction of the radial flow reaction turbine are as follows :

1. **Casing :** In case of reaction turbine, casing and runner are always full of water. The water from the penstocks enters the casing which is of spiral shape in which area of cross-section of the casing goes on decreasing gradually.
2. **Guide mechanism :** The stationary guide vanes are fixed on the guide mechanism. The guide vanes allow the water to strike the vanes fixed on the runner without shock at inlet.

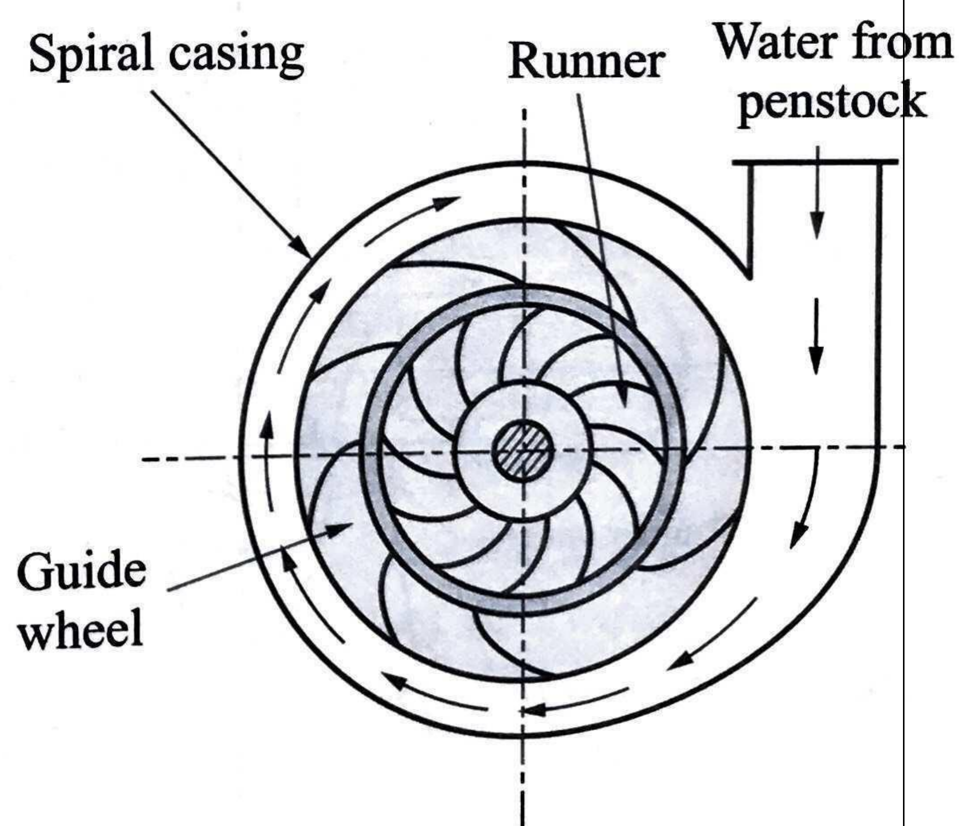


Fig. Radial flow reaction turbine (Francis turbine)

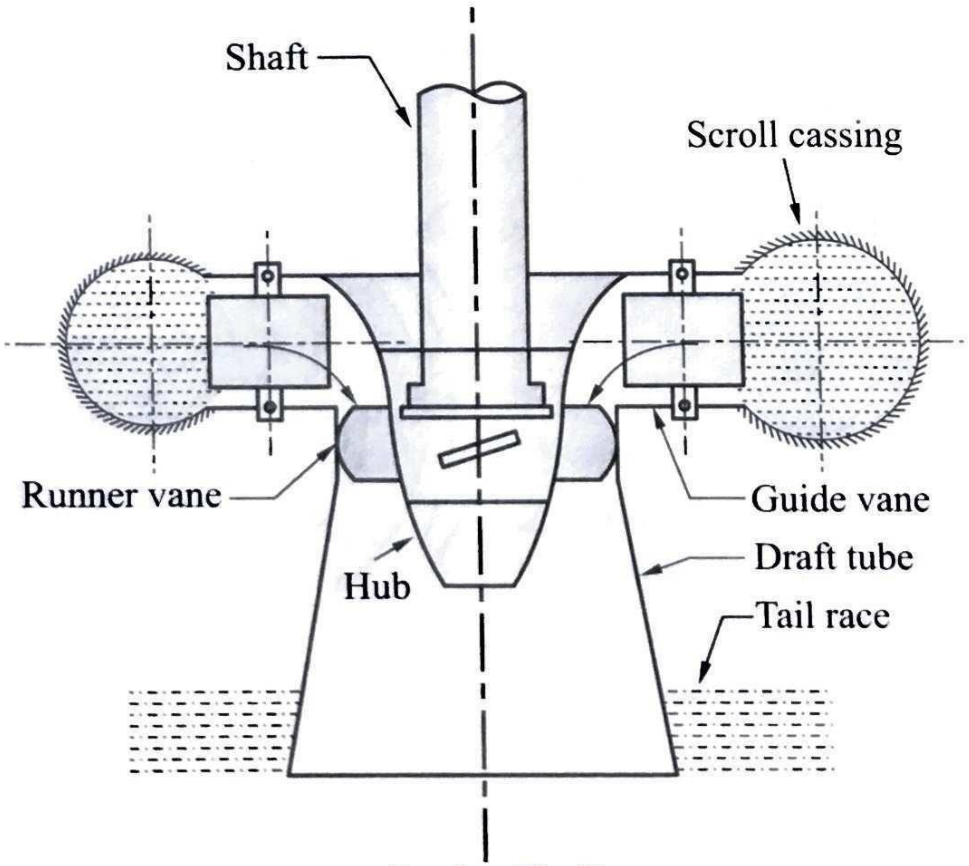
3. **Runner :** It is a circular wheel on which a series of radial curved vanes are fixed. They are keyed to the shaft.
4. **Draft tube :** The pressure at the exit of the runner of a reaction turbine is generally less than atmospheric pressure. A tube or pipe of gradually increasing area is used for discharging water from the exit of the turbine to the tail race.

The working principle of radial flow reaction turbine are as follows :

- The Francis turbine is example of radial flow turbine flow turbine. The Frances turbines is a medium head reaction turbine in which water flow radially inwards.
- It consists of a spiral casing enclosing a number of stationary guide blades fixed all around the circumference of inner ring of moving vanes forming the runner which is keyed to the turbine shaft.
- Water at high pressure enters through the inlet in the casing and flows radially inwards to the outer periphery of the runner through the guide blades.
- During its flow over the moving blades it imparts kinetic energy to the runner to set it into rotational motion.
- To enable the discharge of water at lower pressure, a diverging conical tube called draft tube is fitted at the center of the runner.

Describe with sketch construction and working of Kaplan turbine. **[RGPV June 2010]**

Ans. **Working principle of Kaplan turbine :** In a Kaplan turbine the runner blades are adjustable and can be rotated about pivots fixed to the boss of the runner. The blades are adjusted automatically by servomechanism so that at all loads the flow enters them without shock. Thus a high efficiency is maintain even at part load.



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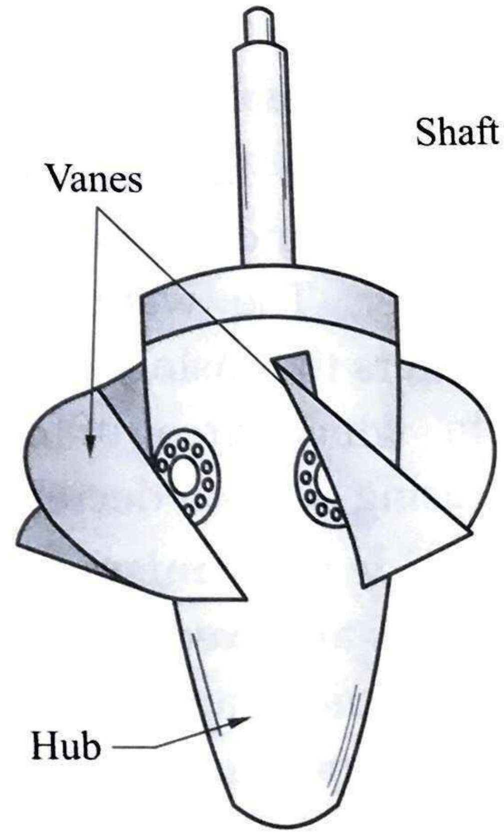


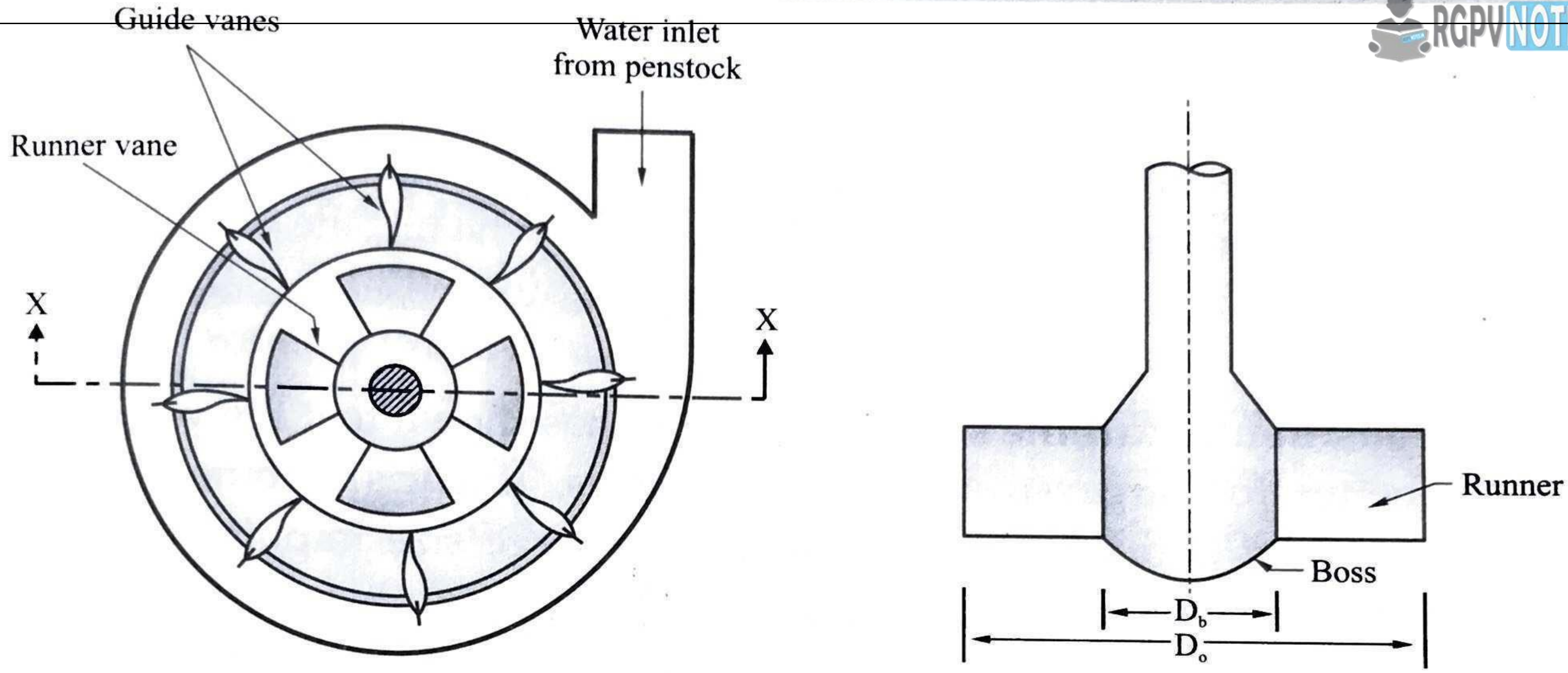


Fig. Main components of Kaplan turbine

Construction of Kaplan turbine are as follows :

1. Scroll casing
2. Guide vanes mechanism
3. Hub with vanes or runner of the turbine
4. Draft tube.

The scroll casing, guide mechanism and draft tube are similar to that in the Francis tur The shape of runner blades is different from that of Francis turbine. The blades of Ka turbine are made of stainless steel.

The water from penstock enters the scroll casing and then moves to the guide. From the g vanes, the water turns through 90^0 and flows axially through the runner.

UNIT IV

Thermodynamics- Thermo-dynamic system, properties, state and process, Zeroth, I & II law of Thermodynamics, thermodynamic processes at constant pressure, volume, enthalpy & entropy

Steam Engineering- Classification and working of boilers, mountings and accessories, Efficiency and performance analysis, Natural & artificial draught, steam properties, use of steam tables

Thermodynamics

Introduction and Definition

Thermodynamics is a branch of science which deals with energy. Engineering thermodynamics is modified name of this science when applied to design and analysis of various energy conversion systems.

"Thermodynamics is the branch of physical science that deals with the various phenomena of energy and related properties of matter, especially of the laws of transformations of heat into other forms of energy and vice-versa."

Thermodynamics 'system' is defined as the quantity of matter or region in space upon which the attention is concentrated. It is separated from the surroundings with the help of its boundary. Everything outside this boundary is termed as the 'surroundings'. System and surroundings when put together result in universe.

There are three classes of systems:-

(a) **Closed System-** It's a system of fixed mass and there is no mass transfer across the boundary of the system. There may be energy transfer in or out of the system.

(b) **Open System-** It is one in which matter crosses the boundary of the system, there may be energy transfer also.

(c) **Isolated System**- It is one in which there is no interaction between system and surroundings in terms of energy and mass.

Thermo dynamic Properties, Process and cycles:-

Every system has certain characteristics by which its physical condition may be described like Volume, Temp, and Pressure etc such characteristics are called **properties of the system**. Properties are of two types intensive which are independent of the mass and extensive are related to mass.

Any operation in which one or more of the properties of a system changes is called a **change of state**, when the path is completely specified the change of state is called a **process** like constant volume process.

A thermodynamic **cycle** is defined as a series of state changes such that the final state is identical with initial state.

Zeroth Law:-

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

It is the basis of temperature measurement.

PdV work or Displacement work: - In a piston cylinder arrangement the force acting on the piston during travelling

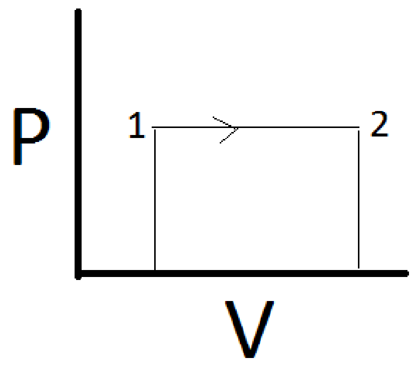
$$F = p \times a$$

And the infinitesimal amount of work done by the gas on the piston

$$dw = F \times dl$$
$$= p \times a \times dl$$
$$= p \times dv \qquad \text{where } dv = a \times dl = \text{displacement volume}$$

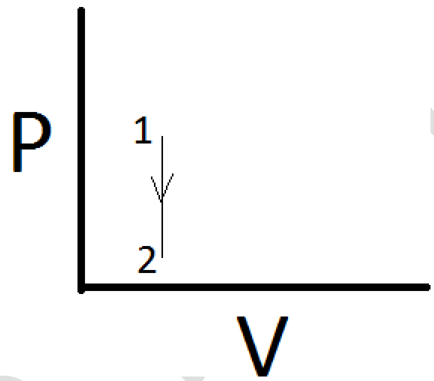
PdV work in various processes:-

(a) Constant pressure process



$W_{1\text{-}2} = p \times (V_2 - V_1)$

(b) Constant Volume process



$W_{1\text{-}2} = p \times (V_2 - V_1) = 0$

First Law of Thermodynamics

The law of conservation of Energy states "Energy can neither be created nor be destroyed but it can only be converted from one form to another".

$\oint Q = J\oint W$

But if a system undergoes a change of state during which both heat and work transfer are involved, the net energy transfer will be stored or accumulated within the system.

If Q is the amount of heat and W is the amount of work transfer during the process the net energy transfer (Q-W) will be stored in the system

Energy in storage is neither heat nor work and is given the name internal energy or simply the energy of the system.

Therefore $Q - W = \Delta E$

Where ΔE is the increase in the energy of the system.

Second Law of Thermodynamics

Heat Reservoir

Heat reservoir is the system having very large heat capacity i.e. it is a body capable of absorbing or rejecting infinite amount of energy without any appreciable change in its' temperature. Heat reservoirs can be of two types depending upon nature of heat interaction i.e. heat rejection or heat absorption from it.

Heat reservoir which rejects heat from it is called source. While the heat reservoir which absorbs heat is called sink.

Heat Engine

Heat engine is a thermodynamic cycle in which there is a net heat transfer to the system and a net work transfer from the system. The system which executes a heat engine cycle is called a heat engine.
The efficiency of a heat engine or a heat engine cycle is defined as

Efficiency = Net work output of the cycle/ Total heat input of the cycle

$$\eta = W_{net} / Q_{in}$$

Heat Pump and Refrigerator

Heat pump refers to a device used for extracting heat from a low temperature surroundings and sending it to high temperature body, while operating in a cycle.

$(COP)_{HP} = Q_1 / (Q_1 - Q_2)$

Refrigerator is a device similar to heat pump but with reverse objective. It maintains a body at temperature lower than that of surroundings while operating in a cycle.

$(COP)_{REF} = Q_2 / (Q_1 – Q_2)$

Statements for II Law of Thermodynamics

Clausiu's statement

Heat always flows from a body at a higher temperature to body at a lower temperature. The reverse process never occurs spontaneously.

Kelvin-Planck statement

"It is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a cooler to a hotter body".
Heat cannot flow itself from a body at a lower temperature to a body of higher temperature. Some work must be expended to achieve this.

Enthalpy

The enthalpy h of a substance is defined as

$$h = u + p \times v$$

It is an intensive property of a system.
Or
Enthalpy is the amount of energy in a system capable of doing mechanical work.

Entropy

It is the degree of randomness or lack of pattern denoted by S.

Steam Engineering

Pure Substance

A pure substance is defined as one that is homogeneous and invariable in chemical composition throughout its mass. The relative proportions of the chemical elements constituting the substance are also constant.
Like air, and combustion product of a fuel.

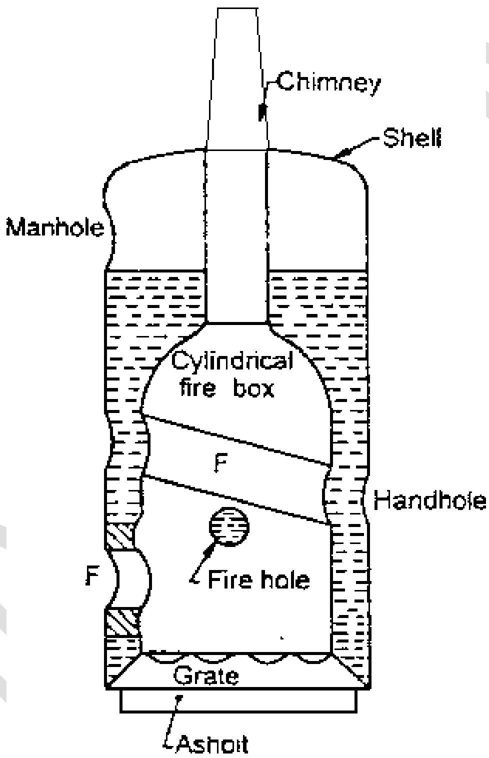
Classification and working of boilers

Working and Classification of Boiler

The Steam Boiler or Steam Generator is a closed vessel in which water is heated, vaporized and converted into steam at a higher pressure than the atmospheric pressure. Indian Boiler Regulation (IBR) states that a vessel exceeding 22.75 lit in capacity, which is used for generating steam under pressure will be treated as Steam Boiler.

In it water from a pump comes inside a water tank and then it passes through the tubes which are placed over the furnace and after receiving heat from the fire water change its phase from liquid to gas that is steam which is further passed to a device known as a super heater to increase the temperature of the steam generated in the boiler which is further used in various works like power generation or in pharmacy Industry.

Vertical Water Tube Boiler



A simple vertical boiler produces steam at a low pressure and in small quantities. It is, therefore used for low capacity plants. It also requires less space area. The boiler consists of a cylindrical shell surrounding a nearly cylindrical firebox. The firebox is slightly tapered towards the top to allow the ready passage of the steam to the surface. A grate is fitted at the bottom of the firebox. Inclined cross tubes are fitted in the firebox, the small inclination (5-15 deg.) is provided to increase the heating surface as well as to improve the natural circulation of water. An uptake tube passes from the top of the firebox to the chimney. A manhole is provided at the top of the shell for a man to enter in it for cleaning. The space between the boiler shell and firebox is filled with water to be heated. Normally it generates wet steam. Incorporating an anti-priming pipe we can increase dryness fraction.

The Boilers can be classified as-

According To Position of Boiler Shell: -

Horizontal Boiler: - In the horizontal boiler, the axis of the boiler shell is horizontal. These are Locomotive,

Lancashire, Babcock and Wilcox Boilers etc.
Vertical Boiler: - In vertical boiler, the axis of the boiler shell is vertical. These are Simple Vertical and Cochran Boilers.

According To the Position of Furnace: -
Internally Fired: - In these boilers the furnace is located inside the boiler shell
Externally Fired: - In these boilers the furnace is located outside the boiler shell

According To Water Circulation Arrangement: -
Natural Circulation: - Water circulates in the boiler due to density difference of hot and cold water
Forced Circulation: - A water pump forces the water along its path, therefore, the steam generation rate increases

According To Number of Tubes: -
Single Tube Boiler: - It consist a single tube generally filled with fire.
Multi Tube Boiler: - It consists of more than one fire or water tubes.

According To Use: -
Stationary Boiler: - These boilers are mounted at fixed platform and do not move from one place to another. These boilers are used in power plants and industries. These are Cochran Boiler, Lancashire Boiler, and Babcock & Wilcox Boiler etc.
Portable Boiler: - It is a small boiler and can be carried easily from one place to another. The Simple Vertical Boiler and locomotives are Portable Boilers.

According To Steam Pressure:-
Low Pressure Boiler: - The boilers, which produce steam from 07 bar to 30 bar.
Medium Pressure Boiler: - The boilers with steam pressure30 bar to 75 bars are called Medium Pressure Boilers.
High Pressure Boiler: - These are boilers, which generate steam at a pressure more than 75 bar.
Super Critical Boiler: - The boilers with steam pressure more than 221 bars are called supercritical boilers. Benson Boiler is a Supercritical Boiler.

Mountings and Accessories
Mountings are required for the safe operation of the boiler. Different types of mountings used are as follows
Safety Valve-

Dead Weight Safety Valve
It is very similar to the Dead Weight (whistle) loaded on a pressure cooker and functions in the similar way. The dead weights in the form of cylindrical disk are placed on the carrier is acting downward. This is the weight of cast iron carrier and valve itself. This weight W is calculated on the basis of working pressure and cross-sectioned area of the valve.

Spring Loaded Safety Valve
Dead weight safety valve cannot be used on locomotive and marine boilers. The jerk and the side movement may change the load on the valve and it can open the valve frequently under the working pressure. Therefore spring loaded safety valves are used on the moving boilers.

High Steam and Low Water Safety Valve
This valve is combination of two valves as shown in fig. It is used in Cornish and Lancashire Boilers. One of

the valves is lever loaded and is operated when steam pressure in boiler exceeds the working pressure. The second valve operates and blows off steam with a louder noise, when water level in the boiler fails below the normal level.

Water Level Indicator

It shows the level of water in the boiler. It consists of a metal tube and a strong glass tube with marking. From the safety point of view, more than one water level indicators are used. If the water level falls below danger mark (shown normally by red mark), the pressure inside the boiler may reach a dangerous limit.

Fusible Plug

It is safety device, which protects the fire tube boiler against overheating. It is located just above the furnace in the boiler. The fusible metal has a low melting point than the other parts. Normally it is covered by the water in the boiler. When the water level falls down, exposing the device direct to the steam, the furnace gases heat up the plug, fusible metal melts and plug falls down. The water and steam rush through the hole and extinguish the fire.

Blow – off Cock

The function of this device is to discharge mud and other rudiments deposited in the bottom most part of the water space in the boiler is in operation. It can also be used to drain-off boiler water

Feed Check Valve

This device is fitted slightly below the working level of water in the boiler. It is used to supply high pressure feed water to the boiler. It also prevents the returning of feed water from the boiler if feed pump fails to work. The feed pump supplies water to the boiler at a pressure higher than the pressure of steam in the boiler.

Accessories

These are used in boilers for improving the efficiency by minimizing the heat losses and recovery of heat loss. Accessories like super heater, economizer and air pre-heater are used in boilers.

Super Heater

The function of a super heater is to increase the temperature of steam above 100 ^{0}C by recovering the un-used heat from the firing chamber.

Economizer

It is used to increase the temperature of water supplied to boiler to increase the rate of steam generation and evaporation.

Air Pre-heater

It is used to increase the temperature of supplied air to the combustion chamber for better combustion of fuel.

Efficiency & Performance Analysis

Efficiency of a Boiler can be calculated by

$$\eta = m_w \times (h_s - h_w) / m_f \times CV$$

Where

m_w = mass of water

m_f = mass of fuel

CV = Calorific value of fuel

h_s = Enthalpy of steam

h_w = Enthalpy of water

And Performance of any boiler is calculated by finding the following

Rate of Evaporation

It is steam generation rate of boilers.

Equivalent evaporation

It is equivalent of evaporation of 1 kg of water at 100 ^{0}C to dry and saturated steam at 100 ^{0}C at 1 atm pressure.

Factor of Evaporation

It is the ratio of heat absorbed by 1 kg of feed water under working conditions to latent heat of steam at atmospheric pressure.

Natural & artificial draught

Draught refers to the pressure difference created for the flow of gases inside the boiler. A chimney or stack is generally used for carrying these combustion products from inside of boiler to outside, i.e. draught is created by use of chimney.

Draught may be created naturally or artificially by using some external device.

In Natural draught the pressure difference is created naturally without using any device.

Artificial draught is created using some external assistance causing forced displacement of gases. It can be created either by using mechanical devices or steam.

Steam properties

(a) Sensible heat: Heat supplied to a substance when used to increase the temperature without changing its phase is known as sensible heating.

(b) Latent heating: The heat supplied to convert 1 kg of ice at 0 ^{0}C into water at 0 ^{0}C is called the latent heat of fusion.

(c)Boiling point: It is the temperature at which vapour pressure equals to atmospheric pressure and phase change from liquid to gas begins.

(d) Melting point: It is the temperature at which phase change from solid to liquid takes place upon supplying heat.

(e) Saturation state: It is the state where a substance is ready to change its state when heat is supplied or absorbed.

(f) Saturation pressure: It is the pressure at which substance changes its phase for any given temperature.

(g) Saturation temperature: It refers to the temperature at which substance changes its phase for any given pressure.

(h) Triple point: Where all three phases of a substance (solid, gas, and liquid) co-exists in equilibrium known as triple point. For water it is at 0.01 ^{0}C temperature and 611 N/m^2 pressure.

$$\sum_{cycle} Q = \sum_{cycle} W$$

$$Q_{net} = W_{net}$$

$$Q_1 - Q_2 = W_T - W_P$$

Here

Boiler, turbine, condenser, and pump all four together constitute a heat engine.

Here a certain quantity of water undergoing the energy interactions in cyclic operations to produce net work from a certain heat input.

The function of a heat engine cycle is to produce work continuously at the expense of heat input to the system.

The efficiency of a heat engine or a heat engine cycle is defined as.

$$\eta = \frac{\text{Net work output of the cycle}}{\text{Total heat input to the cycle}}$$

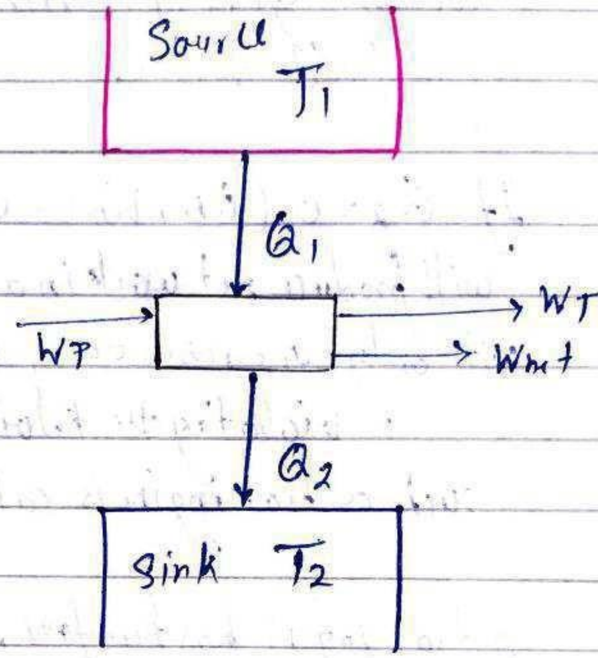
$$= \frac{W_{net}}{Q_1}$$

$$= \frac{W_T - W_P}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$\boxed{\eta = 1 - \frac{Q_2}{Q_1}}$$

A heat engine is very often called upon to extract as much work (net) as possible from a certain heat input, i.e. to maximize the cycle efficiency.

Energy Reservoirs: It is defined as a large body of infinite heat capacity, which is capable of absorbing or rejecting an unlimited quantity of heat without suffering appreciable changes in its thermodynamic coordinates.



— Heat engine —

Kelvin planck statement of second Law:

The efficiency of a heat engine is given by

$$\eta = \frac{W_{net}}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

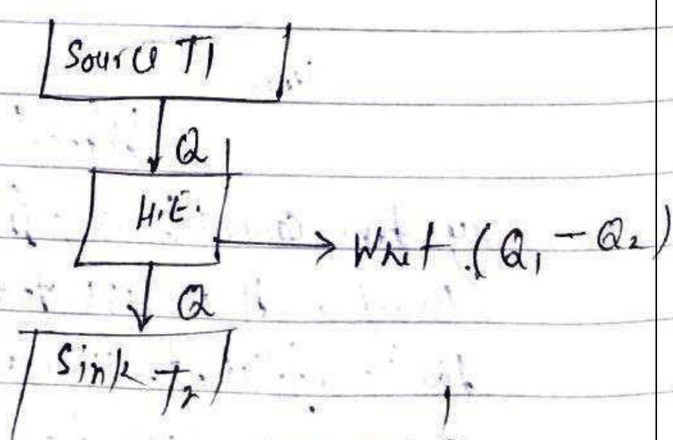
Here

$W_{net} < Q_1$, since heat Q_1 transferred to a system cannot be completely converted to work in a cycle. Therefore η is less than unity. A heat engine can never be 100 % efficient. Therefore, $Q_2 > 0$, i.e., there has always to be a heat rejection. To produce net work in a thermodynamic cycle a heat engine has thus to exchange heat with two reservoirs, the source and sink.

The Kelvin-Plank statement of the second law states:-
It is impossible for a heat engine to produce net work in a complete cycle if it exchanges heat only with bodies at a single fixed temp.

If $Q_2 = 0$. (i.e., $W_{net} = Q_1$, or $\eta = 1.00$), the heat engine will produce net work in a complete cycle by exchanging heat with only one reservoir, thus violating the Kelvin-Planck statement.
Such a heat engine is called a PMM of the second kind.

A heat engine has therefore, to exchange heat with two thermal energy reservoirs at two different temperatures to produce net work in a complete cycle. So long as there is a difference in temp. motive power (i.e. work) can be produced. If the bodies with which heat engine exchanges heat are of finite heat capacities, work will be produced by the heat engine till the temp. of the two bodies are equalized.



Clausius's Statement of the second Law:

Heat always flows from a body at a higher temp. to a body at a lower temp. The reverse process never occurs spontaneously.

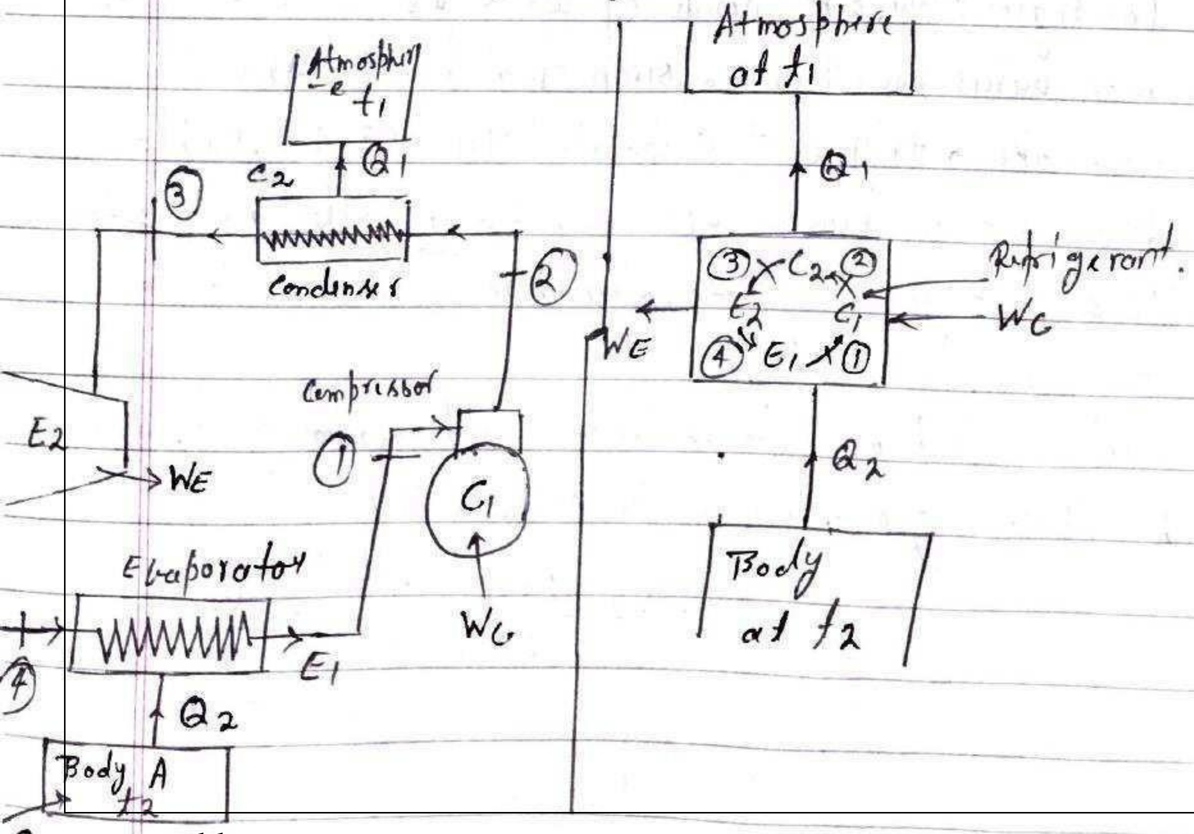
Clausius statement of the second law gives:

It is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a cooler to a hotter body.

Heat cannot flow of itself from a body at a lower temp. to a body at a higher temp. Some work must be expended to achieve this.

Refrigerator and heat pump:

A refrigerator is a device which operating in a cycle, maintains a body at a temp. lower than the temp. of the surroundings.



Let the body A be maintained at t_2, which is lower than the ambient temp. t_1. Even though A is insulated, there will always be heat leakage Q_2 into the body from the surroundings by virtue of the temp. difference. In order to maintain body A at const. temp. t_2, heat has to be removed from the body at the same rate at which heat is leaking into the body.

This heat (Q_2) is absorbed by a working fluid, called refrigerant, which evaporates in the evaporator E_1 at the temp. lower than t_2 absorbing the latent heat of vaporization from the body A which is cooled or refrigerated (Process 4-1). The vapour is first compressed in the compressor C_1 driven by a motor which absorbs work W_c (Process 1-2) and is then condensed in the condenser C_2 rejecting the latent heat of condensation Q_1 at a temp. higher than that of the atmosphere (at t_1) for heat transfer to take place (Process 2-3).

The condensate then expands adiabatically through an expander (an engine or turbine) producing work W_E when the temp. drops to a value lower than t_2 such that heat Q_2 flows from the body A to make refrigerant evaporate (Process 3-4). Such a cyclic device of flow through $E_1-C_1-C_2-E_2$ is called a refrigerator.

In a refrigerator cycle, attentation is concentrated on the body A_2.

Here is a performance parameter in a refrigerator cycle, called the coefficient of performance (C.O.P.), which is

$$C.O.P. = \frac{\text{Desired effect}}{\text{Work Input}} = \frac{Q_2}{W}$$

$$\boxed{(C.O.P.)_{refrig.} = \frac{Q_2}{Q_1 - Q_2}}$$

Heat Pump:- A heat pump is a device which, operating in a cycle, maintains a body, say B, at a temp. higher than the temp. of the surroundings. By virtue of temp. difference, there will be heat leakage Q_1, from the body to the surroundings. The body will be maintained at the const. temp. t_1, if heat is discharged into the body at the same rate at which heat leakes out of the body. The heat is extracted from the low temp. reservoir, which is nothing but the atmosphere, and discharged into the high temp. body B, with the expenditure of work W in a cyclic device called a heat pump. The working fluid operates in a cycle flowing through the evaporator E_1, Compressor C, Condenser C_2, and expander E_2, similar to the refrigerator, but here our target is the high temp. body B. Here Q_1 and W are of primary interest, then

$$C.O.P. = \frac{Q_1}{W}$$

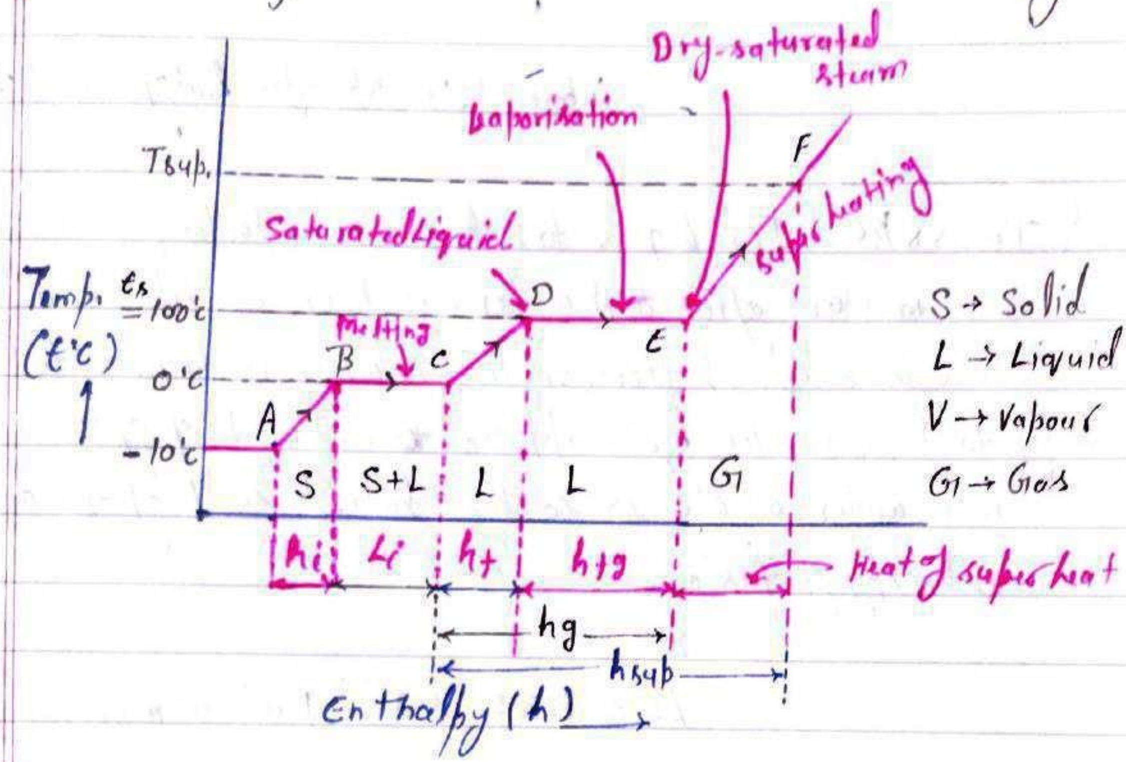
$$(C.O.P.)_{H.P.} = \frac{Q_1}{Q_1 - Q_2}$$

or we can write it

$$= \frac{Q_2}{Q_1 - Q_2} + 1$$

$$\boxed{(C.O.P.)_{H.P.} = (C.O.P.)_{refr.} + 1}$$

Phase transformation at Const. Pressure - Formation of steam



↳ Water in gaseous state or a two phase mixture (liquid + gas) is called steam. The homogeneous mixture of minute particles of mother liquid (water) in suspension with true gas of the same substance is called vapour.

↳ In order to consider the phase changes of water, consider one kg of ice at $t_1 = -10°C$ and at one atmospheric pressure (1.0133 bar) kept in a piston cylinder arrangement which is friction less and weight less. Let this ice be heated at uniform rate. Assuming the heating process to be at Const. atmospheric pressure. Here heat supplied (q) equals to enthalpy (h).

(i) PROCESS (A-B):- Temp. of ice increases from -10 to 0°C as a limit. Heat supplied during heating is called sensible heat of ice (h_i) and temp. 0°C represents the melting point of ice.

sensible heat of ice $h_i = C_{pi}(0 - t_i)$

where C_{pi} = specific heat of ice = 2.1 kJ/kgK

§ Process BC:- Ice begins to melt at 0°C on heating and two phase mixture of ice and water exist in equilibrium at 0°C. There is a small decrease in vol. which is peculiar to (belonging only to) water. The heat supplied to convert 1kg of ice at 0°C into water at 0°C is called latent heat of fusion (L_i) or enthalpy of fusion.

L_i = 335 kJ/kg at atmospheric pressure.

§ Process CD:- On further heating, the temp. of water increases until it reaches to temp. of vaporisation (t_s) or boiling. Such a liquid is called saturated liquid. The temp. corresponding to point D is known as saturation temp. (t_s) or boiling point of water.

The saturation temp. increases with the increase in pressure and it is equal to 100°C at 1 atm pressure.
Heat energy required to convert water at 0°C in saturated liquid is called enthalpy of water (h_f) or sensible heat.

§ Process D-E:- On heating of saturated liquid the vaporization of water starts at const. temp. Again we get two phase mixture of L and V.

↳ The state of steam after complete evaporation of water at saturation temp. is called Dry-saturated steam while the water particles associated with dry-saturated steam in vapour state is called wet steam.

↳ The heat energy required to vaporise the saturated liquid into dry-saturated steam is called latent heat of vaporisation or enthalpy of evaporation (h_{fg}).

↳ During conversion of liquid into steam the specific vol. increases.

§ Process EF:- On further heating the dry-saturated steam, the rise in temp. of steam is resumed and specific vol. of steam also increases. This process is called superheating of steam. The steam is called superheated steam.

↳ If Tsup. represents the temp of superheated steam at a certain state, the difference of Tsup. and saturation temp. (T_S) of steam is called degree of superheat. i.e. ($T_{sup} - T_S$).

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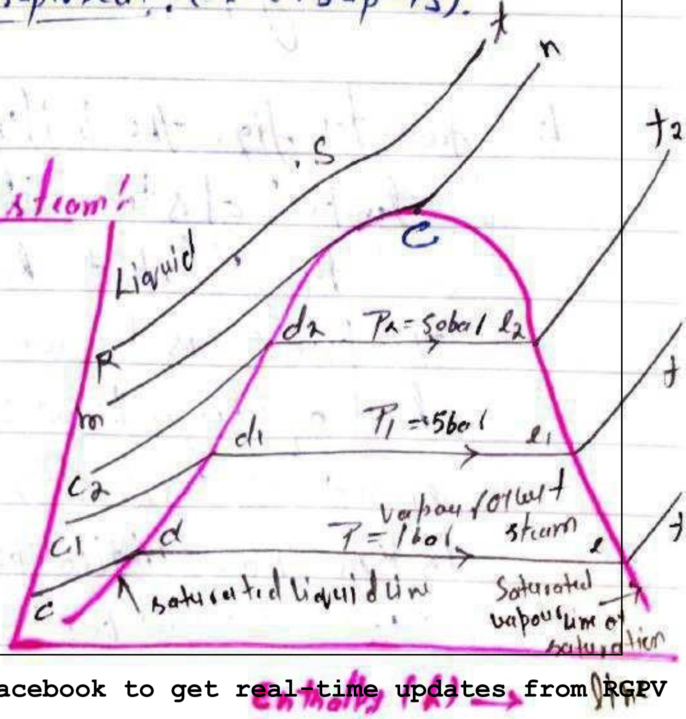
Dont Describe it Until Confirmation for it ↓

§ Temp. enthalpy diagram for steam:



↳ Now water at 0°C is heated at various const. pressures. represented by for $P = 1$ bar is represented by $cdef$ etc.

↳ Points d, d_1, d_2, represents the points of saturated liquid and the locus of such points is called saturated liquid line.

↳ Similarly e, e_1, e_2 represents the condition of steam as dry saturated. The curve joining such points is called the saturated vapour line.

↳ The L.H.S. of saturated liquid line represents the state of fluid as liquid, between the d & e in dome the state of fluid is vapour or wet steam. and at R.H.S. of saturated vapour line represents the superheated steam.

§ The temp. at which the vaporization of water takes place is known as "boiling point" temp. or "saturation temp."

↳ from the fig. the boiling temp. of water or saturation temp. of steam increases with the increase in pressure and the latent heat (enthalpy of vaporisation) decreases. The point C is known as "critical point", where the latent heat of steam becomes zero and density of water is equivalent to density of steam. The temp. & press. at 'C' is known as critical press. & temp.

$(P_C = 225.65 \text{ bar} \quad \& \quad T_C = 374.15°C)$

§ The heat required to evaporate 1kg of water from 0°C is the sum of h_f and the quantity of heat required to evaporate 1kg of water at saturation temp. which is

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

h_{fg} → latent heat of steam.

h_f → sensible heat of water

h_g → total heat or enthalpy of steam at saturated condition.

§ Steam whose temp. is above its saturation temp. is known as superheated steam and amount of heat added above saturation condition is known as enthalpy of superheat.

$$\boxed{h_{sup.} = h_g + C_{ps}(T_{sup} - T_s)}$$

$(T_{sup} - T_s)$ → degree of super heat.

C_{ps} → Specific heat of steam at const. Pressure

§ Dryness fraction:- The quality of steam is designated by the term "Dryness fraction" of steam which is defined as the ratio of mass of dry vapour to the total mass of mixture.

$$x = \frac{\text{mass of Dry vapour}}{\text{mass of mixture}} = \frac{m_g}{m_f + m_g}$$

where m_f = mass of water
& m_g = mass of steam } in a mixture

↳ The heat or enthalpy content of one kg of wet steam is given by

$$h = (1-x)h_f + x h_g$$
$$= (1-x)h_f + x(h_f + h_{fg})$$
$$\boxed{h = h_f + x h_{fg}}$$

§ Thermodynamic properties of steam and steam table:-

p = Absolute Pressure (kPa or bar)
T = Saturation temp. (in °C)
v_f = Specific vol. of saturated liquid (m^3/kg)
v_g = " " " " steam (m^3/kg)
h_f = enthalpy of saturated liquid (kJ/kg)
h_{fg} = enthalpy or latent heat of vaporization (kJ/kg)
h_g = enthalpy of saturated vapour (kJ/kg)
S_f = Entropy of saturated liquid (kJ/kgK)
S_g = " " " vapour (kJ/kgK).

↳ Change of vol. during evaporation $(v_{fg}) = v_g - v_f$

↳ " " enthalpy " " $(h_{fg}) = h_g - h_f$

↳ " " entropy " " $(S_{fg}) = S_g - S_f$

↳ Internal energy $u = h - pv$, for all states of the liquid where h is enthalpy, p is pressure & v is the specific vol.

§ Triple point :- It is a state at which all the three phases of mixture i.e. S, L, G can co-exist in equilibrium.

§ At a Pressure below triple point line the substance can not exist in liquid state and when the solid is heated it is directly converted into vapour state, such a process is called "sublimation process".

↳ The triple point of water is at 0.01°C temp. & 611 N/m² pressure.

§ Properties of Wet and superheated steam :

1. The density of dry steam $\rho_g = \frac{1}{v_g}$

↳ The specific vol. of wet steam whose dryness fraction x is given.

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

↳ Both we can find from steam table at given temp.

At low pressure $v_f << v_g$

$$v = x v_g$$

$$\therefore \rho = \frac{1}{x v_g}$$

2. Specific vol. of superheated steam is given by

$$v_{sup.} = v_g \cdot \frac{T_{sup}}{T_g}$$

↳ The density of superheated steam is given by

$$\rho_{sup.} = \frac{1}{v_{sup.}}$$

↳ Internal Energy:- Internal energy of the steam is given by

$$u = (h_f + x h_{fg}) - p(x v_g - v_f)$$

$$\approx (h_f + x h_{fg}) - p(x \cdot v_g)$$

if $x = 1$ then

$$\boxed{u = h_g - p v_g}$$

Internal energy of superheated steam

$$u_{sup.} = [h_f + h_{fg} + C_{ps}(T_{sup} - T_s)] - p \cdot v_{sup.}$$

where $v_{sup} = v_s \cdot \frac{T_{sup}}{T_s}$

↳ Entropy:- Entropy of saturated water

Natural log

$$s_f = C_w \log_e \left(\frac{T_s}{273}\right)$$

C_w = specific heat of water

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The introphy of evaporation $S_{fg} = \dfrac{h_{fg}}{T_s}$

↳ Entropy of wet steam is given by

Sol $S_g = C_w \log_e\left(\dfrac{T_s}{273}\right) + \dfrac{x \cdot h_{fg}}{T_s}$

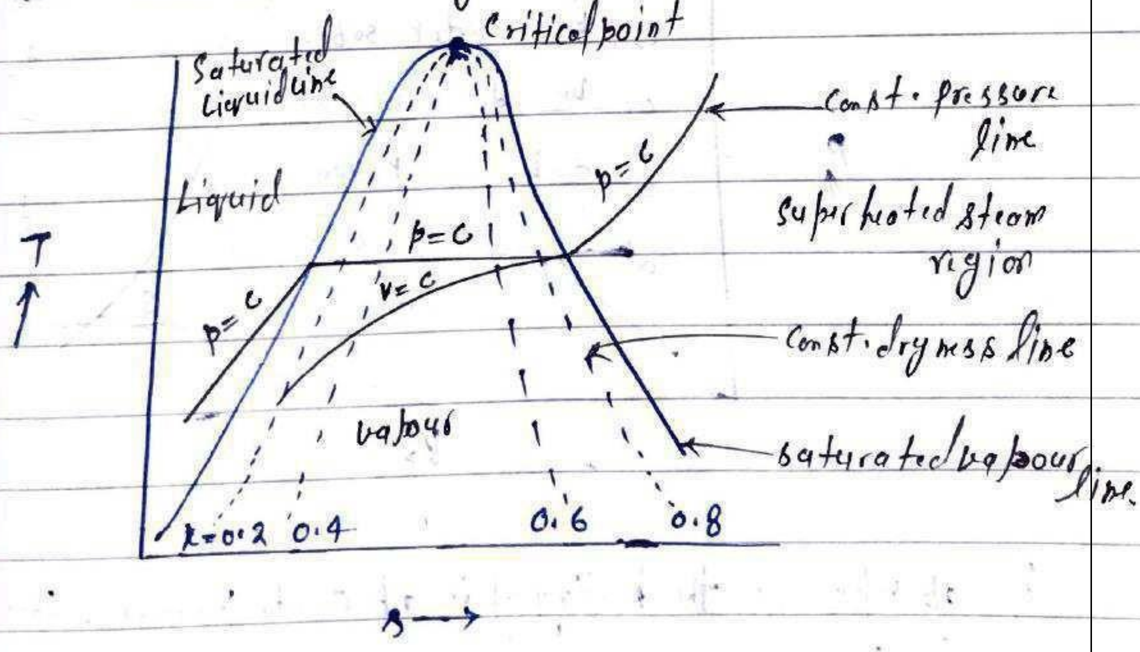
S_g when $x = 1$

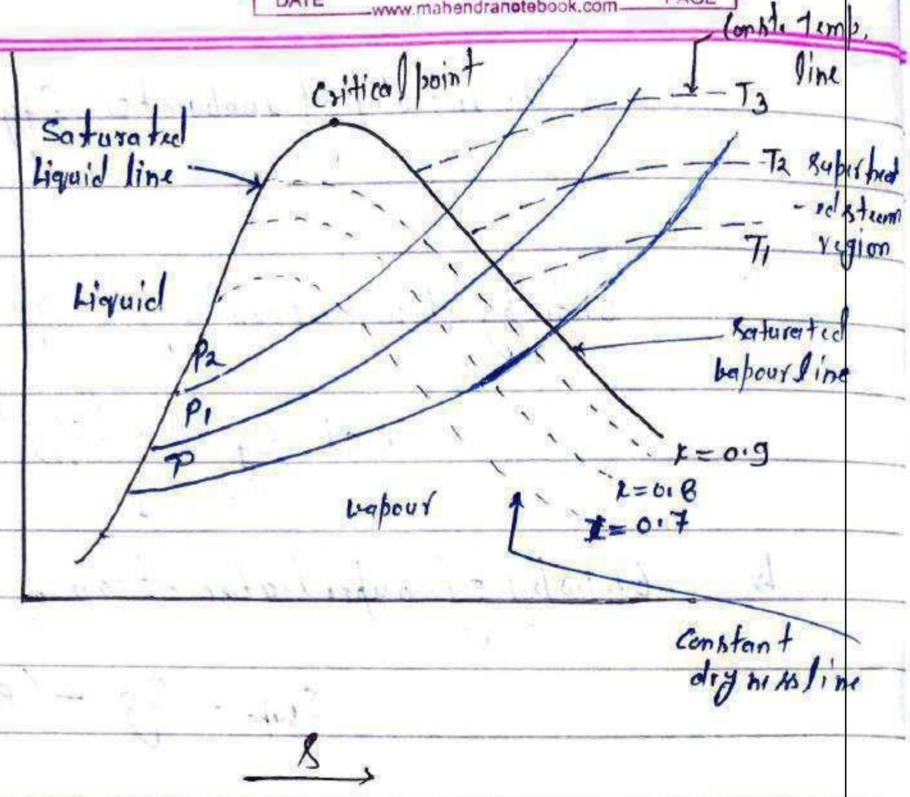
↳ Entropy of superheated steam

$S_{sup.} = S_g + C_{ps} \log_e\left(\dfrac{T_{sup.}}{T_s}\right)$

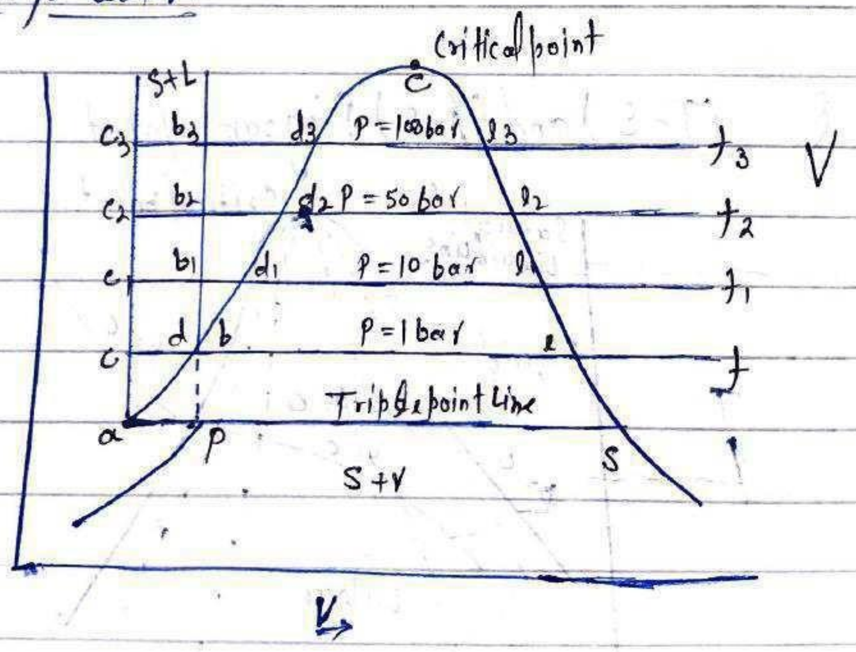
C_{ps} = specific heat of steam at const. Pressure.

§ (T-S) and (h-S) Diagrams for Steam:





§ P-V Diagram for water:



§ ab represents the heating of ice at const. pressure. Specific vol. of ice increases

§ bc represents the melting of ice at 0°C and at atmospheric pressure. During the melting specific vol. decreases.

 $S = S_f + x \cdot S_{fg}$

§ cd represents the heating of water from 0°C upto its saturation temp. ts. water below its saturation at given pressure is called - sub-cooled liquid.

§

de represents the heating of saturated liquid and its conversion into dry-saturated.

§ ef represents the superheating of steam.

§ Line joining the points b_1, b_2, b_3 represents the saturated solid line at which conversion from solid to liquid takes place.

§ Line joining points c, c_1, c_2 etc. and d, d_1, d_2, d_3 etc both shows the saturated liquid lines.
At state 'c' the liquid is saturated w.r. to solidification.
At state 'd' " " " " " " to vaporisation.

§ Points e, e_1, e_2, shows the saturated vapour line. Any point on this curve will represent the dry saturated steam corresponding to its pressure.

§ Saturated liquid line d, d_1, d_2 --- is almost a vertical line since large pressure are needed to compress a liquid.

§ Specific Enthalpy of water:

↳ It represents the amount of heat energy to be supplied to convert 1 kg. of water at 0°c to its saturation temp. (t_s) corresponding to a given steam pressure (P).

$$\therefore h_f = C_{pw}(t_s - 0)$$

$$C_{pw} = \text{Specific heat of water} = 4.187 \text{ KJ/kgK}$$

§ Latent Heat of Vaporisation:

It represents the amount of heat energy needed for complete evaporation of saturated liquid into dry saturated steam, at a given pressure (P.), denoted by h_{fg} (KJ/Kg).

↳ It will decrease with increase in pressure.

§ h of Dry saturated steam: It is the amount of heat energy needed to convert 1 kg of water at 0°c into dry-saturated steam at a given pressure, denoted by h_g

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

§ $$h_{sup} = h_g + C_p(t_{sup} - t_s)$$

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

§ Work of evaporation: $W_e = p.V$

Here $p = N/m^2$
$V = m^3/kg$

Specific vol. of steam $= V$ } m^3/kg
" " " water $= V_f$

then

$$W_e = p(V - V_f) \text{ kJ/kg}$$

§ Internal Energy: It is defined as the actual amount of energy stored in steam. out of the total heat supplied (enthalpy) during Const. pressure heating, a part of this energy is used for work of evaporation and the reminder is stored by the steam.

$$\therefore h = u + p.V$$

$$\boxed{u = h - pV}$$

§ Entropy of Superheated steam:

$$S_{sup} = S_g + C_p . \log_e \frac{T_{sup}}{T}$$

§ All cases:

§ Performance of Boilers:

1- Dry Saturated Steam

$$h_g = h_f + h_{fg}$$
$$u_g = h_g - p v_g$$
$$v_{fg} = (v_g - v_f)$$
$$\rho_g = \frac{1}{v_g}$$
$$s_g = C_w \log_e\left(\frac{T_s}{273}\right) + \frac{h_{fg}}{T_s}$$

2- Wet Steam -

$$h = h_g - (1-x) h_{fg}$$
$$u = h - Pv$$
$$v = x v_g + (1-x) v_f$$
$$\rho_m = \frac{1}{x v_g}$$
$$S_m = C_w \log_e\left(\frac{T_s}{273}\right) + \frac{x h_{fg}}{T_s}$$

3- Superheated Steam

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$$
$$u_{sup} = v_s \cdot \frac{T_{sup}}{T_s}$$
$$\rho_{sup} = \frac{1}{v_{sup}}$$
$$S_{sup} = C_w \log_e\left(\frac{T_s}{273}\right) + \frac{h_{fg}}{T_s} + C_{ps} \log_e\left(\frac{T_{sup}}{T_s}\right)$$

4- Const Vol. heating or cooling

$$x_1 v_{g1} = x_2 v_{g2}$$
$$\text{or } x_1 v_{g1} = v_{sup} = v_{g2} \cdot \frac{T_{sup}}{T_s}$$

5- Const. Pressure heating or cooling

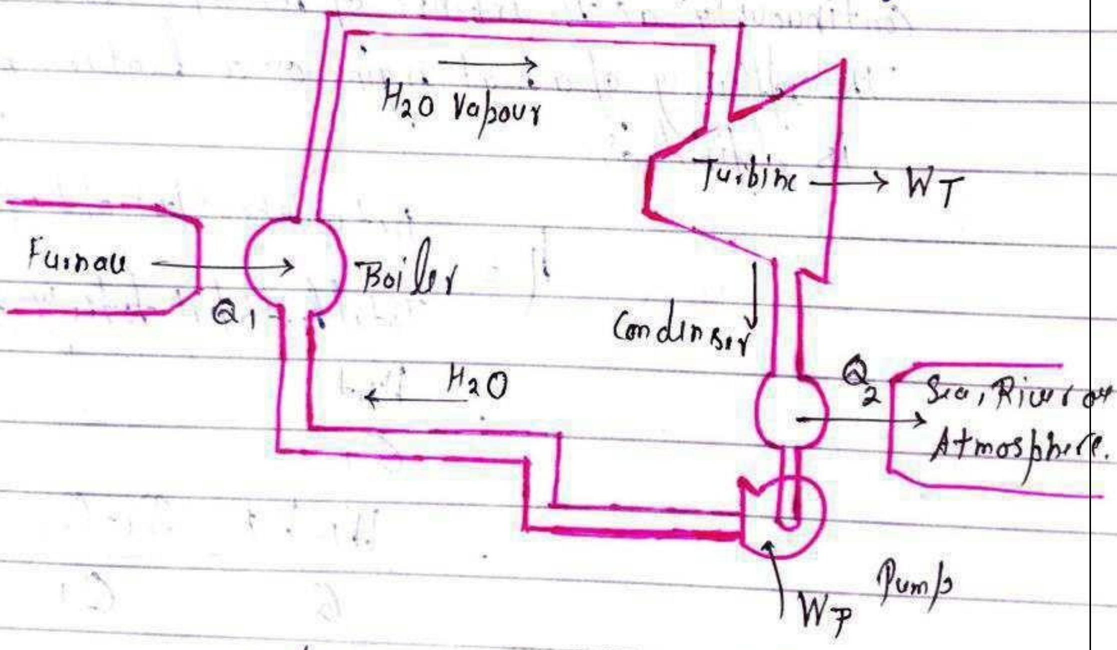
$$Q = h_2 - h_1$$

2nd Law of Thermodynamics:

Cyclic Heat Engine: A heat Engine is a thermodynamic cycle in which there is a net heat transfer to the system and a net work transfer from the system. The system which executes a heat engine cycle is called a heat engine.

In a cyclic heat Engine

heat (Q_1) is transferred from the furnace to the water in the boiler to form steam which then works on the turbine rotor to produce work W_T, then the steam is condensed to water in the condenser in which an ammount Q_2 is rejected from the system, and finally work W_P is done on the system (water) to pump it to the boiler. The system repeats the cycle.



~ Steady flow system interacting with the surroundings ~

The net heat transfer in a cycle to either of the heat engines

$$Q_{net} = Q_1 - Q_2$$

and the net work transfer in the cycle

$$W_{net} = W_T - W_P$$

By first law of thermodynamics we have

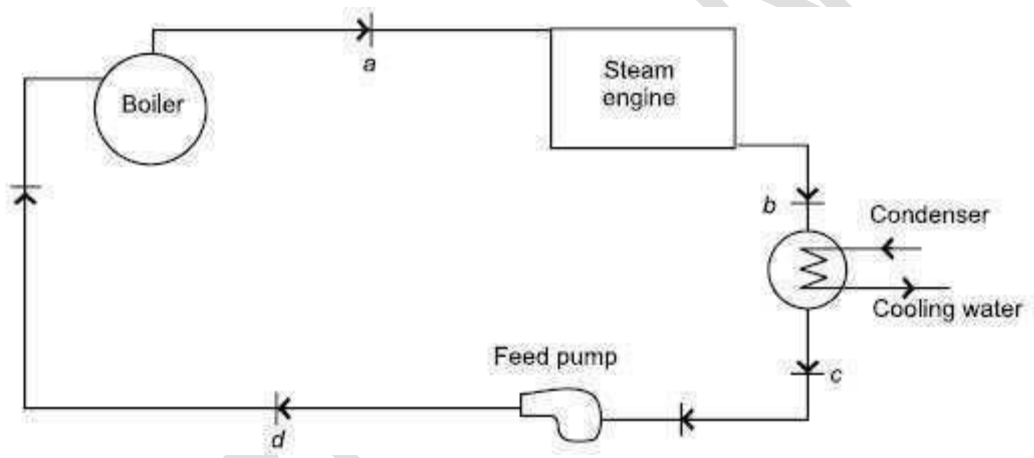
UNIT V

Reciprocating Machines: Working principle of steam Engine, Carnot, Otto, Diesel and Dual cycles P-V & T-S diagrams and its efficiency, working of 2- stroke & 4- stroke Petrol & Diesel engines. Working principle of compressor.

Introduction of Steam Engine

Steam engine is a device which is especially designed to transform energy. In steam engine the mechanical effect is seen due to the expansion of steam which is generated in boiler and supplied to steam engine. Steam engines have been successfully used in the mill, driving locomotive or steam boat, pumps, fans, blowers, small electricity generators, road rollers etc.

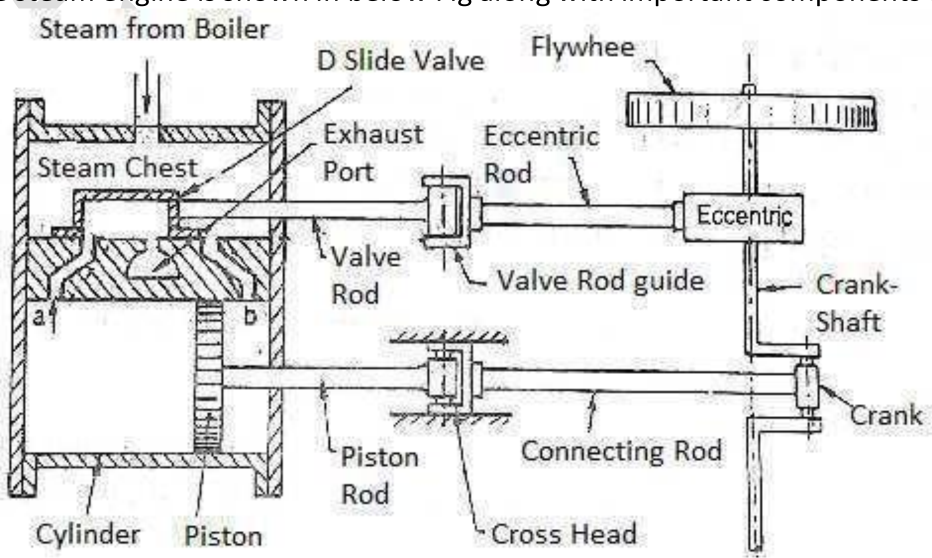
A steam engine plant shall have boiler, condenser, and feed pump along with steam engine. Steam generated in boiler is sent to steam engine where it is expanded up to certain pressure. Steam leaving engine are fed to condenser where steam gets converted into water which is sent back to boiler through feed pump. Figure shows the schematic of steam engine plant.



Schematic for simple steam engine plant

Working of Steam Engine

Schematic of simple steam engine is shown in below Fig along with important components in it.



Schematic of simple steam engine

Simple steam engine shown is a horizontal double acting steam engine having cylinder fitted with cylinder cover on left side of cylinder. Cylinder cover has stuffing box and gland through which the piston rod reciprocates. One end of piston rod which is inside cylinder has piston attached to it. Piston has piston rings upon it for preventing leakage across the piston. Other end of piston rod which is outside cylinder has cross head attached to it. Cross head slides in guide ways so as to have linear motion in line with engine axis. Cross head is connected to the small end of connecting rod by the gudgeon pin. Big end of connecting rod is mounted over crank pin of the crank. Reciprocating motion of piston rod is transformed into rotary motion of crankshaft by cross head, connecting rod and crank. Cross head transmits the motion of piston rod to connecting rod. Cross head guide ways bear the reaction force.
High pressure and high temperature steam enters from main inlet passage into steam chest. D-slide valve occupies such a position that passage from the steam chest to engine cylinder gets opened. High pressure steam enters cylinder and forces piston towards other dead centre. Linear motion of piston is transformed into rotation of crankshaft through crosshead, connecting rod, gudgeon pin and crank. When piston reaches other dead centre then the corresponding displacement of valve rod causes shifting of D-slide valve such that other passage from steam chest to cylinder gets opened and initial passage comes in communication with the exhaust passage. Thus the live steam enters from steam chest to cylinder through passage and dead steam leaves from cylinder to exhaust passage through another passage.

Parts of Steam Engine

1. **Frame: -** It is a heavy Cast Iron part, which supports all the stationary as well as moving parts and holds them in proper position. It generally rests on engine foundations.
2. **Cylinder: -** It is also a Cast Iron cylindrical hollow vessel, in which the piston moves To and Fro under the Steam Pressure. Both ends of the cylinder are closed and made steam tight. In small steam engines, the cylinder is made an integral part of the frame. One end is closed by a separate cover and the other end (Crank Side) carries the Stuffing Box through which the piston rod passes, as shown in fig.
3. **Steam Chest: -** It is Casted as an integral part of the cylinder and is closed by a separate cover. It can have a rectangular or circular section according to the type of valve used. Steam chest is connected to the cylinder through the valve passages as shown in fig. known as Ports. It also contains the D-Slide Valve. The steam is supplied alternately to the cylinder through the ports and it is exhausted alternately to the condenser from the cylinder through the ports as shown in fig.
4. **Inlet and Exhaust Ports: -** An opening at both ends of the cylinder is provided connecting it with the steam chest. These openings are known as Ports. A valve moving over these openings connects the cylinder to the live steam supply and to the exhaust alternately.
5. **D – Slide Valve: -** The function of D-Slide Valve as mentioned earlier is to connect the cylinder to the steam chest and to the exhaust side through the ports at the correct crank positions. The valve is actuated by an eccentric drive.
6. **Piston: -** It is also made of Cast Iron. The steam pressure acts on the piston and exerts a force on the piston. The piston is connected to the piston rod and which transmits the force to the crank through the cross-head and connecting rod. The piston diameter is slightly smaller than that of the cylinder bore to allow free movement. Steam tightness is achieved by the use of piston rings.
7. **Piston Rod: -** It is made of Mild Steel. One end of it is connected to the piston and the other is connected to the cross-head. The main function of the piston rod is to transmit the force on the piston to the cross-head.
8. **Piston Rings: -** These are made of Cast Iron and are fitted in the grooves provided on the piston. The function of the piston rings is to provide a leak tight joint between the cylinder and piston in order to prevent the leakage of steam from the high pressure side to the low pressure side, at the same time allowing the movement of the piston in the cylinder.
9. **Stuffing Box and Gland: -** It is fitted on the crank end side of the cylinder as shown in the fig. It is place at the point where the piston rod passes through the cylinder cover. The main function of the stuffing

box is to prevent leakage of the steam from the cylinder to atmosphere, at the same time allowing the piston rod a free movement.

10. **Cross – Head: -** It forms a connecting link between the piston rod and the connecting rod. It guides the motion of the piston rod and also carries the small end of the connecting rod.
11. **Connecting Rod: -** It is made up forged steel, whose one end is connected to the cross – head and the other to the crank. Its function is to convert reciprocating motion of the piston (or cross – head**)** into rotary motion of the crank.
12. **Crank Shaft:** - It is main shaft of the engine having crank. The crank works on the lever principle and produces rotary motion of the shaft. The crank shaft is supported on main bearing of the engine.
13. **Eccentric:** - It is generally made up of cast iron, and is fitted to the crank shaft. Its function is to provide reciprocating motion of the Slide Valve.
14. **Eccentric Rod and Valve Rod:** - The eccentric rod is made up of forged steel, whose one end is fixed to the eccentric and other to the valve rod. Its function is to convert rotary motion of the crank shaft into to and fro motion of the valve rod. The valve rod connects the eccentric and D-Slide valve. Its function is to provide Simple Harmonic Motion to the D – Slide Valve.
15. **Flywheel: -** It is a heavy cast iron wheel, mounted on the crank shaft. Its function is to prevent the fluctuation of engine. It also prevents the jerks to the crankshaft.
16. **Governor: -** It is a devise to keep the engine speed, more or less, uniform at all load conditions. It is done either by controlling the quantity of pressure of the steam supplied to the engine.

Classification of I. C. Engine:-

The I. C. Engines are classified on the basis on the following:

1. According to piston strokes in the working cycle:
i) Four Stroke Engine, ii) Two Stroke Engine

2. According to the Fuel used in the cycle:
i) Petrol Engine, ii) Diesel Engine, iii) Gas Engine, and iv) Multi-Fuel Engine

3. According to Method of Ignition:
i) Spark Ignition, ii) Compression Ignition

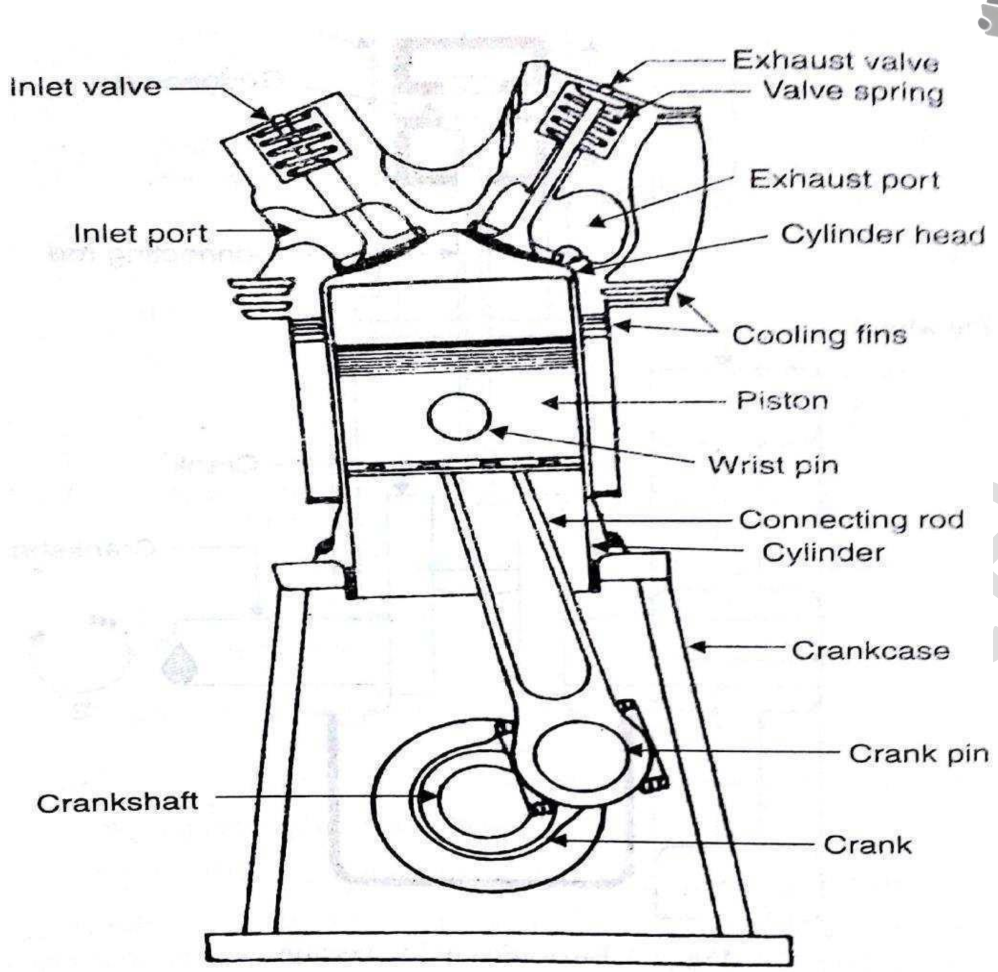
4. According to Cooling System:
i) Air-Cooled Engine, ii) Liquid-Cooled Engine

5. According to the Number of Cylinders:
i) Single Cylinder Engine, ii) Multi-Cylinder Engine

6. According to Speed of Engine:
i) Low Speed Engine, ii) Medium Speed Engine, and iii) High Speed Engine

7. According to Position of Engine:
i) Horizontal Engine, ii) Vertical Engine, and iii) V- Engine

COMPONENTS OF I. C. ENGINES:-
The essential Parts of Otto-cycle and Diesel-cycle Engines are same. A few of them are shown in fig.



Main Components of an Internal Combustion Engine

Cylinder: - It is the heart of the engine. The piston reciprocates in the cylinder. It has to withstand high pressure and temperature, thus it is made strong. Generally it is made up of Cast Iron.

Cylinder Head: - The top cover of the cylinder, towards TDC (Top Dead Centre) is called Cylinder Head. It houses the spark plug in petrol engines and fuel injector in Diesel Engines. For Four Stroke Cycle Engines, the cylinder head has the housing of inlet and exhaust valves.

Piston: - It is reciprocating part of engine. It is made of usually Cast Iron or Aluminum alloys. Its top surface is called Piston Crown and bottom surface is piston skirt. Its top surface is made flat for four stroke engines and deflected for two stroke engines.

Piston Rings: - The two or three piston rings are provided on piston. The piston rings seal the space between cylinder liner and piston in order to prevent leakage (blow by losses) of high pressure gases, from cylinder to crank case.

Crank: - It is rotating member. It makes circular motion in the crank case (its housing). Its one end is connected with shaft called Crank-Shaft and other end is connected with connecting rod.

Crank-Case: - It is housing of the crank and body of the engine to which cylinder and other engine parts are fastened. It also acts as a ground for lubricating oil.

Connecting Rod: - It is a link between piston and crank. It is connected at its one end with crank and on other end with piston. It transmits power developed on the piston to crank shaft through crank. It is usually made of medium carbon steel.

Crank Shaft: - It is shaft, a rotating member, which connects crank and the power developed by the engine is transmitted outside through this shaft. It is made up of medium carbon or alloy steel.

Cam Shaft: - It is provided on four stroke engines. It carries two cams, for controlling the opening and closing of inlet and exhaust valves.

Inlet Valve: - This valve controls the admission of charge into the engine during suction stroke.

Exhaust Valve: - The removal of exhausted gases after doing work on the piston is controlled by the valve.

Fly Wheel: - It is mounted on the crank shaft. It is made of Cast Iron. It stores energy in the form of inertia, when energy is in excess and it gives back energy when it is deficit. In other words, it minimizes the speed fluctuations on the engine.

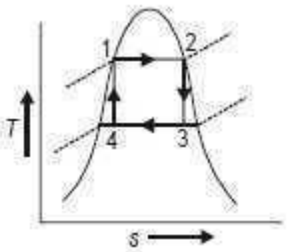
Internal Combustion Engine Terminology
Some of the generally used terms in internal combustion engines are given as under.
Stroke: It is the nominal distance travelled by the piston between two extreme positions in the Cylinder.
Dead centre: It refers to the extreme end positions inside the cylinder at which piston reverses its motion. Thus, there are two dead centers in cylinder, called as 'top dead centre' or 'inner dead centre' and 'bottom dead centre' or 'outer dead centre'.
Swept volume: It is the volume swept by piston while travelling from one dead centre to the other. It may also be called stroke volume or displacement volume. Mathematically,

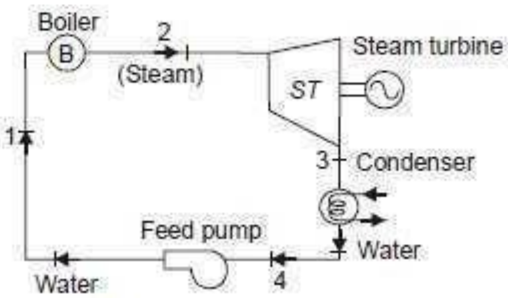
Swept volume = Piston area × Stroke

Clearance volume: It is the volume space above the piston inside cylinder, when piston is at top dead centre. It is provided for cushioning considerations and depends, largely upon compression ratio.
Compression ratio: It is the ratio of the total cylinder volume when piston is at BDC to the clearance volume.

Compression ratio = (Swept Vol. + clearance Vol.)/ Clearance Vol.

Carnot Cycle
Carnot cycle is an ideal cycle having highest thermodynamic efficiency. Let us use Carnot cycle for getting positive work with steam as working fluid. Arrangement proposed for using Carnot vapor power cycle is as follows.
1 – 2 = Reversible isothermal heat addition in the boiler
2 – 3 = Reversible adiabatic expansion in steam turbine
3 – 4 = Reversible isothermal heat rejection in the condenser
4 – 1 = Reversible adiabatic compression or pumping in feed water pump





Carnot vapor power cycle and A schematic arrangement for Carnot cycle

Assuming steady flow processes in the cycle and neglecting changes in kinetic and potential energies, thermodynamic analysis may be carried out.

Thermal Efficiency = Net Work / Heat Added
Net Work = Turbine Work - Compression/Pumping Work
For Unit Mass flow,
$W = (h_2 - h_3) - (h_1 - h_4)$

Heat Added, $Q_{add} = (h_2 - h_1)$

$\eta_{carnot} = (h_2 - h_3) - (h_1 - h_4) / (h_2 - h_1)$

$\eta_{carnot} = 1 - (h_3 - h_4) / (h_2 - h_1)$

Here, Heat Rejected, $Q_{rejected} = (h_3 - h_4)$

Or, $\eta_{carnot} = 1 - Q_{rejected} / Q_{add}$

Also heat added and rejected may be given as function of temperature and entropy as follows:

$Q_{add} = T_1 \times (S_2 - S_1)$

$$Q_{rejected} = T_3 \times (S_3 - S_4)$$

Also $S_1 = S_4$ and $S_2 = S_3$

Therefore substituting values:

$$\eta_{carnot} = 1 - T_3 / T_1$$

Or, $$\eta_{carnot} = 1 - T_{minimum} / T_{maximum}$$

Working of 2-Stroke Petrol Engine:- In 1878, Dugald–Clerk, a British Engineer introduced a cycle which could be completed in Two Strokes of piston rather than Four Strokes as is the case with the Four Stroke Cycle Engines. The following operations take place in Two Stroke or in One Cycle of the engine:

Charge Transfer and Scavenging: When piston is nearer to crank case (Bottom Dead Centre), the Transfer Port and Exhaust Port are uncovered by piston, a mixture of Air and Fuel as a charge, slightly compressed in the crank case, enters through the Transfer Port and drives out the burnt gases of previous cycle through the Exhaust Port.

In Two Stroke Engines, the piston Top is made deflected. Therefore, the incoming charge is directed upward, aids in sweeping of the burnt gases out of the cylinder. This operation is known as Scavenging (A gas exchange process).

As piston moves upward the fresh charge passes into the cylinder 1/6 th of the revolution and exhaust port remains open little longer than transfer port.

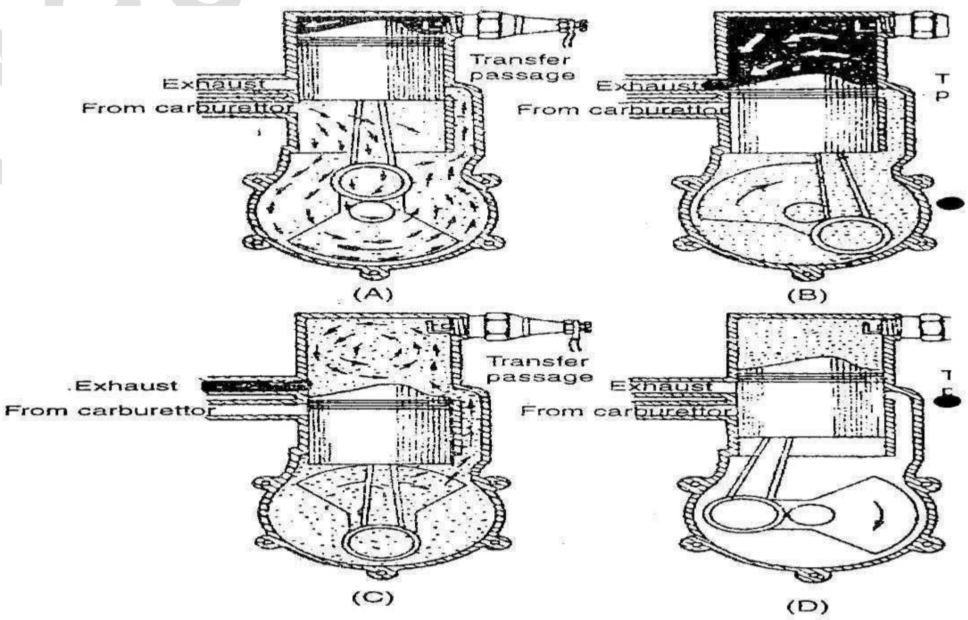
Compression and Suction: As piston moves upward, both Transfer Port and Exhaust Port are covered by piston and the charge trapped in the cylinder is compressed by the piston's upward movement as shown in fig. At the same time, the partial vacuum is created into crank case, the Suction Port opens by moving crank and fresh charge enters the crank case.

Combustion: When the piston reaches at its end of stroke nearer to cylinder head or at Top Dead Centre, a highly intensity Spark from Spark Plug ignites the charge and initiates the combustion in the cylinder. The burning of the charge generates the pressure in the cylinder.

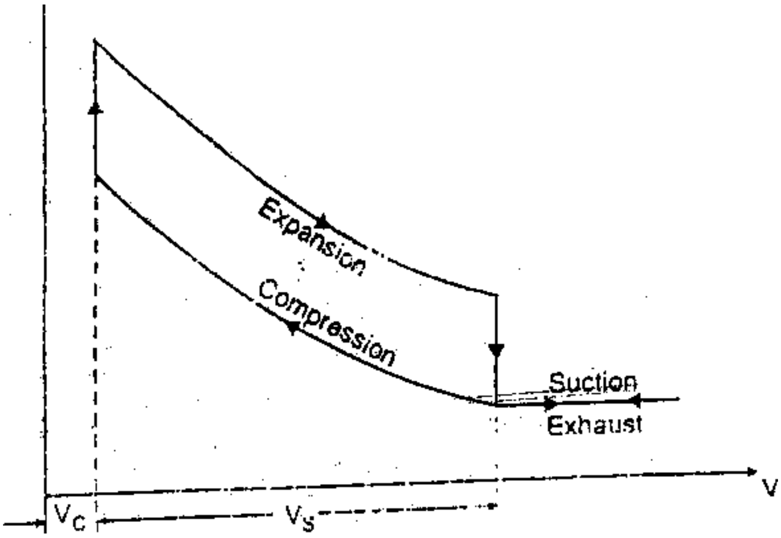
Power and Exhaust: The burning gases exert pressure on the top of the piston and piston is forced downward as a result of pressure generated.

As piston descends through about 80% of the expansion stroke, the Exhaust Port is uncovered by the piston, and the combustion gases leave the cylinder by pressure difference and at the same time, and at the same time, underside of piston causes compression of charge taken into crank case as shown in fig.

Charging: The slightly compressed charge in the crank case passes through Transfer Port and enters the cylinder as soon as it is uncovered by descending piston and when it approaches the Bottom Dead Centre, the cycle is completed.



TWO – STROKE PETROL ENGINE



P- V Diagram of a Two – Stroke Petrol Engine

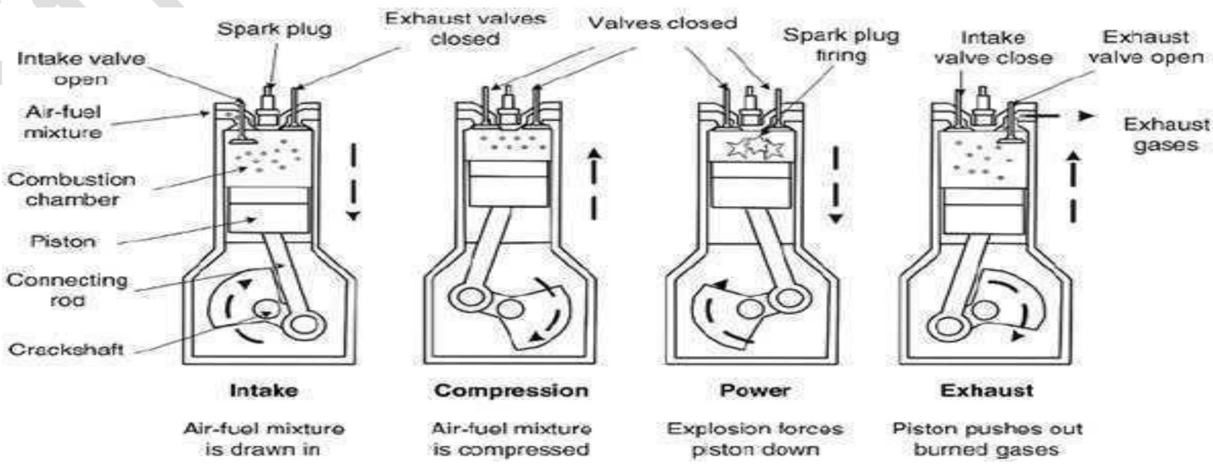
Working of Four Stroke Petrol Engine: - The 4 Stroke Otto Cycle refers to its use in Petrol Engines, Gas Engines, in which the mixture of Air and Fuel are drawn in the engine cylinder. Since ignition in these engines is due to a Spark, therefore they are also called Spark Ignition Engines. The work is obtained only during one stroke out of four. The strokes are as follows:-

Suction: During this stroke, the inlet valve stays open and the exhaust valve closed. The piston moves downward from TDC to BDC by means of crankshaft, this piston movement creates a pressure difference between outside and inside the cylinder and the higher pressure of the atmosphere forces the air fuel mixture from the carburetor into the cylinder through inlet valve.

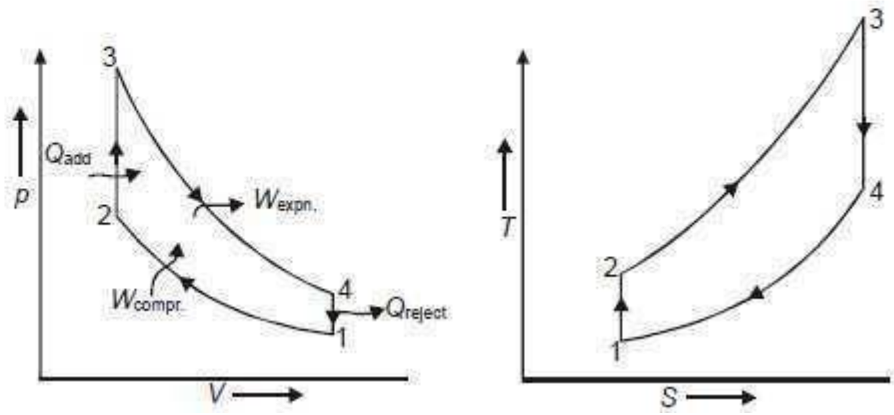
Compression: The air fuel mixture, sucked during the suction stroke, is compressed in this stroke. Piston moves from BDC to TDC. Just a little before the end of compression stroke, a spark produced by spark plug ignites the compressed mixture. Both the inlet and exhaust valves remain closed during this stroke.

Working or Power Stroke: The inlet and exhaust valves remain closed during this stroke. Product of combustion (hot gases) expands due to high temperature and pressure, due to this the piston starts to move downward from TDC to BDC and the power is obtained.

Exhaust: The inlet valve remains closed while the exhaust opens. The major portion of burnt gases escapes due to own expansion. The upward movement of the piston from BDC to TDC pushes the remaining gases out of the open exhaust valve. Only a small quantity of burnt gases stays in the clearance space. This cycle or series of events take place over and over again.

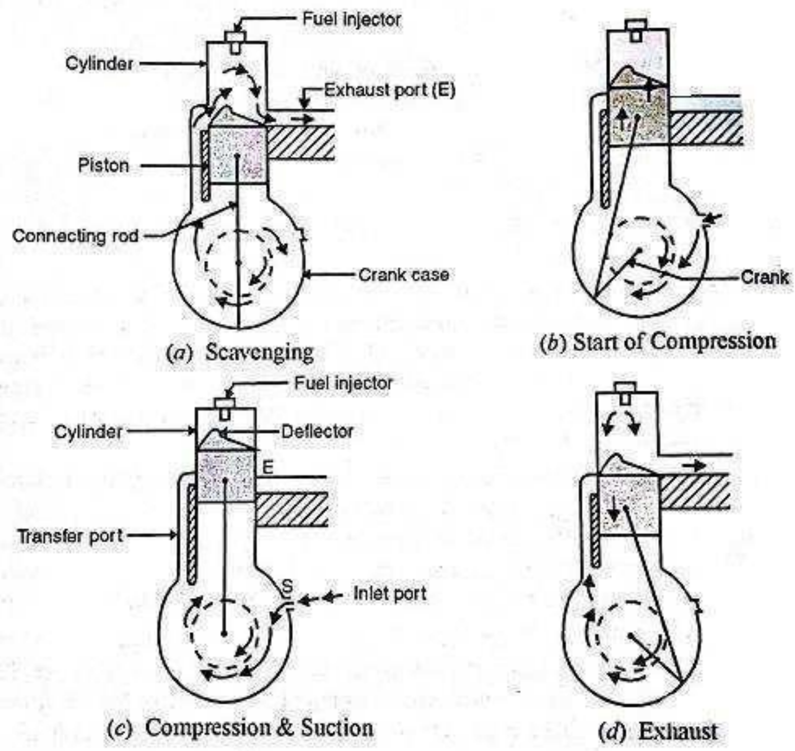


VALVE TIMING DIAGRAM OF FOUR STROKE PETROL ENGINE



P- V and T-S Diagram

Working of Two Stroke Diesel Engine: - All engines using Diesel as a fuel operate on Diesel Cycle. They work similar to Petrol Engine except they take in only Air as charge during suction and fuel is injected at the end of compression stroke. The Diesel Engines have Fuel Injector instead of Spark Plug in Cylinder head as shown in fig. The Diesel engines use high compression ratio in the range of 14 to 21. The temperature of intake air reaches a quite high value at the end of compression. Therefore, the injected fuel is self – ignited.



TWO STROKE DIESEL ENGINE

In Diesel Engines the following operations take place during a power stroke.

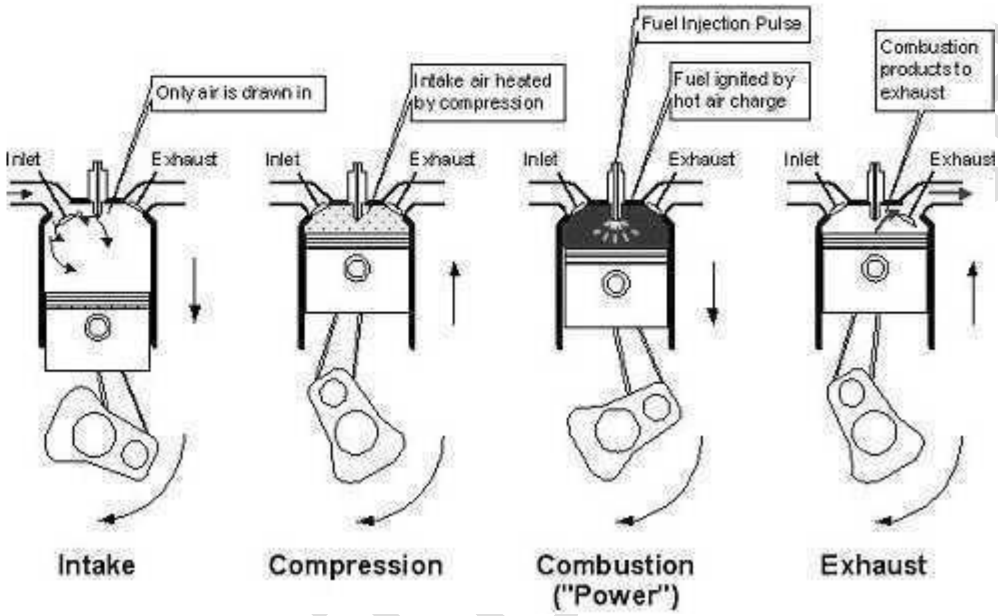
Suction or Induction Stroke: The piston moves down from the Top Dead Centre (TDC) to Bottom Dead Centre (BDC). The air is drawn into the cylinder through inlet valve, which closes at the end of this stroke. The exhaust valve remains closed during this stroke.

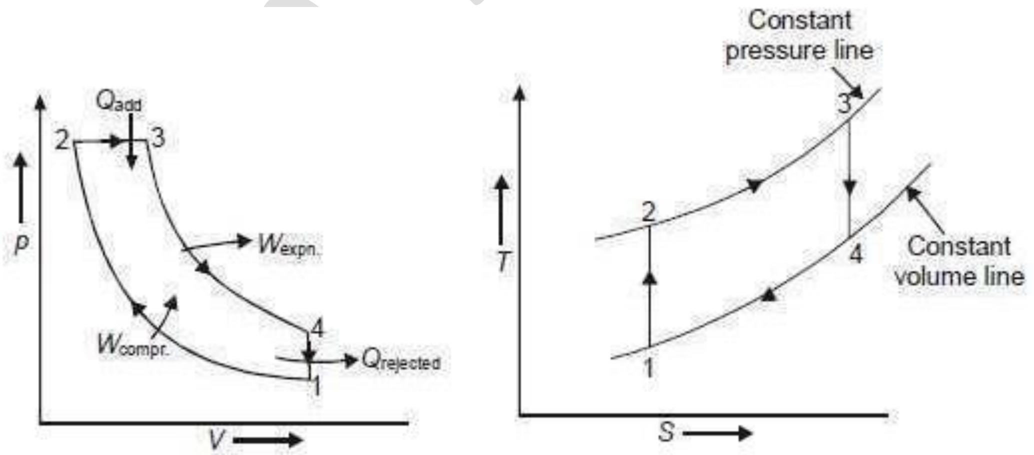
Compression Stroke: In a vertical engine the piston moves up towards TDC from BDC position. The inlet valve is now closed. The air drawn in the cylinder in the previous stroke is entrapped inside the cylinder and compressed with the upward movement of the piston. As the compression ratio used in this engine is high (14: 22) the air is finally compressed to a pressure as high as 40 bars at which its temperature is high (as high as 10000 C) enough to ignite the fuel. As the piston moves after reaching TDC the fuel is injected into the hot compressed air where it starts burning, maintaining the pressure constant.

Working or Power Stroke: Both inlet and exhaust valves remains closed during this stroke. The product of combustion now expands in the engine cylinder pushing the piston down, and hence doing work. The piston finally reaches the BDC position.

Exhaust Stroke: The piston now moves up once again. The inlet and fuel valves are closed but the exhaust valve opens. Major part of the burnt gases escape due to their own expansion. The upward movement of the piston pushes the remaining gasses out through the open exhaust valve. The exhaust valve closes at the end of the exhaust stroke. The cycle is thus completed.

All the above processes are shown in give diagrams

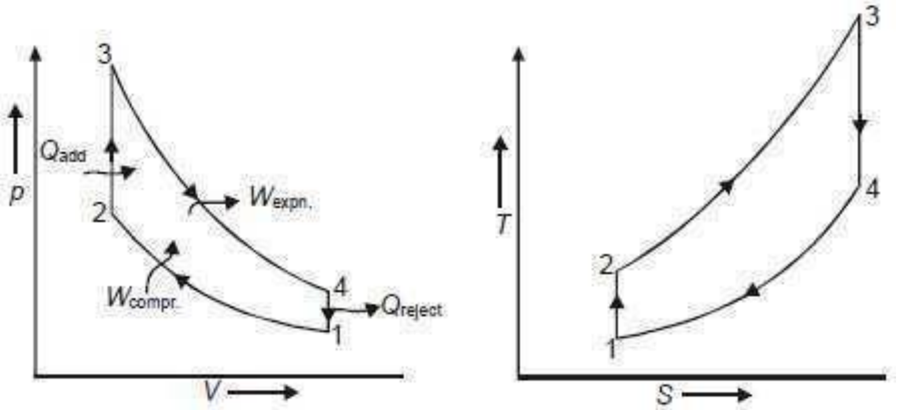




P- V and T-S Diagram for 4-stroke Diesel Engine

Efficiency of Otto Cycle

This is a modified form of Carnot cycle in order to make it a realistic cycle. Otto cycle has two constant volume and two adiabatic processes as shown below.



P- V and T-S Schematic Diagram Of Otto Cycle

Thermodynamic processes constituting Otto cycle are
1 – 2 = Adiabatic compression process,
2 – 3 = Constant volume heat addition process
3 – 4 = Adiabatic expansion process
4 – 1 = Constant volume heat rejection process
In order to have an engine based on Otto cycle let us find out the relevance of above processes. Spark ignition type internal combustion engines are based on this cycle.
Process 1 – 2, adiabatic compression process can be realized by piston moving from volume *V*1 to *V*2 and therefore compressing air.
Process 2 – 3, heat addition process can be undertaken in constant volume manner with piston at volume *V*2 and heat added to working fluid.
Heat addition is practically realized by combustion of fuel and air. As a result of heat addition the compressed air attains state 3 and it is allowed to expand from 3–4 adiabatically. After expansion air is brought back to original state 1 by extracting heat from it at volume *V*1.
Internal combustion engine based on Otto cycle is explained ahead. Let us find air-standard thermal efficiency of Otto cycle.
Compression ratio for the cycle shown can be given by the ratio of volumes of air before and after compression. It is generally denoted by *r*. For unit mass of air and properties at states given with
Subscript 1, 2, 3, 4, we can write,

$$r = V_1/V_2 = V_4/V_3$$

Heat added during 2–3, constant volume process

$$Qadd = CV \times (T3 - T2)$$

Heat rejected during 4–1, constant volume process

$$Qrejected = CV \times (T4 - T1)$$

Air standard efficiency of Otto cycle

$$\eta otto = \text{net work done / heat Supplied}$$

For a cycle,

$$\text{Net work} = \text{Heat added} - \text{Heat rejected}$$
$$= CV \{(T3 - T2) - (T4 - T1)\}$$

Substituting in the expression for efficiency;

$$\eta otto = Cv\,(T_3\text{-}T_2) - (T_4\text{-}T_1) / Cv\,(T_3\text{-}T_2)$$

OR $$\eta otto = 1 - (T_4\text{-}T_1)/ (T_3\text{-}T_2)$$

For perfect gas, by gas laws,

$$T_2 / T_1 = (V_1 /V_2)^{\gamma-1} = r^{\gamma-1}$$

And

$$T_3/T_4 = r^{\gamma-1}$$

From above $T_2 / T_1 = T_3/T_4$

OR $1 - T_2 /T_3 = 1 – T_1 /T_4$

Substituting in the expression for ηotto

$$\eta_{otto} = 1 – (1/r^{\gamma-1})$$

Efficiency of Diesel cycle

Diesel cycle is modified form of Otto cycle. Here heat addition process is replaced from constant volume type to constant pressure type. In a piston cylinder arrangement heat addition with piston at one position allows very little time for heat supply in Otto cycle. By having heat addition at constant pressure the sufficient time is available for heat supply in Diesel cycle. Compression ignition engines work based on Diesel cycles.

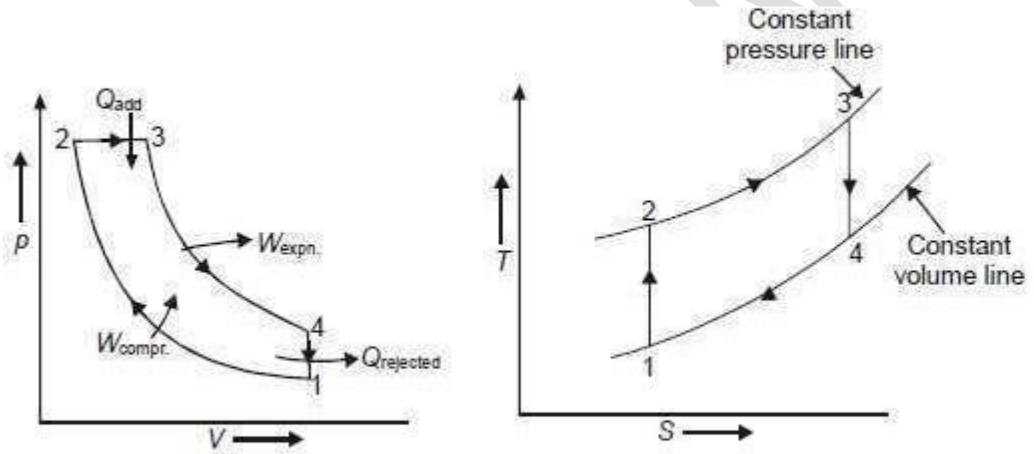
Thermodynamic processes constituting Diesel cycle are as given below.

1 – 2 = Adiabatic compression,

2 – 3 = Heat addition at constant pressure

3 – 4 = Adiabatic expansion,

4 – 1 = Heat rejection at constant volume



P- V and T-S diagram of Diesel Engine

Thermodynamic analysis of the cycle for unit mass of air shows;

Heat added = Cp $(T_3 – T_2)$

Heat rejected = Cv $(T_4 – T_1)$

Let us assume; Compression ratio,

$r = V_1/V_2$

Cut off Ration $\rho = V_3/V_2$ and Expansion Ratio $= V_4/V_3$

Air standard efficiency for Diesel cycle may be given as,

$$\eta_{diesel} = \text{net work done / heat Supplied}$$

$$\eta_{diesel} = 1 – (1/\gamma) (T_4-T_1)/(T_3-T_2)$$

Using perfect gas equation and governing equation for thermodynamic process 1 –2;

PV = RT

And

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

Combining above two, we get

$T_2 = T_1 r^{\gamma-1}$

$T3 = T1\, r^{\gamma-1} \rho$

Also for adiabatic process 3 – 4 combining the following:
We get,

$$T_3/T_4 = (r/\rho)^{\gamma-1}$$

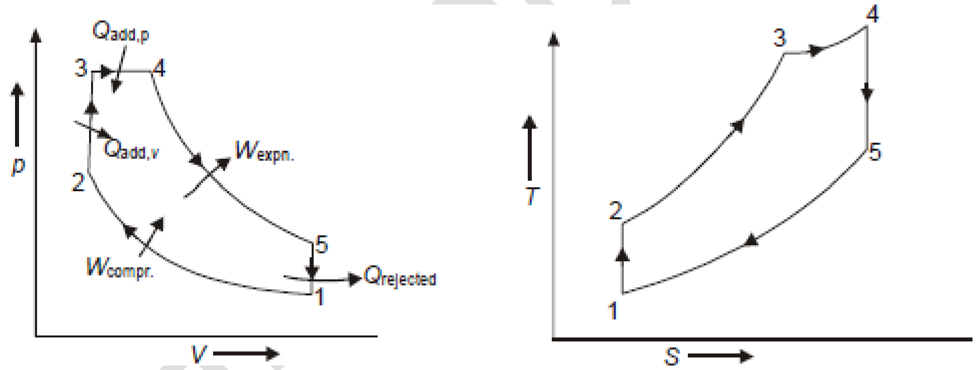
So

$$T_4 = T_1 (r)^{\gamma-1}$$

Substituting T_2, T_3 and T_4 as function of T_1, in the expression of air standard efficiency of Diesel Cycle

$\eta_{diesel} = 1 - (1/\gamma) \{(\rho^{\gamma}-1)/ r^{\gamma-1}(\rho -1)\}$

Efficiency of Dual cycle:
It is also called 'mixed cycle' or 'limited pressure cycle.' Dual cycle came up as a result of certain merits and demerits associated with Otto cycle and Diesel cycle due to heat addition occurring at constant volume and constant pressure respectively. Dual cycle is the combination of Otto cycle and Diesel cycle in which heat addition takes place partly at constant volume and partly at constant pressure.
Thermodynamic processes involved in Dual cycle are given as under.
1 – 2 = Adiabatic compression
2 – 3 = Heat addition at constant volume
3 – 4 = Heat addition at constant pressure
4 – 5 = Adiabatic expansion
5 – 1 = Heat rejection at constant volume



P - V and T - S Diagrams of Dual Cycle

Let us assume for following thermodynamics analysis:
Clearance Volume = Unity

Compression Ratio, $r = V_1/V_2$
Cut-off 'atio, $\rho = V_3/V_4$
Pressure 'atio during Heat Addition, $\alpha = P_3/P_2$
For unit mass of air as working fluid throughout the cycle.
Total Heat added = Heat added at Constant Volume (2 - 3) + Heat added at Constant Pressure (3 - 4)

$Q_{add} = C_v (T_3 - T_2) + C_p (T_4 - T_3)$

$Q_{rejected} = C_v (T_5 - T_1)$

Air standard efficiency for Dual Cycle can be given as:
η_{dual} = (Heat Added - Heat Rejected) / (Heat Added)
$\eta_{dual} = [\{C_v(T_3 - T_2) + C_p (T_4 - T_3)\} - \{C_v (T_5 - T_1)\}] / [C_v(T_3 - T_2) + C_p (T_4 - T_3)]$
$\eta_{dual} = 1 - [C_v (T_5 - T_1)] / [C_v(T_3 - T_2) + C_p (T_4 - T_3)]$

$\eta_{dual} = 1 - [(T_5 - T_1)] / [(T_3 - T_2) + \gamma (T_4 - T_3)]$

From gas laws applied to process 2–3,

$P_3 / T_3 = P_2 / T_2$

Or, $T_2 = (P_2 X T_3) / P_3$

$T_2 = T_3 / \alpha$

For process 3–4,

$V_4 / T_4 = V_3 / T_3$

$T_4 = (V_4 X T_3) / V_3$

$T_4 = \rho T_3$

For adiabatic process 4–5,

$$T_4/T_5 = (V_5/V_4)^{\Upsilon-1}$$

$T_5 = T_4 / (V_5/V_4)^{\Upsilon-1}$

Substituting T_4

$T_5 = T_3 \times \rho^{\Upsilon} / (r)^{\Upsilon-1}$

For adiabatic Process 1-2,

$T_1 = T_2 / r^{\Upsilon-1}$

Substituting for T_2

$T_1 = T_3 /\alpha r^{\Upsilon-1}$

Substituting for T_1, T_2, T_4 and T_5 in expression for efficiency,

$\eta_{dual} = 1 - (1/r^{\Upsilon-1}) [(\alpha . \rho^{\Upsilon} - 1) / (\alpha -1) + \alpha. \Upsilon(\rho -1)]$

Working principle of compressor

Compressors are the devices which is used to compress the fluids like air or gases with the help of energy supplied to them in the form of electricity is used to compress the fluid.

Working of compressor is same as working of an engine in which during suction if only air is supplied when piston moves from TDC to BDC and during movement of piston from BDC to TDC this air will be compressed same as the charge is compressed during this stroke, The difference is only that here engine will run with the help of a electric motor for the movement of piston from TDC to BDC, and there is no spark and ignition as only air is going inside the system, this compressed air will be discharged from the exhaust port of the compressor and will be stored in a tank for further use like to fill the air in tires or for other industrial purpose.