Energy

The energy is defined as the ability to do work. Energy exists in various forms e.g. mechanical, thermal, electrical etc. One form of energy can be converted into other by the use of suitable arrangements.

Sources of Energy

The various sources of energy are:

1. Fuels
   - Solids – Coal, coke anthracite etc
   - Liquids – Petroleum and its derivates
   - Gases – Natural gas blast furnace gas etc
2. Energy stored in water
3. Nuclear energy
4. Wind energy
5. solar energy
6. Tidal Power
7. Geothermal energy
8. Thermoelectric power

Fuels

Fuels may be chemical or nuclear.

A chemical fuel is a substance which releases heat energy on combustion. The principal combustible elements of each fuel are carbon and hydrogen. Though sulphur is a combustible element too but its presence in the fuel is considered to be undesirable.

Fuels can be classified according to whether

1. they occur in nature called primary fuels (or) are prepared called secondary fuels.
2. they are in solid, liquid (or) gaseous state.

Type of Fuel	Natural (Primary)	Prepared (Secondary)
Solid	Wood	coke
	Peat	charcoal
	Lignite coal	Briquettes
Liquid	Petroleum	Gasoline
		Kerosene
		Fuel oil
		Alcohol
		Benzol
		shale oil
Gaseous	Natural gas	Petroleum gas
		Producer gas
		coal gas
		coke-oven gas
		Blast furnace gas
		carburetted gas
		sewer gas

The energy sources are of two types

1. Renewable energy resources — solar energy, Tidal energy, wind energy
2. Non-renewable energy resources – fossil fuels

✓ Electric power generation using the non-renewable energy resources are called as the conventional power generation.

✓ The power generation using the renewable energy resources is known as non conventional power generation.

Research and Development of Power

→ Wind (primarily renewable natural) power harnesses the power of the wind to propel the blades of wind turbines.

→ At the end of 2011, the capacity of wind-powered generators was 238 gigawatts worldwide.

→ Europe has built many solar photovoltaic power stations

→ Charanka solar park (India, 214 MW) is the largest photovoltaic power plant in the world, as of April 2012, and the second place is the Golmud solar park (China, 200 MW)

→ The world's largest geothermal power station is 'The Geysers' in california, with a capacity of 750 MW.

Heat Engines

Any type of engine or machine which derives heat energy from the combustion of fuel or any other sources and converts this energy into mechanical work is termed as a heat engine.

Heat engines may be classified into two main classes

1. External combustion engines
2. Internal combustion engines

External Combustion engines

In this case, combustion of fuel takes place outside the cylinder as in case of steam engines where the heat of combustion is employed to generate steam which is used to move a piston in a cylinder.

Internal Combustion engines

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

Classification of I.C Engines

1. According to cycle of operation
   - i) Two stroke cycle engines
   - ii) Four stroke cycle engines
2. According to cycle of combustion
   - i) Otto cycle engine
   - ii) Diesel cycle engine
   - iii) Dual-combustion or semi-Diesel cycle engine
3. According to arrangement of cylinder
   - i) Horizontal engine
   - ii) Vertical engine
   - iii) V-type engine
   - iv) Radial engine

4. According to the speed of the engine
i) Low speed engine
ii) medium speed engine
iii) High speed engine

5. According to method of ignition
i) spark ignition engine
ii) Compression ignition engine

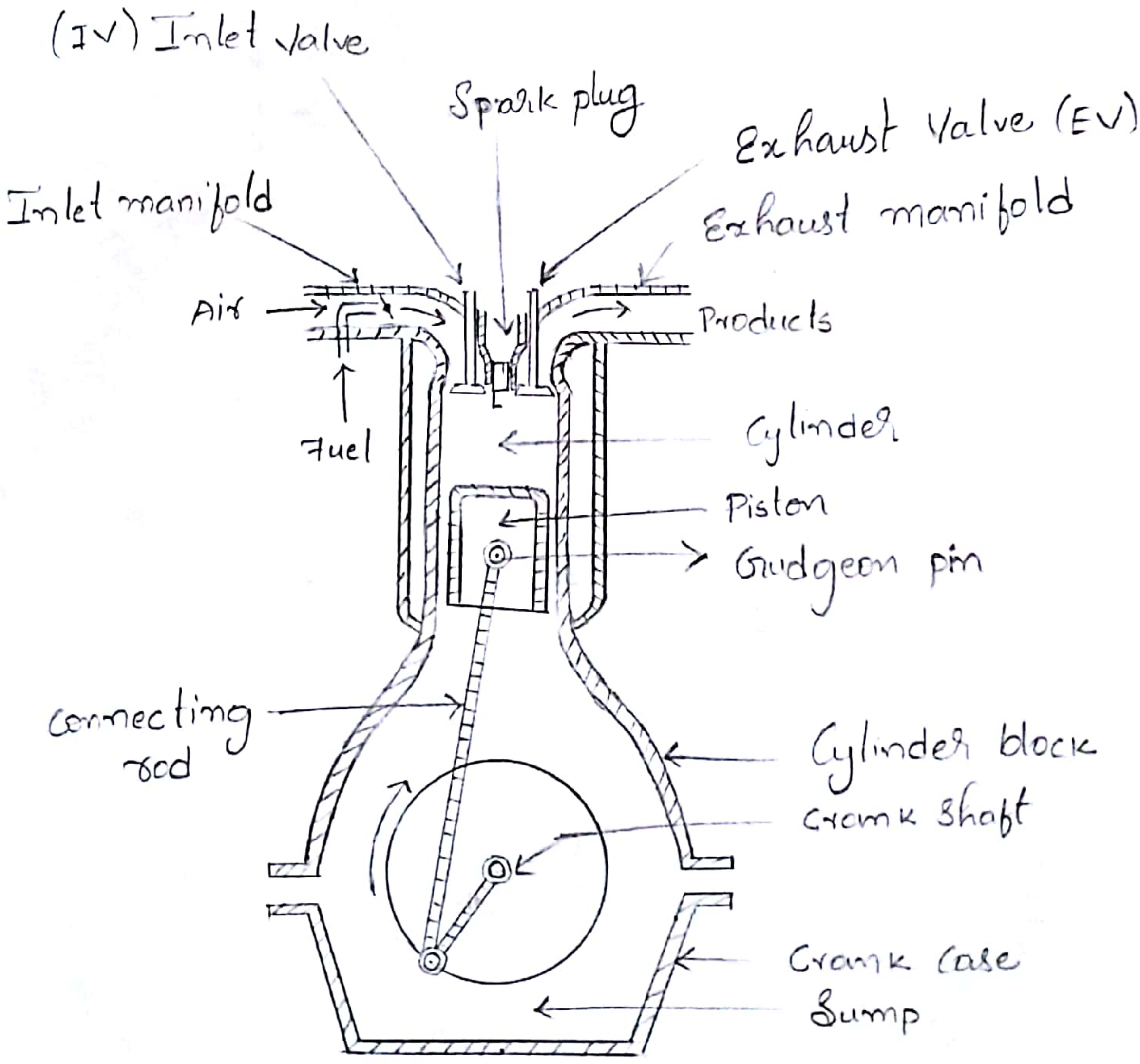
6. According to method of cooling the cylinder
i) Air-cooled engine
ii) water - cooled engine

7. According to number of cylinders
i) single cylinder engine
ii) multi-cylinder engine

8. According to the fuel employed and the method of fuel supply to the engine cylinder
i) oil engine
ii) Petrol engine
iii) Gas engine
iv) Kerosene engine

9. According to their uses
i) stationary engine
ii) Portable engine
iii) Marine engine
iv) Automobile engine
v) Aero engine

Cross-section of a spark-ignition engine



Cylinder Block

The cylinder block is the main supporting structure for the various components. The cylinder of a multicylinder engine are cast as a single unit, called cylinder block. The cylinder head is mounted on the cylinder block. The cylinder head and cylinder block are provided with water jackets in the case of water cooling or with cooling fins in the case of air cooling. Cylinder head gasket is incorporated between the cylinder block and cylinder head. The cylinder head is held tight to the cylinder block by number of bolts or studs. The bottom portion of the cylinder block is called crankcase. A cover called crankcase which becomes a sump for lubricating oil is fastened to the bottom of the crankcase. The inner surface of the cylinder block which is machined and finished accurately to cylindrical shape is called bore or face.

Cylinder

As the name implies it is a cylindrical vessel or space in which the piston makes a reciprocating motion. The varying volume created in the cylinder during the operation of the engine is filled with the working fluid and subjected to different thermodynamic processes. The cylinder is supported in the cylinder block.

Piston

It is a cylindrical component fitted into the cylinder forming the moving boundary of the combustion system. It fits perfectly (snugly) into the cylinder providing a gas-tight space with the piston rings and the lubricant. It forms the first link in transmitting the gas forces to the output shaft.

Combustion Chamber

The space enclosed in the upper part of the cylinder, by the cylinder head and the piston top during the combustion process, is called the combustion chamber. The combustion of fuel and the consequent release of thermal energy results in the building up of pressure in this part of the cylinder.

Inlet Manifold

The pipe which connects the intake system to the inlet valve of the engine and through which air or air-fuel mixture is drawn into the cylinder is called the inlet manifold.

Exhaust Manifold

The pipe which connects the exhaust system to the exhaust valve of the engine and through which the products of combustion escape into the atmosphere is called the exhaust manifold.

Inlet and Exhaust Valves

Valves are commonly mushroom shaped poppet type. They are provided either on the cylinder head or on the side of the cylinder for regulating the charge coming into the cylinder (inlet valve) and for discharging the products of combustion (exhaust valve) from the cylinder.

Spark Plug

It is a component to initiate the combustion process in spark-ignition engines and is usually located on the cylinder head.

Connecting Rod

It interconnects the piston and the crankshaft and transmits the gas forces from the piston to the crankshaft. The two ends of the connecting rod are called as small end and the big end. Small end is connected to the piston by gudgeon pin and the big end is connected to the crank-shaft by crankpin.

Crankshaft

It converts the reciprocating motion of the piston into useful rotary motion of the output shaft. In the crankshaft of a single cylinder engine there are a pair of crank arms and balance weights. The balance weights are provided for static and dynamic balancing of the rotating system. The crankshaft is enclosed in a crankcase.

Piston Rings

Piston rings, fitted into the slots around the piston, provide a tight seal between the piston and the cylinder wall thus preventing leakage of combustion gases.

Gudgeon Pin

It links the small end of the connecting rod and the piston.

Camshaft

The camshaft and its associated parts control the opening and closing of the two valves. The associated parts are push rods, rocker arms, valve springs and tappets. This shaft also provides the drive to the ignition system. The camshaft is driven by the crankshaft through timing gears.

Cams

These are made as integral parts of the camshaft and are so designed to open the valves at the correct timing and to keep them open for the necessary duration.

Flywheel

The net torque imparted to the crankshaft during one complete cycle of operation of the engine fluctuates causing a change in the angular velocity of the shaft. In order to achieve a uniform torque an inertia mass in the form of a wheel is attached to the output shaft and this wheel is called the flywheel.

Nomenclature

Cylinder Bore (d)

The nominal inner diameter of the working cylinder is called the cylinder bore and is designated by the letter d and is usually expressed in millimeter (mm).

Piston Area (A)

The area of a circle diameter equal to the cylinder bore is called the piston area and is designated by the letter A and is usually expressed in square centimeter (cm^2).

Stroke (L)

The nominal distance through which a working piston moves between two successive reversals of its direction of motion is called the stroke and is designated by the letter L and is expressed usually in millimeter (mm).

Stroke to Bore Ratio

L/d ratio is an important parameter in classifying the size of the engine. If $d < L$, it is called under-square engine. If $d = L$, it is called square engine. If $d > L$, it is called over-square engine.

Dead Centre

The position of the working piston and the moving parts which are mechanically connected to it, at the moment when the direction of the piston motion is reversed at either end of the stroke is called the dead centre. There are two dead centres in the engine. They are

i) Top Dead Centre ii) Bottom Dead Centre

Top Dead Centre (TDC)

It is the dead centre when the piston is farthest from the crankshaft. It is designated as TDC for vertical engines and Inner Dead Centre (IDC) for horizontal engines.

Bottom Dead Centre (BDC)

It is the dead centre when the piston is nearest to the crankshaft. It is designated as BDC for vertical engines and Outer Dead Centre (ODC) for horizontal engines.

Displacement or Swept Volume (V_s)

The nominal volume swept by the working piston when travelling from one dead centre to the other is called the displacement volume. It is expressed in terms of cubic centimeter (cc) and given by

$$V_s = A \times L = \frac{\pi}{4} d^2 L$$

Cubic Capacity or Engine Capacity

The displacement volume of a cylinder multiplied by number of cylinders in an engine will give the cubic capacity or the engine capacity. For example, if there are K cylinders in an engine, then

$$\text{Cubic capacity} = V_s \times K$$

Clearance Volume (V_c)

The nominal volume of the combustion chamber above the piston when it is at the top dead centre is the clearance volume. It is designated as V_c and expressed in cubic centimeter (cc).

Compression Ratio (r)

It is the ratio of the total cylinder volume when the piston is at the bottom dead centre, V_T, to the clearance volume, V_c. It is designated by the letter 'r'.

$$r = \frac{V_T}{V_c} = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c}$$

If an engine is to work successfully then it has to follow a cycle of operations in a sequential manner. The sequence is quite rigid and cannot be changed.

The credit of inventing the spark-ignition engine goes to Nicolaus A. Otto (1876) whereas compression-ignition engine was invented by Rudolf Diesel (1892). Therefore, they are often referred to as Otto engine and Diesel engine.

Four-Stroke Spark-Ignition Engine

In a four-stroke engine, the cycle of operations is completed in four strokes of the piston or two revolutions of the crankshaft. During the four strokes, there are five events to be completed, viz., suction, compression, combustion, expansion and exhaust. Each stroke consists of 180° of crankshaft rotation. The cycle of operation for an ideal four-stroke SI engine consists of the following four strokes:
i) suction or intake stroke; ii) compression stroke;
iii) expansion or power stroke and iv) exhaust stroke.

The details of various processes of a four-stroke spark-ignition engine with overhead valves are shown in Fig. When the engine completes all the five events under ideal cycle mode, the pressure-volume (p-V) diagram will be as shown in Fig.

Suction or Intake stroke

Suction stroke 0→1 starts when the piston is at the top dead centre and about to move downwards. The inlet valve is assumed to open instantaneously and at this time the exhaust valve is in the closed position. Due to the suction created by the motion of the piston towards the bottom dead centre, the charge consisting of fuel-air mixture is drawn into the cylinder. When the piston reaches the bottom dead centre the suction stroke ends and the inlet valve closes instantaneously.

Compression Stroke

The charge taken into the cylinder during the suction stroke is compressed by the return stroke of the piston 1→2; During this stroke both inlet and exhaust valves are in closed position. The mixture which fills the entire cylinder volume is now compressed into the clearance volume. At the end of the compression stroke the mixture is ignited with the help of a spark plug located on the cylinder head. In ideal engines it is assumed that burning takes place instantaneously when the piston is at the top dead centre and hence the burning process can be approximated as heat addition at constant volume. During the burning process the chemical energy of the fuel is converted into heat energy producing a temperature rise of about 2000°c (process 2→3). The pressure at the end of the combustion process is considerably increased due to the heat release from the fuel.

Expansion or Power stroke

The high pressure of the burnt gases forces the piston towards the BDC, (stroke 3→4). Both the valves are in closed position. Of the four-strokes only during expansion.

Exhaust stroke

At the end of the expansion stroke the exhaust valve opens instantaneously and the inlet valve remains closed. The pressure falls to atmospheric level a part of the burnt gases escape. The piston starts moving from the bottom dead centre to top dead centre (stroke 5→0) and sweeps the burnt gases out from the cylinder almost at atmospheric pressure. The exhaust valve closes when the piston reaches TDC. at the end of the exhaust stroke and some residual gases trapped in the clearance volume remain in the cylinder.

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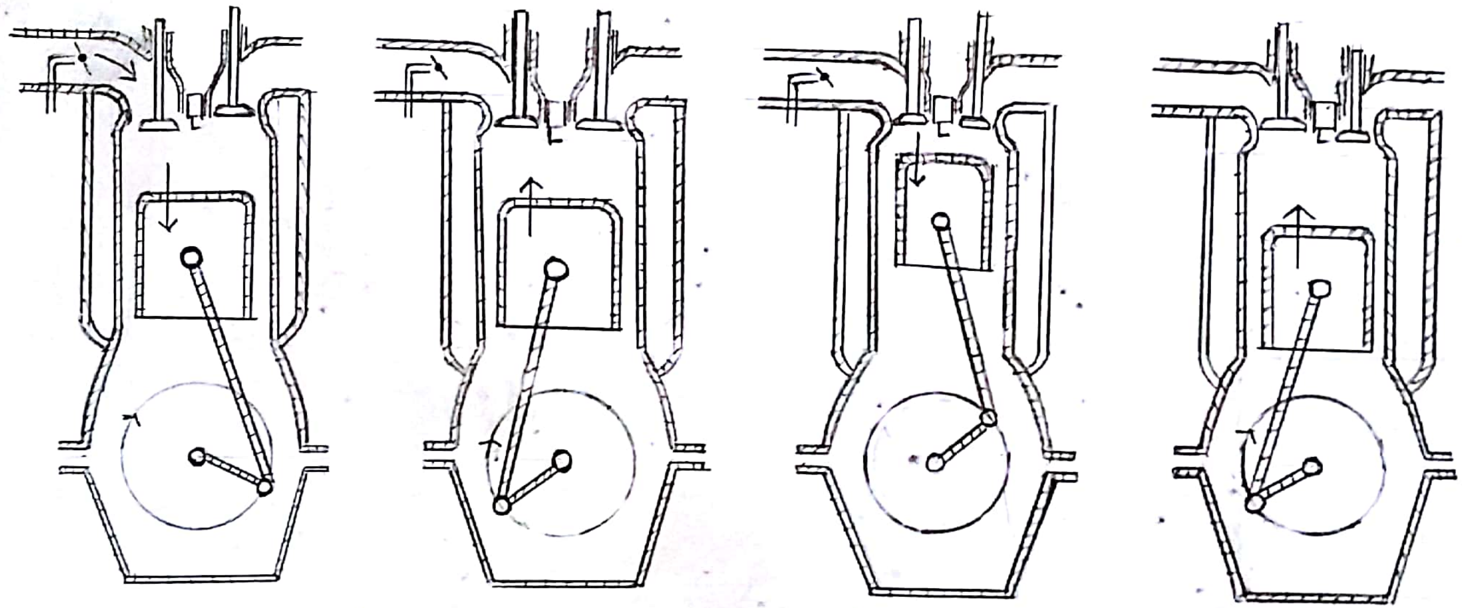
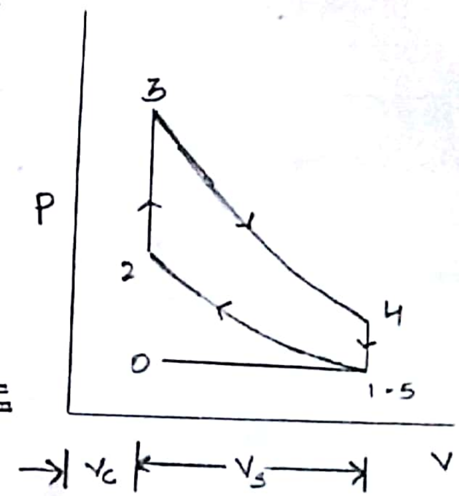
Working principle of a four-stroke SI engine



Intake Compression Expansion Exhaust



Four-Stroke Compression-Ignition Engine

The four-stroke CI engine is similar to the four stroke SI engine but it operates at a much higher compression ratio. The compression ratio of an SI engine is between 6 and 10 while for a CI engine it is from 16 to 20. In the CI engine during suction stroke, air, instead of a fuel-air mixture, is inducted. Due to higher compression ratios employed, the temperature at the end of the compression stroke is sufficiently high to self ignite the fuel which is injected into the combustion chamber. In CI engines, a high pressure fuel pump and an injector are provided to inject the fuel into the combustion chamber. The carburettor and ignition system necessary in the SI engine are not required in the CI engine.

The ideal sequence of operations for the four-stroke CI engine as shown in Fig. is as follows:

Suction Stroke

Air alone is inducted during the suction stroke. During this stroke inlet valve is open and exhaust valve is closed.

Compression Stroke

Air inducted during the suction stroke is compressed into the clearance volume. Both valves remain closed during this stroke.

Expansion stroke

Fuel injection starts nearly at the end of the compression stroke. The rate of injection is such that combustion maintains the pressure constant in spite of the piston movement on its expansion stroke increasing the volume. Heat is assumed to have been added at constant pressure. After the injection of fuel is completed (i.e after cut-off) the products of combustion expand. Both the valves remain closed during the expansion stroke.

Exhaust Stroke

The piston travelling from BDC to TDC pushes out the products of combustion. The exhaust valve is open and the intake valve is closed during this stroke. The ideal p-v diagram is shown in Fig.

In both SI and CI four-stroke engines, there is one power stroke for every two revolutions of the crankshaft. There are two non-productive strokes of exhaust and suction which are necessary for flushing the products of combustion from the cylinder and filling it with the fresh charge respectively. If this purpose could be served by an alternative arrangement, without involving the piston movement, then it is possible to obtain a power stroke for every revolution of the crankshaft increasing the output of the engine. However, in both SI and CI engines operating on four-stroke cycle, power can be obtained only in every two revolution of the crankshaft. Since both SI and CI engines have much in common, it is worthwhile to compare them based on important parameters like basic cycle of operation, fuel induction, compression ratio etc.

Description	SI Engine	CI Engine
Basic Cycle	Works on otto cycle or constant volume heat addition cycle.	Works on Diesel cycle or constant pressure heat addition cycle.
Fuel	Gasoline, a highly volatile fuel. Self-ignition temperature is high.	Diesel oil, a non-volatile fuel. Self-ignition temperature is comparatively low.
Introduction of fuel	A gaseous mixture of fuel-air is introduced during the suction stroke. A carburettor and an ignition system are necessary. Modern engines have gasoline injection.	Fuel is injected directly into the combustion chamber at high pressure at the end of the compression stroke. A fuel pump and injector are necessary.
Load Control	Throttle controls the quantity of fuel-air mixture to control the load.	The quantity of fuel is regulated to control the load. Air quantity is not controlled.

Description	SI Engine	CI Engine
Ignition	Requires an ignition system with spark plug in the combustion chamber. Primary voltage is provided by either a battery or a magneto.	Self ignition occurs due to high temperature of air because of the high compression. Ignition system and spark plug are not necessary.
Compression Ratio	6 to 10. Upper limit is fixed by antiknock quality of the fuel.	16 to 20. Upper limit is limited by weight increase of the engine.
Speed	Due to light weight and also due to homogeneous combustion, they are high speed engines.	Due to heavy weight and also due to heterogeneous combustion, they are low speed engines.
Thermal efficiency	Because of the lower CR, the maximum value of thermal efficiency that can be obtained is lower.	Because of higher CR, the maximum value of thermal efficiency that can be obtained is higher.
Weight	Lighter due to comparatively lower peak pressures.	Heavier due to comparatively higher peak pressures.

Injection Systems

The fuel-injection system is the most vital component in the working of CI engines. The engine performance viz., power output, economy etc. is greatly dependent on the effectiveness of the fuel-injection system. The injection system has to perform the important duty of initiating and controlling the combustion process.

Basically, the purpose of carburetion and fuel-injection is the same viz., preparation of the combustible charge. But in case of carburetion fuel is atomized by processes relying on the air speed greater than fuel speed at the fuel nozzle, whereas, in fuel-injection the fuel speed at the point of delivery is greater than the air speed to atomize the fuel. In carburetors, air flowing through a venturi picks up fuel from a nozzle located there. The amount of fuel drawn into the engine depends upon the air velocity in the venturi. In a fuel-injection system, the amount of fuel delivered into the air stream going to the engine is controlled by a pump which forces the fuel under pressure.

When the fuel is injected into the combustion chamber towards the end of compression stroke, it is atomized into very fine droplets. These droplets vaporize due to heat transfer from the compressed air and form a fuel-air mixture. Due to continued heat transfer from hot air to the fuel, the temperature reaches a value higher than its self-ignition temperature. This causes the fuel to ignite spontaneously initiating the combustion process.

Functional Requirements of an Injection System

For a proper running and good performance from the engine, the following requirements must be met by the injection system:

i) Accurate metering of the fuel injected per cycle. This is very critical due to the fact that very small quantities of fuel being handled. Metering errors may cause drastic variation from the desired output. The quantity of the fuel metered should vary to meet changing speed and load requirements of the engine.

ii) Timing the injection of the fuel correctly in the cycle so that maximum power is obtained ensuring ~~fuel economy and clear burning.~~

iii) Proper control of rate of injection so that the desired heat-release pattern is achieved during combustion.

iv) Proper atomization of fuel into very fine droplets.

v) Proper spray pattern to ensure rapid mixing of fuel and air.

vi) Uniform distribution of fuel droplets in the combustion chamber.

vii) To supply equal quantities of metered fuel to all cylinders in case of multi cylinder engines.

viii) No lag during beginning and end of injection i.e., to eliminate dribbling of fuel droplets into the cylinder.

Classification of Injection Systems

In a constant-pressure cycle or diesel engine, only air is compressed in the cylinder and then fuel is injected into the cylinder by means of a fuel-injection system. For producing the required pressure for atomizing the fuel either air or a mechanical means is used. Accordingly the injection systems can be classified as:

i) Air injection systems

ii) Solid injection systems

Air Injection System

In this system, fuel is forced into the cylinder by means of compressed air. This system is little used nowadays, because it requires a bulky multi-stage air compressor. This causes an increase in engine weight and reduces the brake power output further. One advantage that is claimed for the air injection system is good mixing of fuel with the air with resultant higher mean effective pressure. Another is the ability to utilize fuels of high viscosity which are less expensive than those used by the engines with solid injection systems. These advantages are off-set by the requirement of a multistage compressor thereby making the air-injection system obsolete.

Solid Injection system

In this system the liquid fuel is injected directly into the combustion chamber without the aid of compressed air. Hence, it is also called airless mechanical injection or solid injection system. Solid injection systems can be classified as:

i) Individual pump and nozzle system

ii) Unit injector system

iii) Common rail system

iv) Distributor system

All the above systems comprise mainly of the following components.

i) fuel tank,

ii) fuel feed pump to supply fuel from the main fuel tank to the injection system,

iii) injection pump to meter and pressurize the fuel for injection,

iv) governor to ensure that the amount of fuel injected is in accordance with variation in load,

v) injector to take the fuel from the pump and distribute it in the combustion chamber by atomizing it into fine droplets,

vi) fuel filters to prevent dust and abrasive particles from entering the pump and injectors thereby minimizing the wear and tear of the components.

Fuel Injector

Quick and complete combustion is ensured by a well designed fuel injector. By atomizing the fuel into very fine droplets, it increases the surface area of the fuel droplets resulting in better mixing and subsequent combustion. Atomization is done by forcing the fuel through a small orifice under high pressure. The injector assembly consists of

i) a needle valve

ii) a compression spring

iii) a nozzle

iv) an injector body

When the fuel is supplied by the injection pump it exerts sufficient force against the spring to lift the nozzle valve, fuel is sprayed into the combustion chamber in a finely atomized particles. After, fuel from the delivery pump gets exhausted, the spring pressure pushes the nozzle valve back on its seat. For proper lubrication between nozzle valve and its guide a small quantity of fuel is allowed to leak through the clearance between them and then drained back to fuel tank through leak off connection. The spring tension and hence the valve opening pressure is controlled by adjusting the screw provided at the top.

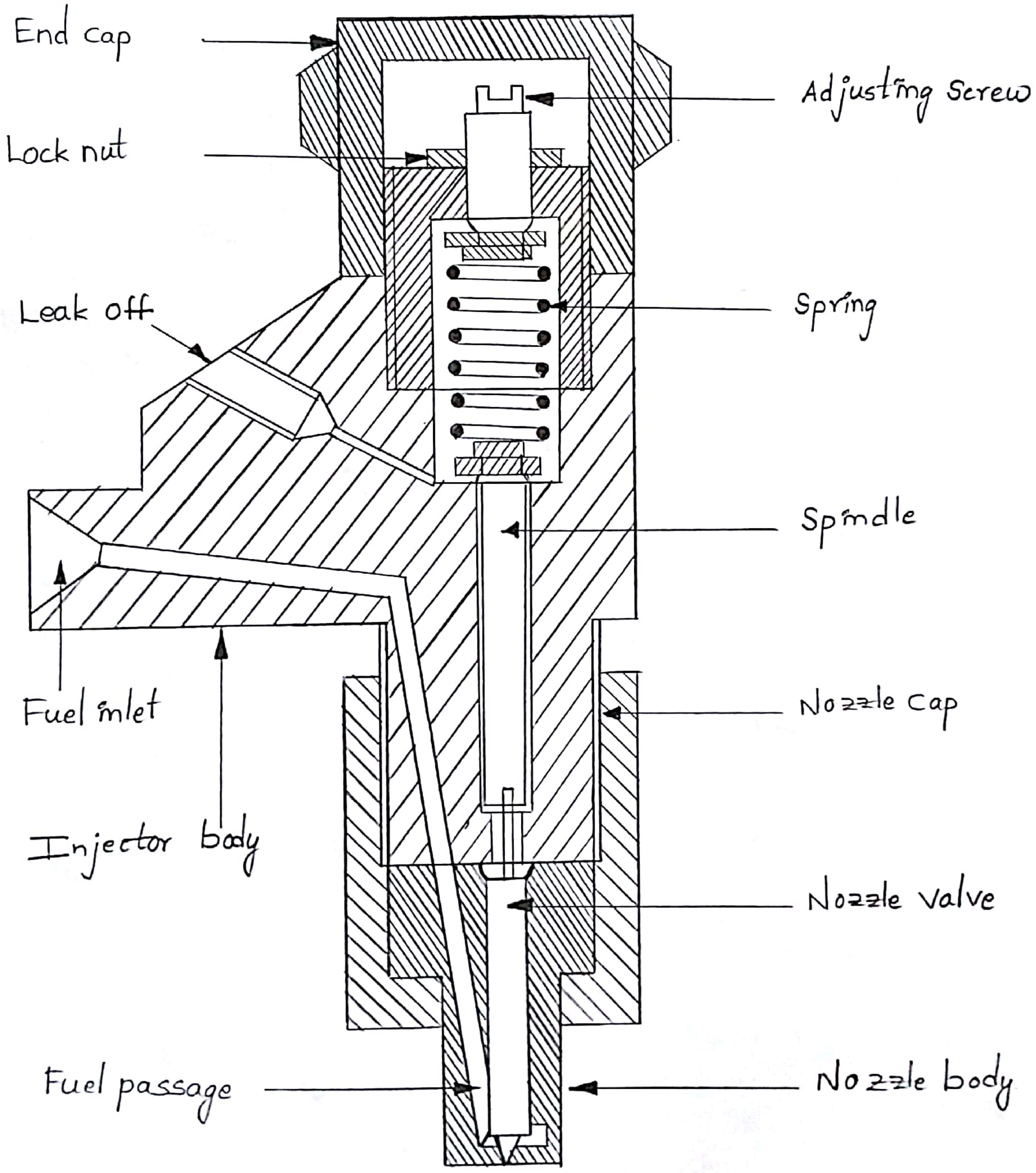


Fig: Fuel Injector (Bosch)

Cooling Systems

Need for cooling system

During the process of converting thermal energy to mechanical energy, high temperatures are produced in the cylinders of the engine as a result of the combustion process. A large portion of the heat from the gases of combustion is transferred to the cylinder head & walls, piston and valves. Unless this excess heat is carried away and these parts are adequately cooled, the engine will be damaged. A cooling system must be provided not only to prevent damage to the vital parts of the engine, but the temperature of these components must be maintained within certain limits in order to obtain maximum performance from the engine. Adequate cooling is then a fundamental requirement associated with reciprocating internal combustion engines. Hence, a cooling system is needed to keep the engine from not getting so hot as to cause problems and yet to permit it to run hot enough to ensure maximum efficiency of the engine. The duty of cooling system, in other words, is to keep the engine from getting not too hot and at the same time not to keep it too cool either.

Characteristics of an efficient cooling system

The following are the two main characteristics desired of an efficient cooling system:

i) It should be capable of removing about 30% of heat generated in the combustion chamber while maintaining the optimum temperature of the engine under all operating conditions of the engine.

ii) It should remove heat at a faster rate when engine is hot. However, during starting of the engine the cooling should be minimum so that the working parts of the engine reach their operating temperatures in a short time.

Lubrication System

The function of a lubrication system is to provide sufficient quantity of cool, filtered oil to give positive and adequate lubrication to all the moving parts of an engine. The various lubrication systems used for internal combustion engines may be classified as

i) mist lubrication system
ii) wet sump lubrication system
iii) dry sump lubrication system

Mist Lubrication System

This system is used where crankcase lubrication is not suitable. In two-stroke engine, as the charge is compressed in the crankcase, it is not possible to have the lubricating oil in the sump. Hence, mist lubrication is adopted in practice. In such engines, the lubricating oil is mixed with the fuel, the usual ratio being 3% to 6%. The oil and the fuel mixture are inducted through the carburettor. The fuel is vaporized and the oil in the form of mist goes via the crankcase into the cylinder. The oil which strikes the crankcase walls lubricates the main & connecting rod bearings, and the rest of the oil lubricates the piston, piston rings and the cylinder.

The advantage of this system is its simplicity and low cost as it does not require an oil pump, filter, etc. However, there are certain disadvantages which are enumerated below.

i) It causes heavy exhaust smoke due to burning of lubricating oil partially or fully and also forms deposits on piston crown and exhaust ports which affect engine efficiency.

ii) Since the oil comes close contact with acidic vapours produced during the combustion process gets contaminated and may result in the corrosion of bearing surface.

iii) This system calls for a thorough mixing for effective lubrication. This requires either separate mixing prior to use or use of some additive to give the oil good mixing characteristics.

v) During closed throttle operation as in the case of the vehicle moving down the hill, the engine will suffer from insufficient lubrication as the supply of fuel is less. This is an important limitation of this system.

In some of the modern engines, the lubricating oil is directly injected into the carburettor and the quantity of oil is regulated. Thus the problem of oil efficiency is eliminated to a very great extent. In this system the main bearings also receive oil from a separate pump. For this purpose, they will be located outside the crankcase. With this system, formation of deposits and corrosion of bearings are also eliminated.

Wet Sump Lubrication System

In the wet sump system, the bottom of the crankcase contains an oil pan or sump from which the lubricating oil is pumped to various engine components by a pump. After lubricating these parts, the oil flows back to the sump by gravity. Again it is picked up by a pump and recirculated through the engine lubricating system. There are three varieties in the wet sump lubrication system. They are

i) the splash system

ii) the splash and pressure system

iii) the pressure feed system

Engine Performance Parameters

The engine performance is indicated by the term efficiency, η.

i) Indicated thermal efficiency (η_{ith})

ii) Brake thermal efficiency (η_{bth})

iii) Mechanical efficiency (η_m)

iv) Volumetric efficiency (η_v)

v) Relative efficiency or Efficiency ratio (η_{rel})

vi) Mean effective pressure (p_m)

vii) Mean piston speed ($\bar{s}_p$)

viii) Specific power output (P_s)

ix) specific fuel consumption (sfc)

x) Inlet-valve Mach Index (Z)

xi) Fuel-air or air-fuel ratio (F/A or A/F)

xii) Calorific value of the fuel (CV)

Figure shows the diagrammatic representation of energy distribution in an IC engine.

Indicated Power

The total power developed by combustion of fuel in the combustion chamber is called indicated power.

$$I.P = \frac{n P_{mi} LANK \times 10}{6} \text{ kW}$$

where, n - No. of cylinders

P_{mi} - Indicated mean effective pressure, bar

L - Length of stroke, m

A - Area of piston, m^2

$k = \frac{1}{2}$ for 4-stroke engine

$= 1$ for 2-stroke engine

Brake Power

The power developed by an engine at the output shaft is called the brake power.

$$B.P = \frac{2\pi NT}{60000} \text{ kW}$$

where, N - speed in rpm

T - Torque in N-m

The difference between I.P and B.P is called frictional power, F.P.

$$F.P = I.P - B.P$$

The ratio of B.P to I.P is called mechanical efficiency.

$$\eta_{mech} = \frac{B.P}{I.P}$$

Indicated Thermal Efficiency

It is the ratio of energy in the indicated power, I·P, to the input fuel energy in appropriate units.

$$\eta_{ith} = \frac{I \cdot P \ [kJ/s]}{\text{energy in fuel per second } [kJ/s]}$$

$$\eta_{ith} = \frac{\text{Indicated Power}}{\text{mass of fuel/sec} * \text{calorific value of fuel}}$$

Brake thermal Efficiency

It is the ratio of energy in the brake power, B·P, to the input fuel energy in appropriate units.

$$\eta_{bth} = \frac{B \cdot P}{\text{mass of fuel/sec} * \text{calorific value of fuel}}$$

Mechanical Efficiency

It is the ratio of brake power (delivered power) to the indicated power (power provided to the piston).

$$\eta_m = \frac{B \cdot P}{I \cdot P} = \frac{B \cdot P}{B \cdot P + F \cdot P}$$

$$F \cdot P = I \cdot P - B \cdot P$$

It can also be defined as the ratio of the brake thermal efficiency to the indicated thermal efficiency.

Volumetric Efficiency

This is one of the very important parameters which decides the performance of four-stroke engines. Four-stroke engines have distinct suction stroke and therefore the volumetric efficiency indicates the breathing ability of the engine. It is to be noted that the utilization of the air is what going to determine the power output of the engine. Hence, an engine must be able to take in as much air as possible.

Volumetric efficiency is defined as the volume flow rate of air into the intake system divided by the rate at which the volume is displaced by the system.

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_{disp} N/2}$$

$\rho_a \rightarrow$ Inlet density

An alternative equivalent definition for volumetric efficiency is

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_d}$$

It is to be noted that irrespective of the engine whether SI, CI or gas engine, volumetric rate of air flow is what to be taken into account and not the mixture flow.

If ρ_a is taken as the atmospheric air density, then η_v represents the pumping performance of the entire inlet system. If it is taken as the air density in the inlet manifold, then η_v represents the pumping performance of the inlet port and valve only.

The normal range of volumetric efficiency at full throttle for SI engines is between 80 to 85% where as for CI engines it is between 85 to 90%. Gas engines have much lower volumetric efficiency since gaseous fuel displaces air and therefore the breathing capacity of the engine is reduced.

Relative Efficiency (or) Efficiency ratio

It is the ratio of thermal efficiency of an actual cycle to that of the ideal cycle. The efficiency ratio is a very useful criterion which indicates the degree of development of the engine.

$$\eta_{rel} = \frac{\text{Actual thermal efficiency}}{\text{Air-standard efficiency}}$$

Mean Effective Pressure (P_m)

Mean effective pressure is the average pressure inside the cylinders of an IC engine based on the calculated or measured power output. It increases as manifold pressure increases. For any particular engine, operating at a given speed and power output, there will be a specific indicated mean effective pressure, imep, and a corresponding brake mean effective pressure, bmep. They are derived from the indicated and brake power respectively.

Indicated power can be shown to be

$$I.P = \frac{P_{im} LAnK}{60 \times 1000}$$

then, the indicated mean effective pressure can be written as

$$P_{im} = \frac{60000 \times I.P}{LAnK}$$

Similarly, the brake mean effective pressure is given by

$$P_{bm} = \frac{60000 \times B.P}{LAnK}$$

where, I.P – Indicated power (kW)

P_{im} – Indicated mean effective pressure (N/m^2)

L – Length of the stroke (m)

A – Area of piston (m^2)

N – Speed in revolutions per minute (rpm)

n = Number of power strokes

n = N/2 for 4-stroke & N for 2-stroke engines

K = Number of cylinders

Another way of specifying the indicated mean effective pressure P_{im} is from the knowledge of engine indicator diagram (p-V diagram). In this case, P_{im}, may be defined as

$$P_{im} = \frac{\text{Area of the indicator diagram}}{\text{Length of the indicator diagram}}$$

Thus the length of the indicator diagram is given by the difference between the total volume and the clearance volume.

Mean Piston speed ($\bar{S}_p$)

An important parameter in engine applications is the mean piston speed, $\bar{S}_p$. It is defined as

$$\bar{S}_p = 2LN$$

where L is the stroke and N is the rotational speed of the crankshaft in rpm. It may be noted that $\bar{S}_p$ is often a more appropriate parameter than crank rotational speed for correlating engine behaviour as a function of speed.

Resistance to gas flow into the engine or stresses due to the inertia of the moving parts limit the maximum value of $\bar{S}_p$ to within 8 to 15 m/s. Automobile engines operate at the higher end and large marine diesel engines at the lower end of this range of piston speeds.

Specific Power Output (P_s)

Specific power output of an engine is defined as the power output per unit piston area and is a measure of the engine designer's success in using the available piston area regardless of cylinder size. The specific power can be shown to be proportional to the product of the mean effective pressure and mean piston speed.

$$\text{specific power output, } P_s = B.P/A$$

$$= \text{constant} * P_{bm} * \bar{S}_p$$

As can be seen the specific power output consists of two elements, viz., the force available to work and the speed with which it is working. Thus, for the same piston displacement and bmep, an engine running at a higher speed will give a higher specific output. It is clear that the output of an engine can be increased by increasing either the speed or the bmep. Increasing the speed involves increase in the mechanical stresses of various engine components. For increasing the bmep better heat release from the fuel is required and this will involve more thermal load on engine

Specific Fuel Consumption (sfc)

The fuel consumption characteristics of an engine are generally expressed in terms of specific fuel consumption in kilograms of fuel per kilowatt-hour. It is an important parameter that reflects how good the engine performance is. It is inversely proportional to the thermal efficiency of the engine.

$$sfc = \frac{\text{Fuel consumption per unit time}}{\text{power}}$$

Brake specific fuel consumption and indicated specific fuel consumption, abbreviated as bsfc and isfc, are the specific fuel consumptions on the basis of bp and ip respectively.

Inlet-Valve Mach Index (Z)

In a reciprocating engine the flow of intake charge takes place through the intake valve opening which is varying during the induction operation. Also, the maximum gas velocity through this area is limited by the local sonic velocity. Thus gas velocity is finally chosen by the following equation,

$$u = \frac{A_p}{C_i A_i} V_p$$

where, u – gas velocity through the inlet valve at smallest flow area

A_p – piston area

A_i – nominal intake valve opening area

C_i – inlet valve flow coefficient

and

$$\frac{u}{\alpha} = \frac{A_p}{A_i}\frac{V_p}{C_i \alpha} = \left(\frac{b}{D_i}\right)^2 \frac{V_p}{C_i \alpha} = Z$$

where, b – cylinder diameter

D_i – inlet valve diameter

V_p – mean piston speed

α – inlet sonic velocity

C_i – inlet valve average flow coefficient

Pressure →

1 standard atmosphere = 760 mm Hg

= 1.01325 bar

1 bar = 10^5 N/m² = 100 kN/m² = 100 kpa

1 MPa = 10^6 Pascals = 10^6 N/m² = 10 bar

Temperature → The degree of hotness or level of intensity of heat in a body.

$$\frac{C}{5} = \frac{F-32}{9}$$

Internal Energy (U)

The total molecular energy of a fluid, most of which is the kinetic energy of linear motion of the molecules is called internal energy.

$$\Delta U = \Delta K + \Delta P$$

ΔK ↙ Internal K.E ΔP ↘ Internal P.E

In case of gases ΔP is small & it can be neglected.

$$\Delta U = \Delta P$$

When gas of mass m kg is heated from T_1 to T_2

Change in Internal energy, $du = m\,C_v\,(T_2 - T_1)$

C_v → Specific heat of gas at constant volume

Enthalpy (H)

$$H = U + PV$$

U → Internal energy; PV → pressure & volume

change in enthalpy, $dH = m C_p (T_2 - T_1)$

Specific heat (c) → The amount of heat ~~sup~~ required to rise a unit mass of the substance through a unit rise in temperature.

$$C = \frac{Q}{m \cdot \Delta T} \quad KJ/kg\text{-}K$$

specific heat of water is 4.19 KJ/kg-K.

Solids & liquids donot change the volume on heating, therefore they have only one specific heat. But the gases have the following two specific heats depending upon the process adopted for heating the gas

1) specific heat at constant pressure (C_p)
2) specific heat at constant volume (C_v)

Laws of Perfect Gases

A perfect gas or Ideal gas is defined as the gas in which molecular attraction is zero.

(or)

The gas which strictly obeys the all gas laws under all conditions of pressure & temperature is called perfect gas.

No gas is known perfect

Laws

Boyle's law → The volume of given mass of perfect gas varies inversely as the absolute pressure when the temperature remains constant.

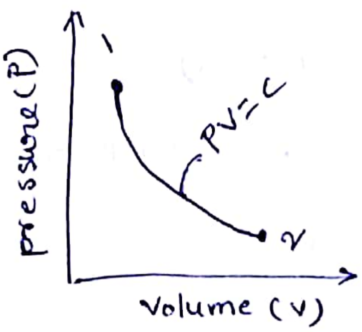
[Robert Boyle in 1662 A.D]

$V \propto \frac{1}{P}$ when temperature is constant

$V = \frac{C}{P}$ $C \rightarrow$ constant of proportionality

$PV = C$

$P_1V_1 = P_2V_2 = \cdots = P_nV_n$

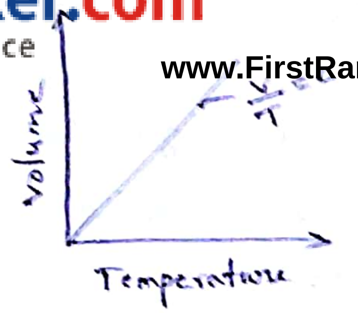


Charle's Law → The volume of a given mass of a gas varies directly as its absolute temperature when the pressure remains constant.

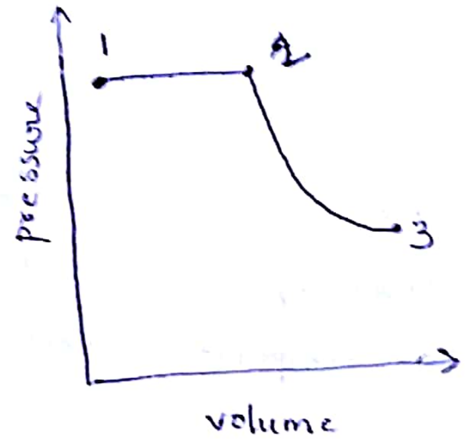
$V \propto T$ $C \rightarrow$ constant of proportionality

$V = TC$

$\frac{V}{T} = C$ $\frac{V_1}{T_1} = \frac{V_2}{T_2} = \cdots = \frac{V_n}{T_n}$



Characteristic Gas Equation
(combination of Boyle's & Charle's Law)



Now applying charle's law (1-2)

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$ (when pressure constant)

$$V_2 = \frac{V_1}{T_1} \times T_2 \longrightarrow (1)$$

applying boyle's law (2-3)

$$P_2 V_2 = P_3 V_3$$ (when temp constant)

$$V_2 = \frac{P_3 V_3}{P_2} \longrightarrow (2)$$

By Equating (1) & (2)

$$\frac{P_3 V_3}{P_2} = \frac{V_1}{T_1} \times T_2$$

But $P_2 = P_1$ & $T_2 = T_3$

$$\frac{P_3 V_3}{P_1} = \frac{V_1}{T_1} \times T_3 \qquad \frac{P_3 V_3}{T_3} = \frac{P_1 V_1}{T_1}$$

Since states 1 & 3 are selected arbitrarily is follows

that

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3}$$

$$\frac{PV}{T} = \text{const}$$

This constant is called characteristic gas constant (R)

$R \rightarrow J/kg\text{-}K$

$$\frac{PV}{T} = R$$

$\boxed{PV = RT}$ → Equation of perfect gas (or) characteristic gas equation.

For a system consisting of a mass of m kg of gas

$\therefore \quad PV = mRT$

mass of the gas → m kg

molecular weight → M kg

no. of moles → n

$$n = \frac{m}{M} \Rightarrow m = nM$$

product of molecular weight (M) of the gas & characteristic gas constant is known as universal gas constant (or) molar constant.

$$R_u = M \times R$$

$R_u \rightarrow 8314$ J/kg mole-K (or) 8.314 KJ/kg mole-K

$PV = mRT$

$PV = nMRT \qquad (\because m = nM)$

$PV = nR_uT$

Specific heat at constant pressure & specific heat at constant volume

Total heat supplied at constant pressure

$$Q = m\,C_p\,(T_2 - T_1) \quad \text{(pressure constant)}$$

$$Q = m\,C_v\,(T_2 - T_1) \quad \text{(volume constant)}$$

$C_p = 1.005$ kJ/kg K

$C_v = 0.718$ kJ/kg K

Joule's law → The change of internal energy of a perfect gas is directly proportional to the change of temp.

$$du \propto dT$$

$$du = C \cdot dT$$

$$du = C_v \cdot dT$$

$$du = m\,C_v\,(T_2 - T_1)$$

Regnault's law → The two specific heats C_p & C_v of a gas donot change with the change of temp. & pressure.

$$\frac{C_p}{C_v} = \gamma \qquad \text{adiabatic constant} \rightarrow \gamma \text{ (gamma)}$$

for atm air $\gamma = 1.4$

Thermodynamic Processes in Gases

A thermodynamic process is one which causes a change in the state of a working medium substance from one equilibrium condition to another with the flow of energy. During this flow a change takes place in properties of the substance such as pressure, volume, temperature and also the energy quantities such as internal energy, heat & work.

The following are the different non-flow processes (Reversible) as applied to perfect gas

1) Constant volume process (or) Isochoric process
2) Constant pressure process (or) Isobaric process
3) Constant temperature process (or) Isothermal process
4) Hyperbolic process (PV = C)
5) Adiabatic process (or) Isentropic process
6) polytropic process

In the above process, the working medium does not leave the boundary. Only energy crosses the boundary in the form of heat & work.

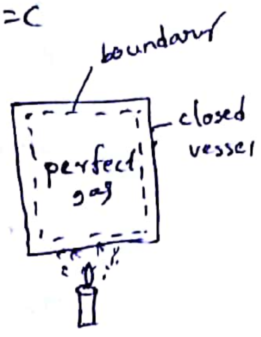
Constant volume process

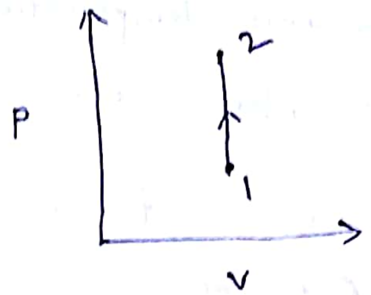
The heating of perfect gas in a completely closed vessel is known as constant volume process.

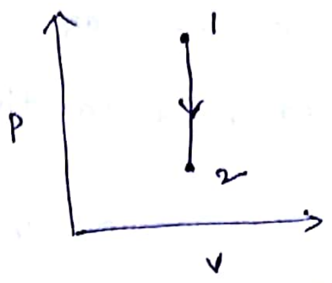
Gay - Lussac's law

$P \propto T$ when volume is constant $\because V = C$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$







a) workdone by the gas

workdone by the gas for non flow reversible process

$$W = \int_{V_1}^{V_2} P dV$$

since change in volume of the gas is zero, $dv = 0$

$$W = \int_{V_1}^{V_2} P(0) = 0$$

In isochoric process, workdone by the gas is equal to zero.

b) change in internal energy

change in internal energy

$$du = mC_v \, dT$$

if the gas is heated from state 1 to state 2

$$\int_1^2 du = mC_v \int_{T_1}^{T_2} dT$$

$$U_2 - U_1 = mC_v (T_2 - T_1)$$

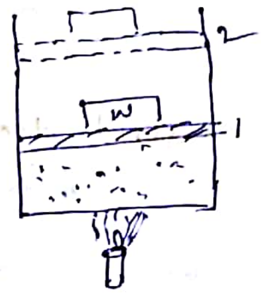
c) Heat supplied by NFEE

$$Q = du + W$$

since $W = 0$

$$Q = du = u_2 - u_1 = m C_v (T_2 - T_1)$$

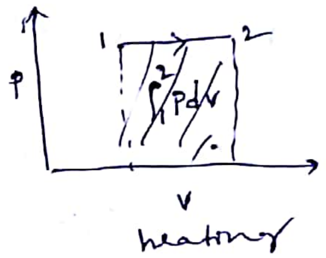
constant pressure process



charle's Law

$\frac{V}{T} = \text{Const}$ (when pressure is constant)

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$



a) workdone by the gas

for non-flow reversible process

$$W = \int_{V_1}^{V_2} P dv = P \int_{V_1}^{V_2} dv = P(V_2 - V_1)$$

$$W = P(V_2 - V_1) \qquad PV = mRT$$

$$W = mR(T_2 - T_1)$$

b) Change in Internal energy

$$du = m C_v (T_2 - T_1)$$

c) Heat supplied (or) Heat Transferred

by NFEE

$$Q = du + W \qquad C_p = C_v + R$$

$$= m C_v (T_2 - T_1) + P(V_2 - V_1)$$

$$= m C_v (T_2 - T_1) + mR(T_2 - T_1)$$

$$Q = m(T_2 - T_1)(C_v + R)$$

$$Q = m C_p (T_2 - T_1)$$

... enthalpy

$$dH = mC_p(T_2 - T_1)$$

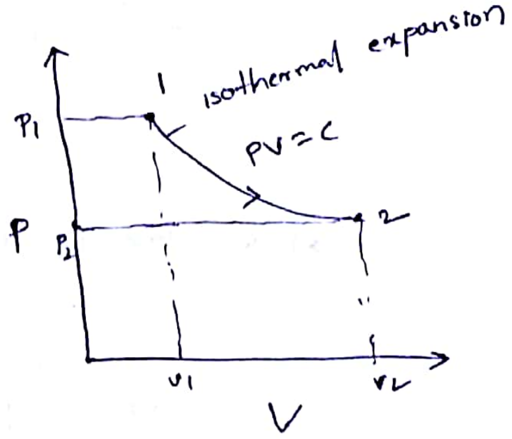
$$\therefore \; Q = dH$$

Therefore enthalpy may be defined as amount of heat supplied at constant pressure

$$Q = dH = mC_p(T_2 - T_1)$$

Constant temperature process

A process in which the temperature of working substance remains constant during its expansion or compression is called isothermal process.



General gas equation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

since the gas is heated at temp. constant

$$T_1 = T_2$$

$$P_1 V_1 = P_2 V_2 \quad (\text{or}) \quad PV = \text{constant}$$

Boyle's law

a) workdone by the gas

for non-flow reversible process

$$W = \int_{V_1}^{V_2} p\,dv = \int_{V_1}^{V_2} \frac{c}{v}\,dv = c\int_{V_1}^{V_2} \frac{1}{v}\,dv \qquad (\because pv = c)$$

$$= c\left[\log_e v\right]_{V_1}^{V_2} = P_1 V_1 \left[\log_e\left(\frac{V_2}{V_1}\right)\right]$$

$$= mRT_1 \log\left(\frac{V_2}{V_1}\right)$$

$$W = P_2 V_2 \log_e\left(\frac{V_2}{V_1}\right) = mRT_2 \log_e\left(\frac{V_2}{V_1}\right)$$

$$W = P_1 V_1 \log_e(r)$$

$$\text{where } r = \frac{P_1}{P_2} = \frac{V_2}{V_1} \qquad (\because P_1 V_1 = P_2 V_2)$$

internal energy

$du = mC_v(T_2 - T_1)$

$= mC_v(0)$

$du = 0$

In an isothermal process, change in internal energy is zero.

c) Heat Transfer

by NFEE

$Q = du + W$ $(\because du = 0)$

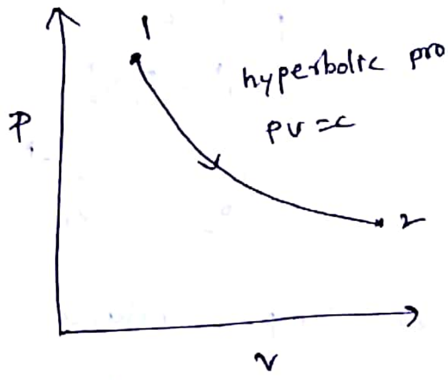
$Q = W$

Hyperbolic process

A process in which the gas is heated or expanded in such a way that the product of pressure & volume remains constant is called Hyperbolic process.

$\therefore pv = c$

Boyle's law



General gas equation

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

if $T_1 = T_2$ → isothermal process

then $P_1V_1 = P_2V_2$

i.e $pv = c$ (Hyperbolic process)

then $T_1 = T_2$

it is applicable only for gases

Adiabatic process (or) isentropic process

The process in which no exchange of heat take place b/w the system and the surroundings is known as adiabatic process. During this process, the gas is thermally insulated so that no heat is permitted to enter or leave the gas.

For an ideal adiabatic process the following conditions must be satisfied

i) No heat is added (or) rejected during the process

ii) The temp. of the gas changes, as the work is done at the cost of internal energy

iii) Since, there is no heat transfer, the change in internal energy is equal to workdone.

This process is governed by the equation

$$pV^{\gamma} = \text{constant}$$

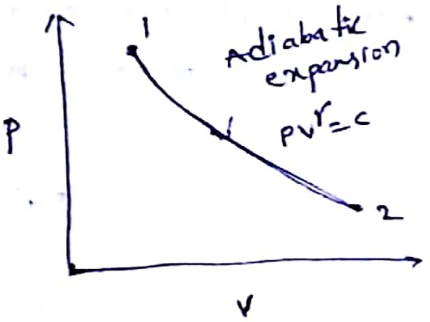
$$\gamma \rightarrow \text{adiabatic index} = \frac{C_p}{C_v}$$

a) P-V relation

$$pV^{\gamma} = c$$

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

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



b) Temp. - volume relation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{P_1}{P_2} = \frac{V_2}{V_1} \times \frac{T_1}{T_2} \longrightarrow ②$$

② in ①

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

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

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} \longrightarrow ③$$

c) Pressure-temperature relation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{P_1}{T_1} \times \frac{T_2}{P_2} = \frac{V_2}{V_1} \qquad \left(\because \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma} \right)$$

$$\frac{V_2}{V_1} = \frac{P_1}{P_2} \times \frac{T_2}{T_1} \longrightarrow (4)$$

(4) in (1)

$$\frac{P_1}{P_2} \times \frac{T_2}{T_1} = \frac{V_2}{V_1}$$

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

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

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

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \longrightarrow (5)$$

d) work done by the gas

for any non-flow process

$$W_{1-2} = \int_{V_1}^{V_2} p\,dV \longrightarrow (6)$$

But we know that, the process follows

$$PV^{\gamma} = C$$

$$P = \frac{C}{V^{\gamma}} \longrightarrow (7)$$

(7) in (1)

$$W_{1-2} = \int_{V_1}^{V_2} \frac{C}{V^{\gamma}}\, dV = C \int_{V_1}^{V_2} V^{-\gamma}\, dV = C\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_{V_1}^{V_2}$$

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

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

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$$= \frac{P_2 V_2^{\gamma} \cdot V_2^{-\gamma+1} - P_1 V_1^{\gamma} \cdot V_1^{-\gamma+1}}{-\gamma+1} = \frac{P_2 V_2 - P_1 V_1}{-\gamma+1}$$

$$W_{1-2} = \frac{P_2 V_2 - P_1 V_1}{-\gamma+1} \rightarrow ⑧$$

$$W_{1-2} = \frac{P_1 V_1 - P_2 V_2}{\gamma-1} = \frac{mR(T_1 - T_2)}{\gamma - 1} \quad (\because PV = mRT)$$

e) Heat transfer There is no heat transfer

$$Q_{1-2} = 0$$

f) change in internal energy

by NFEE

$$Q_{1-2} = W_{1-2} + du$$

$$0 = W + du$$

$$du = -W = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1}$$

$$du = -W = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} = \frac{mR(T_2 - T_1)}{\gamma - 1} = m C_v (T_2 - T_1)$$

$(\because PV = mRT)$ $\quad (\because C_v = \frac{R}{\gamma - 1})$

HEAT TRANSFER

Introduction:

Defination of heat transfer:

→ "Transmission of energy from one region to another as a result of temperature gradient"

→ Study of heat transfer is carried out for the following purposes.

i, To estimate the rate of flow of energy as heat through the boundary of a system under steady and transient conditions.

ii, To determine the temperature field under steady and transient conditions.

→ The Areas covered under the discipline of heat transfer

i, Design of thermal & nuclear power plants including heat engines, steam generators condensers and other heat exchange equipments.

ii, I.C engines.

iii, Refrigeration and air conditioning units

iv, Heat treatment of metals

v, Thermal control of space vehicles.

Design of cooling systems for electric motors, generators, and transformers.

<u>Heat</u>! It is a transient form of energy
It occured becomes Temperature.

<u>Difference b/w Thermodynamics & Heat transfer</u>:

→ In general, Thermodynamics will deal with the quantities of heat energy changes taking place in a substance. but it will never deal with rate at which heat energy changes are takes place in a substance.

→ For this purpose only another subject called as heat transfer is developed which is mainly deal with rate at which heat energy changes taking place in substance.

* Basic law of heat transfer:

1. first law of thermodynamics:
When a system undergoes a thermodynamic cycle then the heat supplied to the system from the surroundings is equal to net work done by the system on the surroundings.

$$\oint dQ = \oint dW$$

2. Second law of thermodynamics:
Heat will flow automatically from one reservoir to another at a lower temperature but not is opposite direction

3. law of Conservation of mass:
This law is used to determine the parameter of flow.

4. Newton's laws of motion:
This laws are used to determine fluid flow parameters.

5. The rate equations:
This equations are appliable depending up on the mode of heat transfer

Modes of heat transfer:

It is classified in to 3 types

1. Conduction
2. Convection
3. Radiation.

1. Conduction: Conduction is a transfer of heat from one part of a substance to another part of same substance or one substance to another substance in physical contact with it, with out appraisble displacement of molecules.

In solids heat is conducted by following machnism.

1. By lattics vibrations:-
The faster moving molecules in the hottest part of a body transfer heat by impact some of there energy to adjustment molecules.

2. By transport of free electrons:

Fourier's law of heat conduction:
The rate of flow of heat through a simple homogeneous solid is directly proportional to the area of the section at the right angles to the direction of heat flow, and to changes of temperature with respect to the length of the path of

$$Q \propto A \frac{dt}{dx}$$

Q = Rate of heat flow per unit time

A = Surface area of heat flow perpendicular to the heat flow in (meter^2)

dt = change in temperature in °c or °k

dx = Thickness of the body in the direction of flow

$$Q = (-k) A \frac{dt}{dx}$$

k = Thermal conductivity and the nagetive sign indicate temperature

Assumptions!

1. Conduction of heat takes place onder the steady state.
2. Heat flow is onidirectional
3. Temperature gradient is constant
4. There is no internal that generation
5. The boundary surfaces are isothermal
6. The material is homogeneous and isotropic.

Some essential feature of fourier's law

1. It is applicable to all matters
2. It is based on experimental avidance and cann't be derive from the first principle.
3. It is a vector expression
4. It helps to define thermal conductivity.

Thermal conductivity

$$K = \frac{Q}{A} \cdot \frac{dx}{dt}$$

$$= q \frac{dx}{dt} \quad (Q/A = q)$$

q = heat flux

It is the amount of energy conducted through a body of unit area, and unit thickness in unit time when the difference in temperature cause in the heat flow

factors effecting k:

1. Material
2. Moisture containt
3. density of material and oprating conditions

Material	Thermal conductivity (w/mk)
1. Silver	410
2. Copper	385
3. Aluminum	225
4. Cast iron	55 - 65
5. Steel	20 - 45
6. Concrete	1.20

	Glass (window)	0.75
8.	Asbestos sheet	0.17
9.	Ash	0.12
10.	Cork, felt	0.05 - 0.10
11.	Saw dust	0.07
12.	Glass wool	0.03
13.	Water	0.55 - 0.17
14.	freon	0.0083

Vapour, gas, freon is low (k) value.

Thermal resistance:

The heat transfer may be compaired with electrical analogous as for ohm's law current is equal to voltage by potential difference by electrical resistance i.e

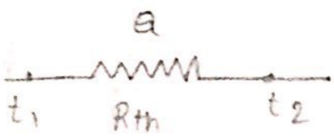
$$I = \frac{dv}{R} \qquad \frac{\text{potential difference}}{\text{electrical resistance}}$$

As for fourier's law

$$\text{heat flow } Q = \frac{dt}{(dx/kA)} \quad (\text{thermal resistance})$$

Where $\frac{dx}{dA}$ is called thermal resistance

it indicate like $R_{th} = \frac{dx}{dA}$



Convection is the transfer of heat with in a fluid by mixing of one portion of the fluid with another

1. Convection is possible only in a fluid medium and is directly linked with the transport of medium it self

2. Convection Consititues the ~~macro scopic particles of a fluid~~ ~~medium and~~ micro form of the heat transfer since macro scopic particles of a fluid moving in space causes the heat exchange.

3. The efficitiveness of convection is depends on mixing motion of the fluid.

* Newton's law of cooling:

The rate equation for Convection between Surface and adjecent fluid is given by

$$Q = hA(T_s - T_f) \rightarrow \text{Newton's law of Cooling}$$

Q = Convection of rate of convective heat transfer

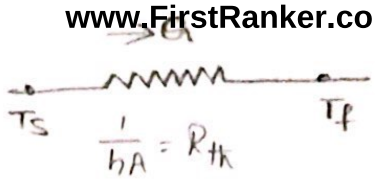
A = Area exposed to heat transfer

T_s = Surface temperature

T_f = Co-efficient of convect to heat transfer

h = Co-efficient of convect to heat transfer

$$h = \frac{Q}{A(T_s - T_f)}$$



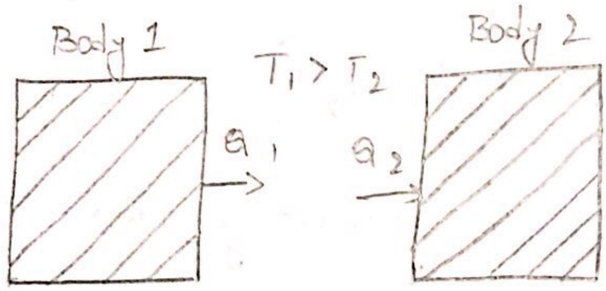
$$R_{th\ \text{convection}} = \frac{1}{hA}$$

Radiation:

Radiation is the transfer of heat through space or matter by means of other than conduction or Convection. Radiation heat at is through of a electro magnetic waves or quanta an emination of the same nature has light or radio waves.

The transfer of heat by radiation accures because of hot body emits more than heat it recives and a Cooled body recives more heat than it emits. These more energy is called radient energy.

Law's of Radiation



$$\frac{1}{F\sigma A(T_1+T_2)(T_1^2+T_2^2)}$$

's law:

It states that the wave length corresponding to the maximum energy is inversly proportional to absolute temperature of hot body.

$$\lambda_m \propto \frac{1}{T}$$

Kirchhoff 's law:

It states that the emissivity of the body at particular temperature is numerical is quals to is absorptivity for radient energy from the body at the same temperature.

Stefan boltzmann's law

It states that the emissive power of a black body is directly proportional to fourth power of its absolute temperature.

$$Q \propto T^4$$

2 bodys

$$Q = F\sigma A \left(T_1^4 - T_2^4\right)$$

F = factor depends up on geomentry and surface properties.

σ = Stefan boltzmann constant

5.67×10^{-8} watt per m^2 K^4

$$Q = F\sigma A \left(T_1^4 - T_2^4\right)$$

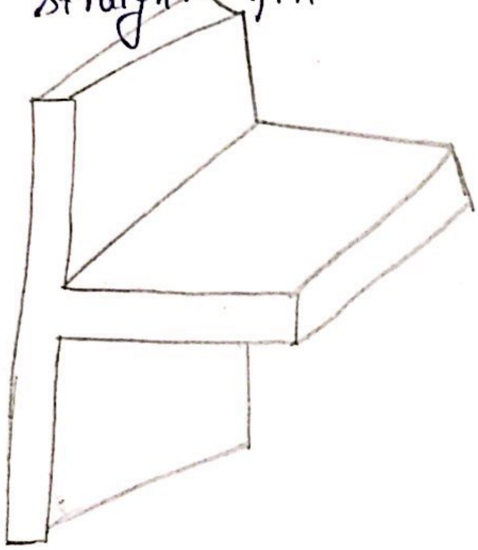
FINS

Fin: It is possible to increase the heat transfer rate by increasing the surface of heat transfer

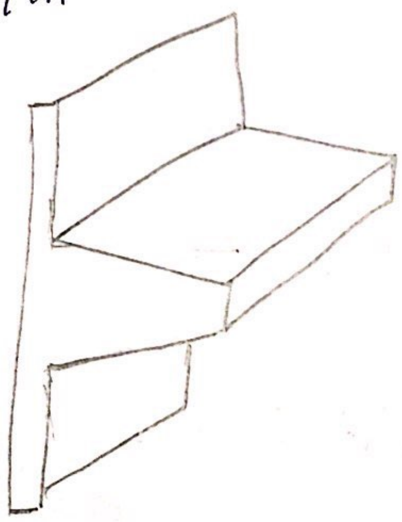
The surfaces used for increasing the heat transfer are called externded surfaces or fins.

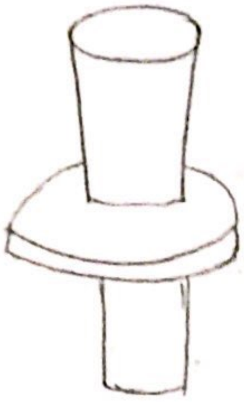
Types of Fins.

1. Uniform Straight fin

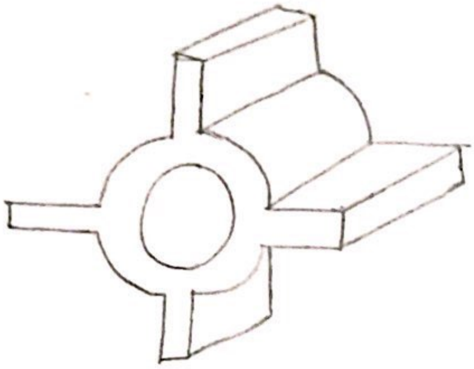


2. Tapered fin

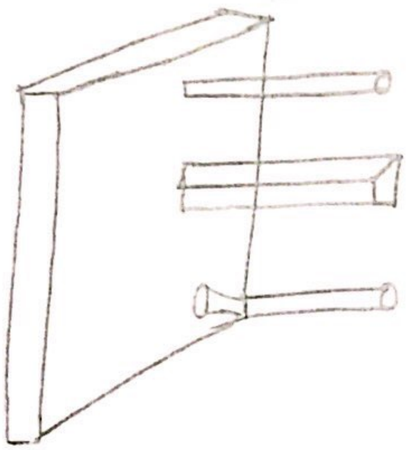




4. Spline shaft.



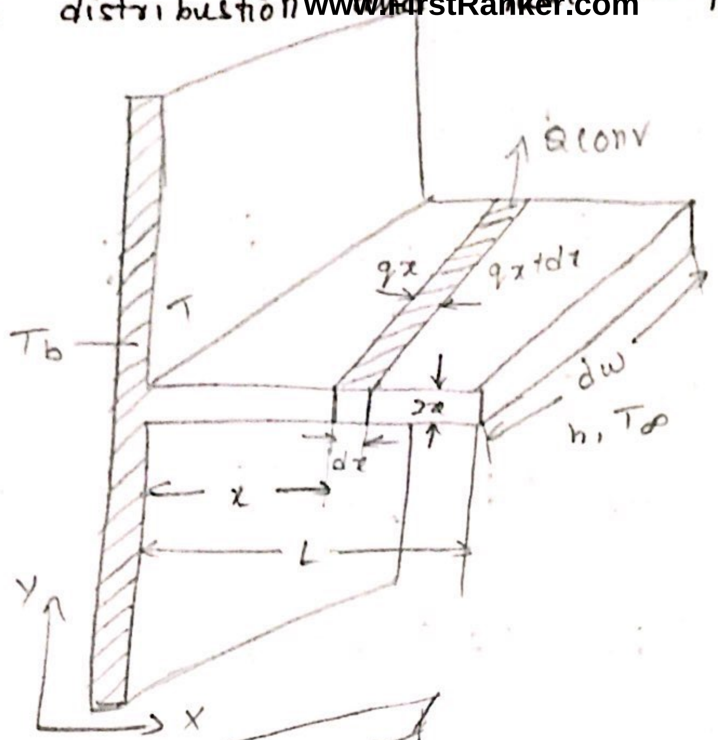
5. Pin fin

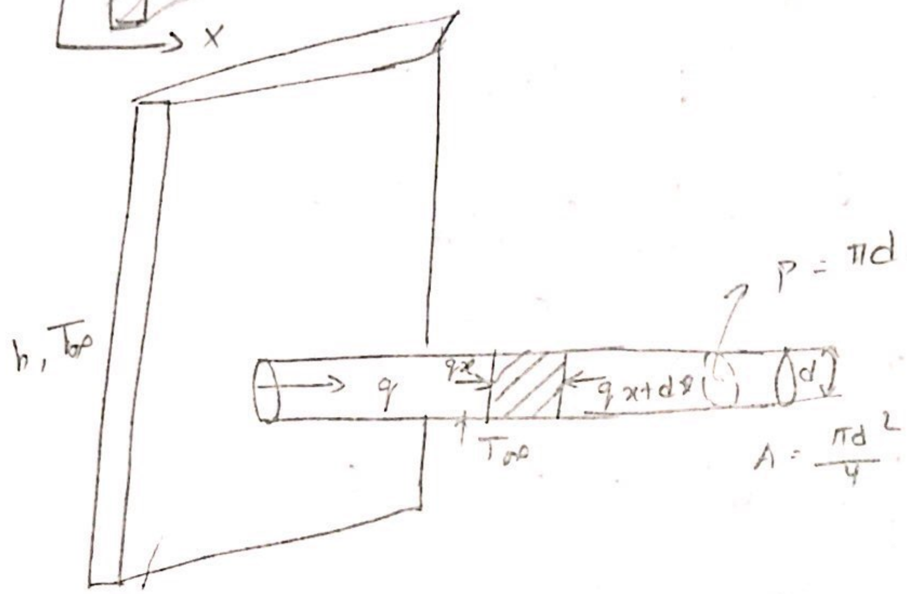


These are commonly 3 types.

1. Infinitly long fin
2. Short fin with insulated end
3. Short fin with out insulated end

Temperature distribution and heat desipation





1. Heat transfer occure the rectangular fin and circular rod by Conduction.
2. from the Surface of the fin heat transfer to the air by Convection let as Consider a small element of thickness dx which is at a distance of x from the base

By study state condition heat blancing equation =

Heat conducted in to element = heat conducted out of the element + heat convected to the surrounding

$$Q_x = Q_{x+dx} + Q_{conv} \quad — (1)$$

$$Q_x = -KA\,(dT/dx)$$

$$Q_{x+dx} = -KA\left(\frac{dT}{dx}\right) - KA\left(\frac{d^2T}{dx^2}\right)dx$$

$$Q_{conv} = h_A\,(T - T_\infty)$$

$$-KA\left(\frac{dT}{dx}\right) = -KA\left(\frac{dT}{dx}\right) - KA\left(\frac{d^2T}{dx^2}\right)dx + hA\,(T - T_\infty)$$

$$KA\left(\frac{d^2T}{dx^2}\right)dx = hA\,(T - T_\infty)$$

$$KA\left(\frac{d^2T}{dx^2}\right)dx = hP\,dx\,(T - T_\infty)$$

$$\frac{d^2T}{dx^2} - \frac{hP}{KA}(T - T_\infty) = 0$$

Let us say $m = \sqrt{\frac{hP}{KA}}$

$$\frac{d^2T}{dx^2} - m^2(T - T_\infty) = 0$$

$$\theta = T - T_\infty$$

$$\frac{d^2T}{dx^2} - m^2\theta = 0$$

it will show temperature is a function of x & m it is a function of second order linear differential equation. and the solution for the equation is

$$\theta = c_1 e^{-mx} + c_2 e^{mx}$$

This temperature distribution depends upon following conditions.

Infinitly long fin

Boundary conditions at $x = 0$

$T = T_b$, $x = \infty$, $T = T_\infty$

we have.

$$\theta = c_1 e^{-mx} + c_2 e^{mx}$$

$$T - T_\infty = c_1 e^{-mx} + c_2 e^{mx} \quad \text{— (1)}$$

Apply condition (1)

At $x = 0$, $T = T_b$

$$(T_b - T_\infty) = c_1 e^0 + c_2 e^0$$

$$T_b - T_\infty = c_1 + c_2 \quad \text{— (2)}$$

at $x = \infty$, $T = T_\infty$

$$(T_\infty - T_\infty) = c_1 e^{-m\infty} + c_2 e^{m\infty}$$

$$0 = c_1 e^{-m\infty} + c_2 e^{m\infty}$$

$$e^{m\infty} \neq 0$$

$$\therefore c_2 = 0$$

$$c_1 = T_b - T_\infty$$

we have c_1 & c_2

$$T_b - T_\infty = (T_b - T_\infty) e^{-mx} + 0$$

$$\therefore e^{-mx} = \frac{T - T_\infty}{T_b - T_\infty} \quad \text{— (3)}$$

T = Intermediate temperature

T∞ = surrounding temperature

T_b = base temperature

x = distance.

$$m = \sqrt{\frac{hP}{KA}}$$

$h \rightarrow$ Convective heat transfer coefficient

$P \rightarrow$ perimeter

$K \rightarrow$ Thermal Conductivity

$A \rightarrow$ Area

for heat desipation from the fin would be obtain by integrating the heat lost by convection over the entire fin surface.

$$Q_{conv} = hA(T - T_\infty)$$

$$Q = \int_0^\infty h(P\,dx)(T - T_\infty)\,dx$$

from equation (3)

$$(T - T_\infty) = (T_b - T_\infty)\,e^{-mx}$$

$$= \int_0^\infty hP(T_b - T_\infty)\,e^{-mx}\,dx$$

$$= \left[hP(T_b - T_\infty) - \frac{1}{m}e^{-mx}\right]_0^\infty$$

$$= hP(T_b - T_\infty) - \frac{1}{m}(-1)$$

$\frac{hP}{m}(T_b - T_\infty)$

$$= \frac{hP}{\sqrt{\frac{hP}{KA}}}(T_b - T_\infty)$$

$$= hP \times \sqrt{\frac{KA}{hP}}\,(T_b - T_\infty)$$

$$Q = \sqrt{hPKA}\,(T_b - T_\infty)$$

Short fin with insulated end:

Case-II:

Boundary conditions (for short fin)

at $x = 0$, $T = T_b$

at $x = L$, $T = T_\infty$, $\frac{dT}{dx} = 0$

We have.

$$\theta = c_1 e^{-mx} + c_2 e^{mx} \quad \text{--- (1)}$$

$$(T - T_\infty) = c_1 e^{-mx} + c_2 e^{mx}.$$

$$\frac{dT}{dx} = c_1 e^{-mx}(-m) + c_2 e^{mx} m$$

Apply boundary Condition

$x = L$

$$0 = c_1 e^{-mL}(-m) + c_2 e^{mL}(m)$$

$$c_1 = c_2 e^{2mL} \quad \text{--- (2)}$$

at $x = 0$

$$(T_b - T_\infty) = c_1 e^0 + c_2 e^0$$

$(T_b - T_\infty) = c_1 + c_2$

Substitue the equation (2)

$$c_2 e^{2mL} + c_2 = (T_b - T_\infty)$$

$$c_2 = \frac{T_b - T_\infty}{(e^{2mL} + 1)}$$

$$c_1 = c_2 e^{2mL}$$

$$= \left(\frac{T_b - T_\infty}{(e^{2mL} + 1)} \right) e^{2mL}$$

$$c_1 = \frac{T_b - T_\infty}{(e^{2mL} + 1) e^{-2mL}}$$

$$c_1 = \frac{T_b - T_\infty}{1 + e^{-2mL}}$$

subtitute in equation (1)

$$T - T_\infty = \left(\frac{T_b - T_\infty}{1 + e^{-2mL}} \right) e^{-mx} + \frac{T_b - T_\infty}{(e^{2mL} + 1)} e^{mx}$$

$$\frac{T - T_\infty}{T_b - T_\infty} = \left[\frac{e^{-mx}}{1 + e^{-2mL}} + \frac{e^{mx}}{1 + e^{2mL}} \right]$$

Multiply numerator and denominator by e^{mL} and e^{-mL}

$$\left(\frac{T - T_\infty}{T_b - T_\infty} \right) = \frac{e^{-mx}}{1 + e^{-2mL}} \times \frac{e^{mL}}{e^{mL}} + \frac{e^{mx}}{1 + e^{2mL}} \times \frac{e^{-mL}}{e^{-mL}}$$

$$= \frac{e^{-m(x-L)}}{e^{mL} + e^{-mL}} + \frac{e^{m(x-L)}}{e^{mL} + e^{-mL}}$$

$$\frac{e^{m(x-L)} + e^{-m(x-L)}}{e^{mL} + e^{-mL}}$$

$$= \frac{e^{m(L-x)} + e^{-m(L-x)}}{e^{Lm} + e^{-Lm}}$$

$$= \frac{\cosh(m(L-x))}{\cosh(mL)}$$

$$T - T_\infty = (T_b - T_\infty)\frac{\cosh m(L-x)}{\cosh(mL)}$$

$$\frac{dT}{dx} = (T_b - T_\infty)(-m)\frac{\sinh m(L-x)}{\cosh mL}$$

we have.

$$Q = -KA\frac{dT}{dx}$$

$$Q = -KA(T_b - T_\infty)(-m)\frac{\sinh m(L-x)}{\cosh mL}$$

$$= KAm(T_b - T_\infty)\frac{\sinh m(L-x)}{\cosh mL}$$

At $x = 0$

$$Q = KAm(T_b - T_\infty)\tanh mL$$

$$= KA\sqrt{hP/KA}\,(T_b - T_\infty)\tanh mL$$

$$= \sqrt{hPKA}\,(T_b - T_\infty)\tanh mL$$

Applications of fins:

The many applications are

1. Cooling the electronic components

2. Cooling the motor cycle engines
3. Cooling the small capacity compressors
4. Cooling the transformers
5. Cooling the radiators and refrigerators.

fin efficiency:

It is the ratio of actual heat transfer in the fin to maximum possible heat transfer

$$\eta = \frac{Q_{fin}}{Q_{max}}$$

fin effectiveness:

It is the ratio of heat transfer with fin to the with out fin

$$\epsilon = \frac{Q_{with\ fin}}{Q_{with\ out\ fin}}$$

Transient heat Conduction / un steady state heat Conduction:

If the temperature of the body doesn't vary with time it is set to be steady state if there is an abrupt change in it surface temperature it attains steady state after some time during this period the temperature varys with the time and that body is said to be in an un steady state (or) transient state

Convective heat transfer:

Convection → free convection (fluid circulate by Natural density difference by hot and cold fluid)
→ forced convection (fluid motion created by external agency)

(H.T b/w surface & fluid moving over it)

Total / Average heat transfer coefficient:-

We know that local heat flux (q) for an arbitary body of area (A). The temperatures of surface and surroundings are T_s, T_∞.

$$q = h(T_s - T_\infty) \quad \text{— (1)}$$

This equation is known as newton's law of cooling for simplicity we are taken the equation but it actual process heat transfer coefficient is a complicated function.

1. Nature of fluid flow
2. Thermal properties of fluid flow
3. Conferication of the system

Due to variation of fluid flow the value of heat flux and h values varies from point to point find out total heat transfer rate we have to integrate heat flux for over complete area.

$$Q = \int_A q \, dA$$

$$= \int_A h (T_s - T_\infty) \, dA$$

$$= (T_s - T_\infty) \int_A h \, dA \quad \text{—— (1)}$$

Here defining the $\bar{h}$ as average / total heat transfer coefficient for entire surface.

$$Q = \bar{h} A (T_s - T_\infty) \quad \text{—— (2)}$$

$$(1) = (2)$$

$$(T_s - T_\infty) \int_A h \, dA = \bar{h} A (T_s - T_\infty)$$

$$\bar{h} = \frac{1}{A} \int_A h \, dA$$

for a specified length L

$$\bar{h} = \frac{1}{L} \int_0^L h \, dL$$

$L = x$

$$\bar{h} = \frac{1}{x} \int_0^x h \, dx$$

If plate for point width the above equation becomes for forced convection the heated horizontal plate the

...cal heat transfer coefficient may be expressed as

$$h_x = C x^{0.5}$$

$$\therefore \bar{h}_x = \frac{1}{x}\int_0^x C x^{0.5}\,dx$$

$$= \frac{C}{x}\int_0^x \sqrt{x}\,dx$$

$$= \frac{C}{x}\,\frac{x^{0.5}}{0.5}$$

$$= 2Cx^{-0.5}$$

$$\therefore \bar{h}_x = 2h_x.$$

The average heat transfer coefficient is twice to the local value.

Dimensional Analysis (D.A):-

DA is a mathematically technique to study the dimensional perameters for solving several engineering problem. Its helps to determine a systematic arrangement of the varibles in the physical relationship the dimensional variables to form a non-dimensional parameters. Dimensional perameters has became important tooling analysing the fluid flow

Various physical quantities in fluid phenomena can be expressed in terms of fundamental quantities.

quantity	unit	symbol
Mass	kg	M
Length	m	L
Temperature	K	θ
Time	sec	T
force	N-(kg-m/s^2)	MLT^{-2}
density	kg/m^3	ML^{-3}
kinematic viscosity	m^2/sec	L^2T^{-1}

Methods of dimensional analysis:-

DA → Raylaigh's method
DA → Buckinghom's π theorem

Buckinghom's π theorem:- Its a thumb rule of determining a number of independent dimensionless groups (π - terms) that can be obtained from a set of variaibles (n) with a fundmental dimensions (m). that is number of

Convection:

If the fluid motion is produced due to change in density resulting from temperature rating this mode of heat transfer is set to be free or natural convection.

Ex:

1. The heat of rooms by use of radiators
2. Cooling of transmission lines electrical transformers and rectifiers
3. The heat transfer from the pipe carrying steam from the wall of furnaces, from the wall of air conditioning house from the refrigerator condenser unit the rate of heat transfer is given below

$$Q = hA(T_w - T_\infty)$$

T_w = pipe surface temperature

T_∞ = fluid temperature

A = surface area

1. film temperature $T_f = \frac{T_w + T_\infty}{2}$

2. Coefficient of thermal expansion

$$\beta = \frac{1}{T_f \text{ in } K}$$

3. Nusselt Number

$$Nu = \frac{hL}{k}$$

4. Grashoff Number of vertical plate.

$$Gr = \frac{g \beta L^3 \Delta T}{\upsilon^2}$$

L = length of plate

$\Delta T = T_w - T_\infty$

υ = kinematic viscosity

5. If $Gr.Pr < 10^9$

flow is laminar

$Gr.Pr > 10^9$

flow is Turbulent

6. for laminar $Nu = 0.59\,(Gr.Pr)^{0.25}$

for $10^4 < Gr\,Pr < 10^9$

7. for turbulent (vertical plate)

$$Nu = 0.10\,(Gr.Pr)^{0.333}$$

8. heat transfer (vertical plate)

$$Q = hA\,(T_w - T_\infty)$$

9. for horizontal plate

$$Gr = \frac{g \beta L_c^3 \Delta T}{\upsilon^2}$$

L_c = characteristic

w = width

Nusselt Number

for horizontal plate upper surface heated

$$Nu = 0.54\,(Gr.Pr)^{0.25}$$

for $2\times10^{4} < Gr.Pr < 8\times10^{6}$

$$Nu = 0.15\,(Gr.Pr)^{0.333}$$

for $8\times10^{6} < Gr.Pr < 10^{11}$

11. lower surface heater.

$$Nu = 0.27\,(Gr.Pr)^{0.25}$$

for $10^{5} < Gr\,Pr < 10^{11}$

12. Heat transfer horizontal

$$Q = (h_u + h_l)\,(A)\,(T_w - T_\infty)$$

h_u = upper surface heat transfer coefficient

h_l = lower surface H.T.C

13. for horizontal cylinder

$$Nu = C\,(Gr.Pr)^{m}$$

14) for Horizontal cylinder

$$Q = hA\,(T_w - T_\infty)$$

$$A = \pi D L$$

15. for sphere

$$Nu = 2 + 0.43\,(Gr.Pr)^{0.25}$$

 $Q = hA\,(T_w - T_\infty)$

$A = 4\pi r^2$

16. Boundary layer thickness

$$\delta_x = \left[3.98 \times (Pr)^{-0.5} (0.952 + Pr)^{0.25} \times Gr^{-0.25}\right] x$$

17. Maximum velocity

$$v_x = 0.766 \times \nu \times (0.952 + Pr)^{-1/2} \times \left[\frac{g\beta (T_w - T_\infty)}{\nu^2}\right]^{1/2} \times x^{1/2}$$

18. Mass flow rate

$$m = 1.7\, \rho \nu \left[\frac{Gr}{(Pr)^2 (Pr - 0.952)}\right]^{0.25}$$

1. A vertical plate of 0.75 m high is a 170°c exposed to air and 105°c and one atmosphere calculate mean heat transfer coefficient . rate of heat transfer : for unit width of plate

Sol): G.D

$L = 0.75\,m$

$T_w = 170°c$

$T_\infty = 105°c$

$T_f = \frac{170 + 105}{2} = 137.5°c$

$= 140°c$

$\beta = \frac{1}{T_f \text{ in } K}$

$= \frac{1}{137.5 + 273}$

$\beta = 2.4 \times 10^{-3}\, K^{-1}$

→ properties of air @ 140°c

$\rho = 0.854$

$\mu = 23.73 \times 10^{-6}$

$\nu = 27.80 \times 10^{-6}\ m^2/s$

$Pr = 0.684$

$Cp = 1013$

$k = 0.03489\ w/mK$

$$Gr = \frac{g \beta L^3 \Delta T}{\nu^2}$$

$$= \frac{9.81 \times 2.4 \times 10^{-3} \times (0.75)^3 \times (170-105)}{(27.80 \times 10^{-6})^2}$$

$$= 8.4 \times 10^8$$

$$Gr.Pr = 8.4 \times 10^8 \times 0.684$$

$$= 5.71 \times 10^8 < 10^9$$

flow is laminar

$$Nu = 0.59 (Gr.Pr)^{0.25}$$

$$= 0.591 (5.71 \times 10^8)^{0.25}$$

$$Nu = 91.2$$

$$Q = hA (T_w - T_\infty)$$

$$Nu = \frac{hL}{K}$$

$$h = \frac{Nu K}{L}$$

$$= \frac{91.2 \times 0.03489}{0.75}$$

$$h = 4.242624$$

$$Q = hA\,(T_w - T_\infty)$$

$$= 4.24 \times \pi \times 0.75\,(170 - 105)$$

$$Q = 649.36$$

2. A steam pipe 10cm outside dia runs horizontally in a room at 23°c take the outside surface temperature of pipe as 165°c determine heat loss per meter length of pipe

Sol:- G.D

$$D = 10cm = 0.1\,m$$

$$T_\infty = 23^\circ c$$

$$T_w = 165^\circ c$$

$$T_f = \frac{T_w + T_\infty}{2} = \frac{165+23}{2} = 94^\circ c$$

properties of air at 95°c

$$\rho = 0.995\ kg/m^3$$

$$\nu = 22.615 \times 10^{-6}$$

$$Pr = 0.689$$

$$k = 0.03169$$

$$\beta = \frac{1}{T_f \text{ in } K} = \frac{1}{94+273} = 2.72 \times 10^{-3}$$

$$Gr = \frac{g\beta L^3 \Delta T}{\nu^2}$$

$$= \frac{9.81 \times 2.72 \times 10^{-3} \times 0.1^{3} (165-23)}{(22.615 \times 10^{-6})^{2}}$$

$$Gr = 7.4 \times 10^{6}$$

$$Gr \cdot Pr = 7.4 \times 10^{6} \times 0.689$$

$$= 5.09 \times 10^{6}$$

laminar flow

$C = 0.48$, $m = 0.25$

$$Nu = C (Gr\,Pr)^{m}$$

$$= 0.48 (5.09 \times 10^{6})^{0.25}$$

$$= 22.79$$

$$h = \frac{Nu\,K}{D}$$

$$= \frac{22.79 \times 0.03169}{0.1}$$

$$h = 7.22 \text{ W/mK}$$

$$Q = hA (T_w - T_\infty)$$

$$= 7.22 \times \pi \times 0.1 \times L (165 - 23)$$

$$Q/L = 322.18 \text{ W/m}$$

3. A large vertical plate 5m high maintained at 100°C and exposed to air at 30°C Calculate the heat transfer coefficient.

given

$L = 5\,m$

$T_\infty = 30^\circ C$

$T_w = 100^\circ C$.

$$T_f = \frac{30+100}{2} = 65^\circ C$$

properties of $65^\circ C$

$\rho = 1.0445\ kg/m^3$

$\nu = 19.495 \times 10^{-6}\ m^2/s$

$Pr = 0.695$

$k = 0.02931\ w/mK$

$$\beta = \frac{1}{T_f \text{ in } K} = \frac{1}{65+273} = 2.95 \times 10^{-3}$$

$$Gr = \frac{g \beta L^3 \Delta T}{\nu^2}$$

$$= \frac{9.81 \times (2.95 \times 10^{-3})(5^3)(100-30)}{(19.495 \times 10^{-6})^2}$$

$= 6.6 \times 10^{11}$

$Gr.Pr = 6.6 \times 10^{11} \times 0.695$

$= 4.587 \times 10^{11}$

Turbulent flow

$Nu = 0.10\ (Gr.Pr)^{0.333}$

$= 0.10\ (4.587 \times 10^{11})^{0.333}$

$= 764.3$

$$h = \frac{Nu\,k}{L}$$

$$= \frac{764.3 \times 0.02931}{5}$$

$h = 4.48\ w/mK$

Radiation heat transfer :-

Introduction :-

The heat transferred from one body to another without any transmitting medium is known as radiation. It is an electromagnetic wave phenomenon.

All types of electromagnetic waves are classified in terms of wavelength and are propagated at the speed of light, i.e. 3×10^8 m/s

Thermal Radiation :-

The energy which a radiating surface releases is not continuous but in the form of successive and separate packet or quanta of energy called photons. The photons are propagated through space as rays. The movement of swarm of photons is described as electromangetic waves. The photons travel in straight paths with unchanged frequency; when they approach the receiving surface, there occurs reconversion of wave motion into thermal energy which is partly absorbed, reflected, or transmitted through the receiving surface (the magnitude of each fraction depends, upon the nature of the surface that receives the thermal radiation).

The emission of thermal radiation (range lies between wavelength of 10^{-7} m and 10^{-4} m depends upon the nature of the surface ~~that receives~~, temperature and state of the emitting surface, however, with gases the dependence is also upon the thickness of the emitting layer and the gas pressure.

~~Radia~~
Black body Radiation:-

A body that emits the maximum amount of heat for its absolute temperature is called a black body. Radiation heat transfer rate from a black body to its sourroundings can be expressed by the following equation.

$$Q = \sigma A T^4$$

Q = heat transfer rate

σ = stefan Boltzman constant.

A = surface area

T = temperature.

$$\sigma = 5.67 \times 10^{-8} \text{ watts} \cdot m^{-2} k^{-4}$$

$$= 0.174 \times 10^{-8} \text{ BTU}/Hr\text{-}ft^{2}\text{-}R^{4}$$

Two black bodies that radiate toward each other have a net heat flux between them. The net flow rate of heat between them is given by equation.

$$Q = \sigma A (T_1^4 - T_2^4)$$

T_1 = tem of first body

T_2 = tem of second body

λ_{max} = 2.898 mmk.

$\lambda_{max} T = 2.9 \times 10^{-3}$ mk.

3. Stefan - Boltzmann law :-

The emissive power of a black body is proportional to the fourth power of absolute temperature.

$$E_b \propto T^4$$

$$E_b = \sigma T^4$$

E_b = emissive power - W/m^2.

T = temperature - K.

4. Maximum emissive power $(E_{b\lambda})_{max}$:-

A combination of planck's law and wien's displacement law yields the condition for the maximum monochromatic emissive power for a black body.

$$(E_{b\lambda})_{max} = C_4 T^5$$

$C_4 = 1.307 \times 10^{-5}$ (Radiation constant)

$$(E_{b\lambda})_{max} = 1.307 \times 10^{-5} T^5$$

5. Lambert's cosine law :-

It states that the total emissive power E_b from a radiating plane surface in any direction is directly proportional to the cosine of the angle of emission.

$$E_b \propto \cos\theta.$$

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→ surface emission properties:-

The rate of emission of radiation by a body depends upon the following factors.

i) the temperature of the surface.
ii) the nature of the surface.
iii) the wavelength or frequency of radiation.

→ Basic Laws of Radiation:-

1. planck's Distribution Law:-

The relationship between the monochromatic emissive power of a black body and wave length of a radiation at a particular temperature is given by the following expression. by planck

$$E_{b\lambda} = \frac{C_1 \lambda^{-5}}{e^{\left[\frac{C_2}{\lambda T}\right]} - 1}$$

$E_{b\lambda}$ = Monochromatic emissive power W/m^2.

λ = wavelength - m.

$C_1 = 0.374 \times 10^{-15}\ W\text{-}m^2$

$C_2 = 14.4 \times 10^{-3}\ mk$.

2. Wien's Displacement Law:-

The wien's law gives the relationship between temp and wavelength corresponding to the maximum spectral emissive power of the black body at that temperature.

6. Kirchoff's Law of Radiation:

This law states that the ratio of total emissive power to the absorptivity is constant for all surfaces which are in thermal equilibrium with the surroundings

$$\frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_3}{\alpha_3} \dots$$

→ Intensity of Radiation:

It is defined as the ratio of energy leaving a surface in a given direction per unit solid angle per unit area of the emitting surface normal to the mean direction in space.

$$I = \frac{E_b}{\pi}$$

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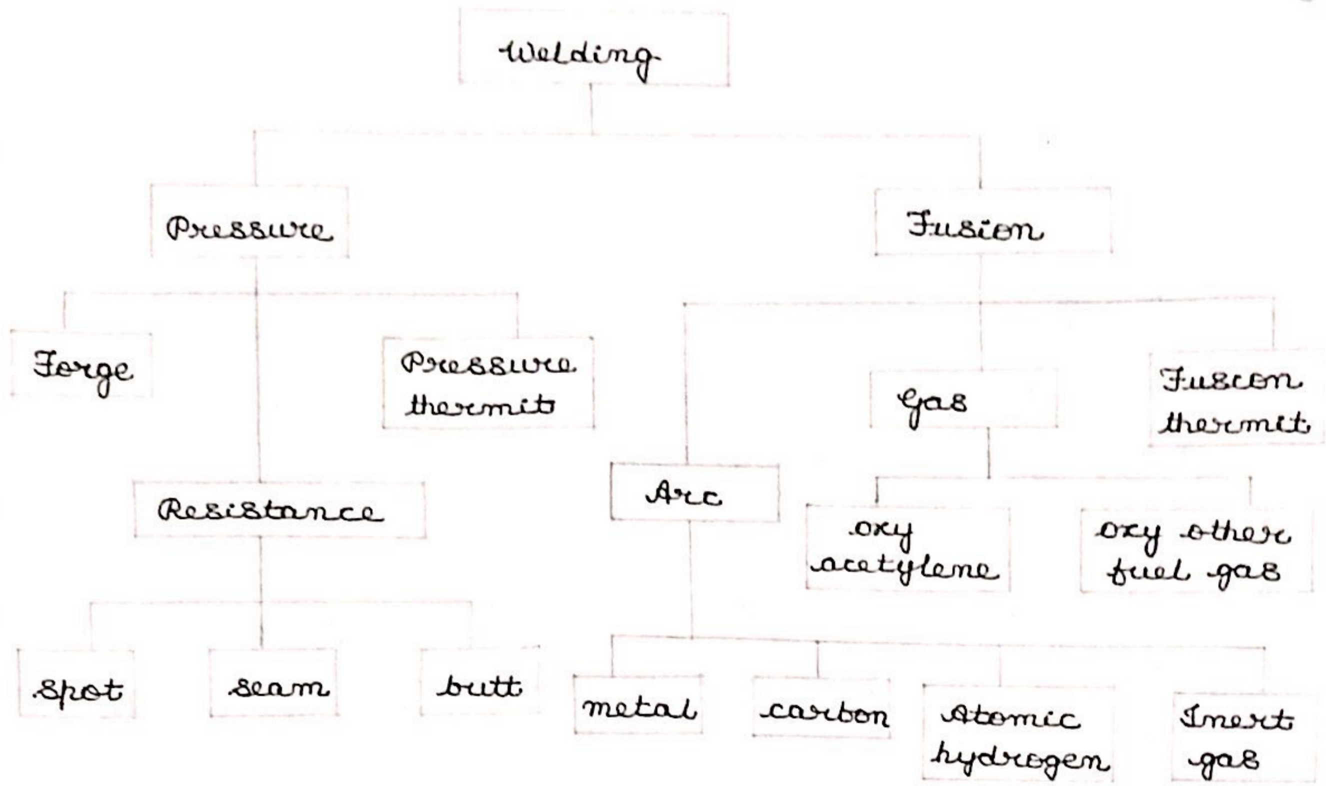
Unit-VI Metal Joining; Metal forming Methods Castings



Arc welding: In welding generation of heat by an electric arc is one of the most efficient methods. Approximately 50% of energy is liberated in the form of heat. This process makes use of the heat produced by the electric arc to fusion weld metallic process. It is one of the most widely used process.

Principle of arc:

* An arc is generated between two conductors of electricity to the cathode and anode.
* Consider DC current. When they touched to establish the flow of current and then separated by small distance.
* An arc is sustained by electric discharge through the ionised gas column called plasma between 2 electrodes

* Generally electrons liberated from cathode move towards anode and are accelerated in their movement.
* When they strike the anode at velocity, a large amount of heat is generated.
* Electrons are moving through the air gap between the electrodes also called arc column.
* They collide with the ions in the ionised gas column between the electrodes.
* The positive charged ions move from the anode and impinge on cathode. Thus heat is liberated.
* About 65-75% heat is liberated at anode by striking electrons.
* A temperature order of 6000°C is generated at anode. In order to produce arc, high potential difference is needed.

~~Principle of arc~~ welding:

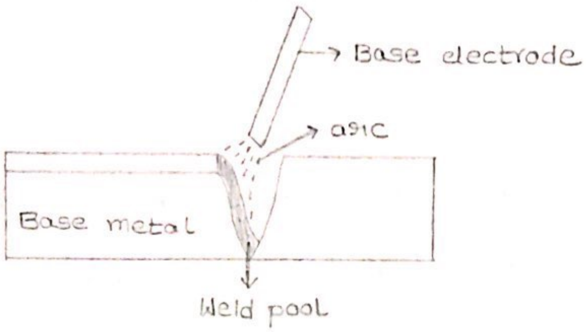
Arc welding:

* Arc welding is based upon formation of an electric arc between a consumable electrode (bare or coated) under base metal.
* The heat of arc is concentrated at the point of welding. As a result it melts electrode and the base metal.
* When the weld metal solidifies, a slag gets deposited on the surface. As a result it is lighter than the metal and the weld metal is allowed to cool gradually and slowly.
* After cooling, a strong joint is formed.

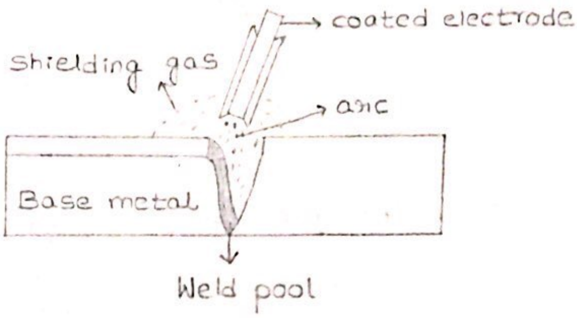
* The slag is removed by chipping hammer.

* Air gap between electrode and base metal is 2-4 mm.

* Arc welding involves 20-80 volts and 80-500 Amps



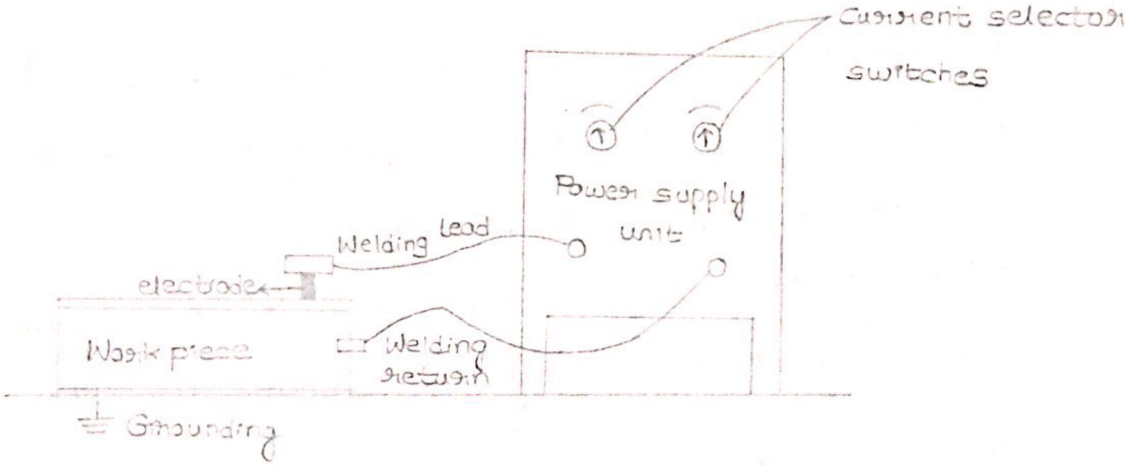
Arc welding



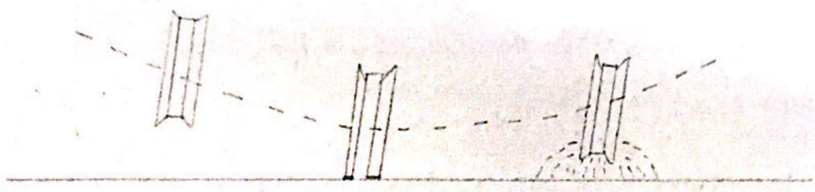
Shielded arc welding

Steps involved in building:

① Preparation of edges
② Holding the work piece in a fixture
③ Striking the arc.
④ Welding the joint.



Manual metal arc welding set up



Applications of arc welding:

* Fabrication of pressure vessals, ships, structural steel work joints in pipe work.
* Construction and repair of machine parts and broken parts.

Advantages:

* It is faster and lower in cost than gas welding.
* The process is quite versatile and welds can be made in any position.
* Suitable for wide range of metals like ferrous and non-ferrous.
* Less sensitive to weld to other process.

Limitations:

* It is not suitable for thin sections.
* It is not suitable for mechanisation.
* Electrode replacement is necessary for long joints.
* Not suitable for heavy fabrication because less metal is deposited per hour.
* Failure to remove slag when run is interupted will result in slag inclusions in the welding.

Arc welding - Equipment & Accessories:

Equipment:

① Transformer for AC

② Generator (or) Rectifier for DC

Accessories:

① Electrodes ② Electrode holder ③ Cable

④ Safety devices ⑤ Tools

Transformer:

* The purpose of transformer is to change high input voltage and low current to a low voltage (50-80 V) and high current (80-500 Amps).
* Its cost is low and AC gives a smoother or with high current used in mostly ferrous metals.

Generator:

* It is given by a motor or an engine. It generates and supply DC for electric arc welding.

Rectifier:

* The purpose is to change output AC to DC for electric arc welding.
* The output of step down transformer is connected to rectifier which converts AC to DC.

AC plant - advantages:

* It is simple equipment and costs only about 60% as much as DC.
* Low maintanance cost because there is no moving parts.
* No change of polarity when working with various types of electrodes.

Disadvantages:

* Not suitable for non-ferrous metals and thin sheets.
* Electric shock is more intense.

DC supply Advantages:

* Ferrous and non-ferrous
* Stable or smoother welding facilitates welding of thin sheets.
* Easy of operation and suitable for overhead welding.
* Safer to use where the risk of an electric shock is great.

Disadvantages:

* More expensive to purchase.
* High maintanance cost because of moving parts.
* Troubles from arc blows i.e. the arc is forced away from the weld pool/point.
* This condition encountered in DC equipment only.

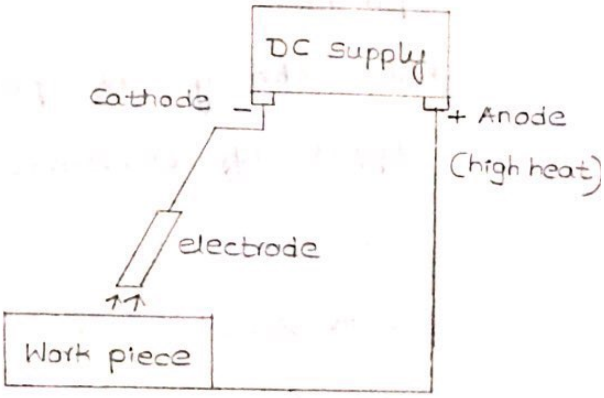
DC polarity:

It is of two types

① Straight polarity ② Reverse polarity

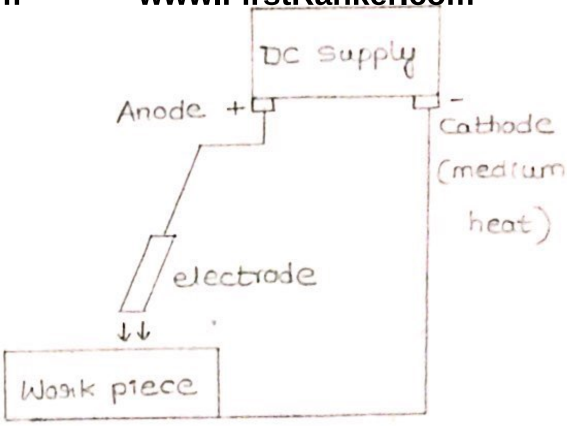
Straight polarity:

* Here electrode is connected to negative terminal and workpiece is connected to positive terminal.
* It is used for weld thick sections with medium coated electrodes.



Reverse polarity:

* Here electrode is connected to positive terminal and workpiece is connected to negative terminal.
* It is used for weld non-ferrous metals and cast iron with heavy coated electrodes.



* It is also used in sheet metal welding.

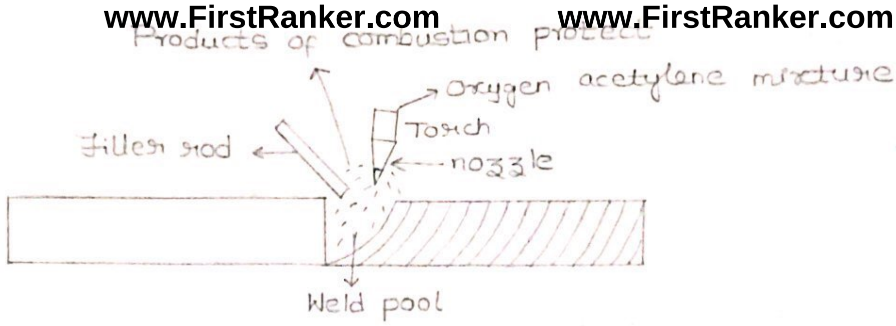
Selection of electrodes:

* Type of metal to be welded.
* The position in which the weld is to be done.
* The power source
* The polarity in case of DC.
* Thickness of the base metal.

Gas welding:

Principle:

* In gas welding heat is necessary for melting base metal and filler rod is obtained by gas flame.
* The composition of filler rod is same as that of the base metal.
* Different gas combinations can be used for producing a flame.
* However oxygen and acetylene mixture is most widely used.



* In oxy-acetylene welding, acetylene is burnt in the presence of oxygen at the tip of the nozzle which is fitted to torch.
* The temperature of this flame is 3250°c and it melts parent metal and filler metal to create weld pool.
* No flux is used in gas welding. The weld pool gets solidified by cooling.

Filler rods:

* Pieces of wires or rods used as a filler material in welding are called filler rods or welding rods.
* Good quality filler rods are necessary to reduce oxidation and to control the mechanical properties.

Specifications as per IS 1278-1972

The sizes are as follows:

Diameter: 1, 1.2, 1.6, 2.0, 2.5, 3.15, 4, 5, 6.3, 8.0, 10, 12.5

all are in mm.

Length: 500 mm (or) 1000 mm

Oxygen cylinder:

* Oxygen is produced by separating the various constituents of air by liquefaction.

* It is made of steam and painted black for identification.

* The oxygen pressure in the cylinder is 17.5 N/mm^2 (or) 175 bars.

* This can store $7m^3$ gas about 80 kg of mass when it is completely full.

Acetylene cylinder:

* Acetylene is a full gas of 92.3% carbon and 7.7% hydrogen

* It is a product of chemical reaction between calcium carbide and water.

* It is produced in 2 methods.

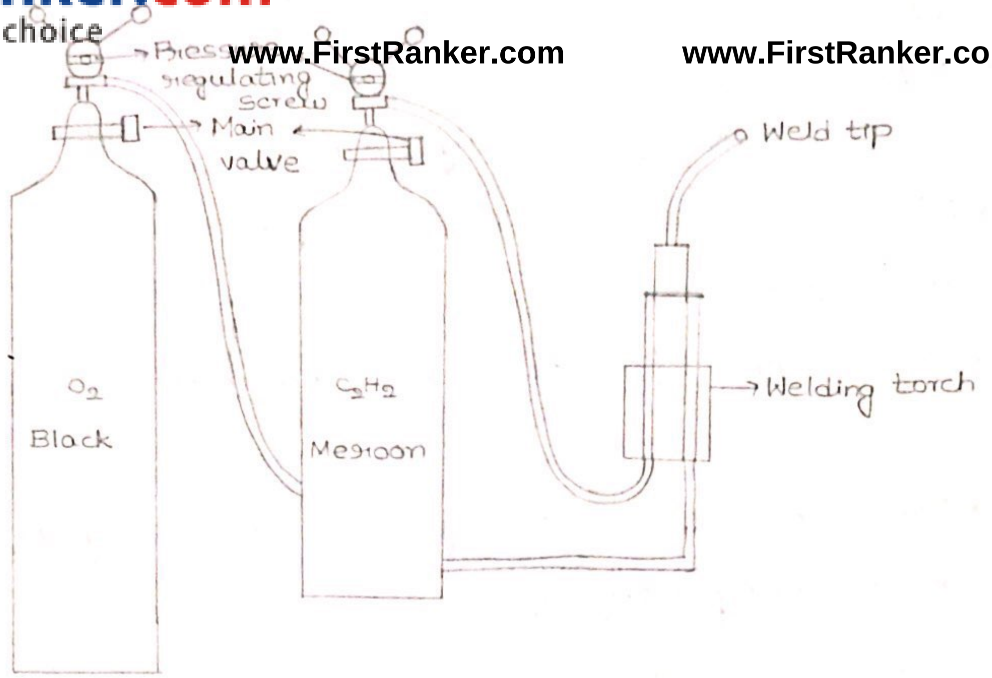
① water to carbide method:

For high pressure systems, water falls on carbide to produce acetylene at high pressure.

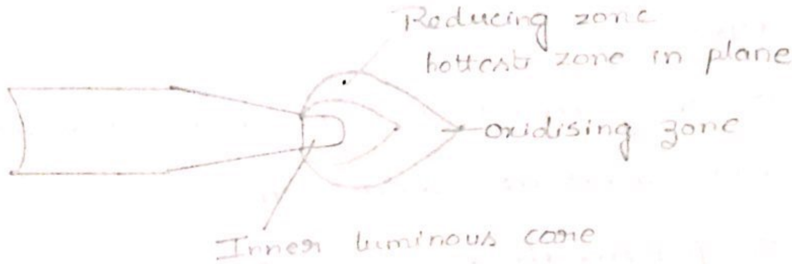
② Carbide to water method:

For low pressure systems, calcium carbide grains fall in water to produce acetylene at low pressure

* The cylinder is made of steel painted maroon and having pressure of 1.5 N/mm^2 (or) 15 bar pressure and $6m^3$ of volume. It can be stored in 0.07 bar of pressure condition.



Oxy-acetylene flames:



Inner luminous:

* In this partially decomposed product of acetylene and the separated solid particles of carbon.
* It is in the shape of trunkated cone.

Reducing zone:

* It is the brightest section of flame.
* The highest temperature of this zone is 3250°C.
* It is in the form of bright white cone.

Oxidising zone:

* In this carbonmonoxide and hydrogen combine with the atmospheric oxygen and gives rise to bluish flame.

Temperature ranges:

S.no	Gas flame	Temperature	Applications
1.	Oxy-acetylene	3100 – 3300°c	All ferrous and non-ferrous metals and their alloys.
2.	Oxy-hydrogen.	2400 – 2700°c	Brazing, silver soldering & under water gas cutting of steel.
3	Oxy-coal gas	1800 – 2200°c	Silver soldering and under water gas cutting of steel.
4.	Oxy-liquid.	2700 – 2800°c	Gas cutting of steel petroleum.
5.	Air-acetylene	1825 – 1875°c	Soldering & brazing.

Advantages of gas welding:

* Low capital cost.
* High portability and convenience.
* It can be easily altered for brazing, cutting and heating.
* Oxy-acetylene flame is more easily controlled and can be used for different metals and alloys.
* welding skills are relatively easy.

Limitations:

* Takes longer time to weld.
* Heat affected zone and distortion are longer.
* Oxygen and acetylene gases are expensive and there is safety problems in handling and storing these gases.
* Shielding provided by gas is not effective.

Applications:

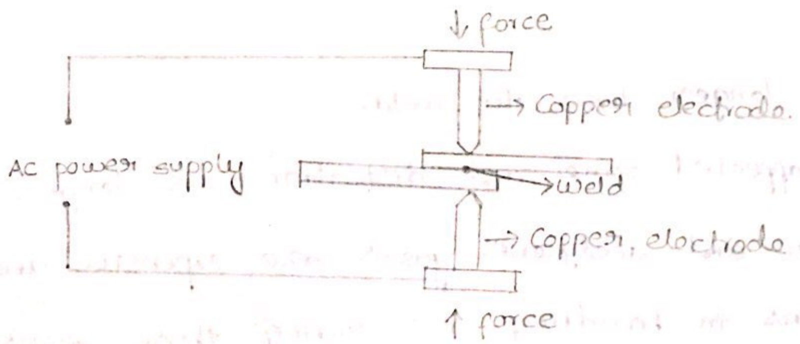
* Oxy-acetylene is a versatile process and can be used for welding all commercial metals & alloys.
* Due to low temperature of gas flame, this process is employed for welding thin sections.
* This process is mostly used in sheet metal fabrication. workshop, aircraft industries, garage and maintanence shops.

Resistance (or) Electric resistance welding:

* In this the welding is obtained at the location of the desired metal by the electrical resistance through the metal pieces to a relatively short duration, low voltage, high ampere. electric current.
* The amount of current can be regulated by the changing the primary turns of the transformer.
* When the area to be welded is sufficiently heated, the pressure varying from 25 megapascals - 55 megapascals is applied to the joining area by suitable electrodes until the weld is solid.

There are various types of welds:

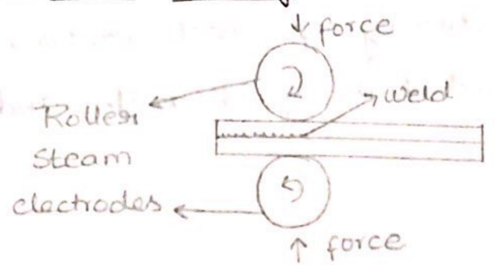
① Spot welding:



* It is used for welding lap joints, joining components made from plate material having 0.025 to 1.25 mm in thickness.
* The plates to be join together are placed between the two electrode tips of copper alloy.

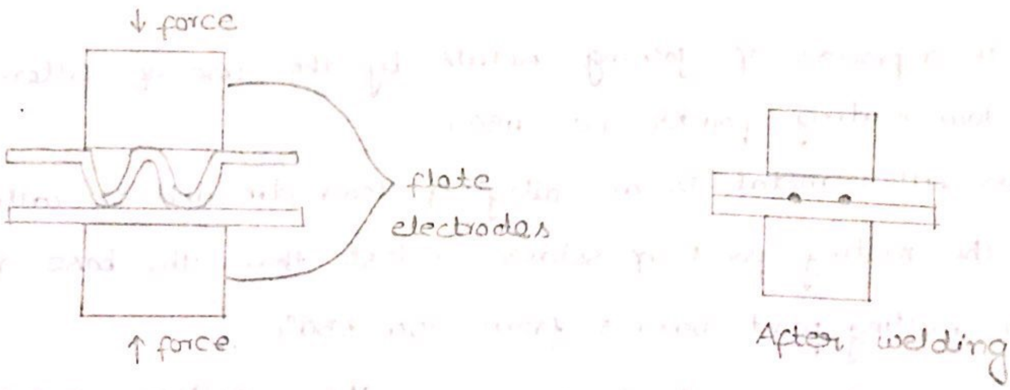
* These the electrodes are connected to primary, secondary bindings of a transformer.
* When we make contact with the plate there is huge amount of heat is generated between the electrodes and this heat wont be necessary to weld the joints.
* We need to apply some force to complete the welding and the power supply to this welding is AC power supply.

② Seam welding:



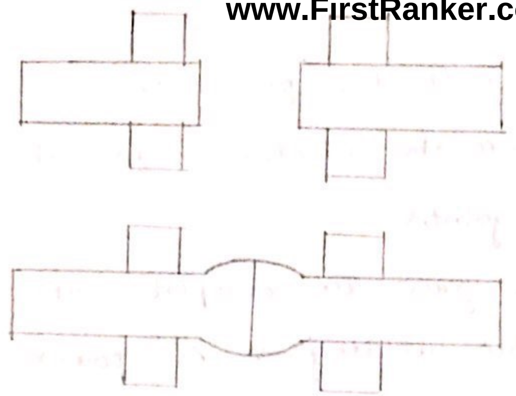
* When the spot welds on two over-lapping pieces of metal are spaced, the process of welding is known as roll spot welding (or) Seam welding.
* This process is best for metal thickness raising from 0.025 - 3 mm.

③ Projection welding:



* It is similar to spot welding except that one of the metal pieces to be welded has projections on its surface at the points where the welds are to be made.
* In other words it is a mult spot welding process.

① Butt welding



* This is extensively used in manufacturing of steel containers and welding of mild steel stalks and high speed drills and reamers.

Soldering & Brazing

* Soldering and brazing processes differ from the welding.
* In soldering and brazing there is no direct melting of base metal that is to be joined.
* Further, the strength of soldered & brazed joints is much less than the welding joints.

Soldering:-

* It is a process of joining metals by the use of filler materials of low melting points i.e. 450°C.
* This filler metal is an alloy of lead, tin and is called solder. & the melting point of solder is less than the base metal.
* The melting point varies from 150-350°C.
* The percentage of lead increases the melting point.

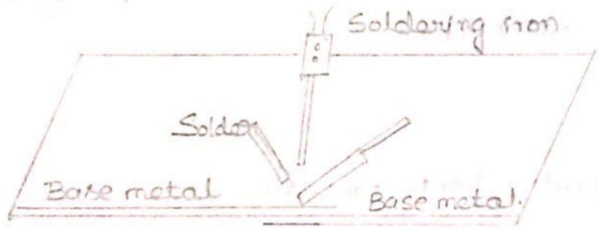
S.no.	Solder.	Tin	lead	M.P	Applications.
1.	Soft solder.	63	37	184	sheet metal components which damaged by heat.
2.	Medium.	50	50	204	General workshop.
3.	Plumber.	30	70	250	Plumbing work.
4.	Electricians	42	58	220	Electrical components.

Soldering fluxes

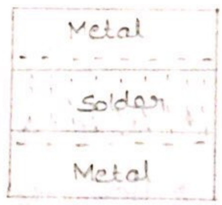
* The strength of soldering joint is primarily depends on the cleanliness of the surfaces to be joined.
* The surface must be free from oil, grease are oxide films which prevent satisfactory adhesion of the solders.
* In soldering operation, flux is used to produce the chemically clean surface to prevent oxidation of the surface to be soldered and to dissolve oxides that settle on the metal surfaces.

Flux	Metal
Zinc chloride (corrosive)	Thin plates, Brass and suitable for most metals.
Aluminium chloride (corrosive)	Steel.
Diluted HCl (Corrosive)	Zinc and galvanised work.
Resin (non-corrosive)	Electrical work.
Talloo (non-corrosive)	Lead.

Method of Soldering:



(a) Technique



(b) Principle

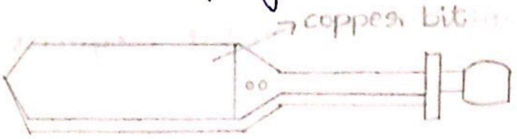
* For a successful soldering, the metal should be clean.
* This is done with a file or emergy paper.
* The soldering joint is made by heating the joint applying the flux and adding the solder.
* Molten solder transfer to the joint surfaces.
* The two surfaces in contact should be pressed together and give sufficient time to cool down.

* Any surplus solder can be removed by heat the work wipe the join with a cloth dipped in the flux.

* The heat required for the solder is given by soldering iron.

Soldering iron:

* Heat is supplied by the soldering iron in soldering and the bit is made with a copper because it is a good conductor of heat and it can transfer heat rapidly.



Advantages:

* Operation is simply & faster than the other process
* Strong enough for most sheet metal work and electrical, electronic components

Disadvantages:

* Joints are weak and cannot withstand high temperature.

Applications:

* Soldering is employed when liquid type joints with comparatively low mechanical strengths.

Hard soldering:

* It is a permanent joint process.
* Here the solder melts at 650 – 700°c.
* It is also called as silver soldering.
* Here silver is employed as a solder and borax mixture used as a flux.

Brazing:

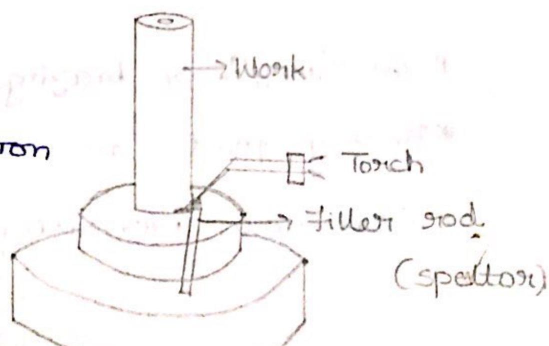
* Brazing is similar to soldering but it gives much stronger joint.
* It is accomplished at a temperature about 450°c using a no. of non-ferrous alloys (Brazing alloys).
* Copper-zinc alloy is most widely used as filler material. It is called as spelter.
* Depending upon the composition it has different melting points.
* Its range is 875 to 898°c.

Type.	Composition	Melting temp °c	Applications.
Aluminium alloy	Si = 10% Cu = 4% Remaining Al.	535 - 595	Aluminium alloys.
Silver alloy	Ag = 34% Cu = 25% Zn = 20% Cd = 21%	610 - 670	General brazing alloys.
Copper alloy.	Cu = 60% Zn = 40%	875 - 895	Ferrous alloys.
Nickel alloy.	Cr = 14% Si = 5% B = 3% Fe = 4% Ni (remaining)		

Methods of brazing:

① Torch brazing. ② Furnace brazing. ③ Induction brazing. ④ Resistance brazing. ⑤ Dip of immersion.

Torch brazing:



* In this base metal is heated upto required temperature by the application of oxy-acetylene flame.
* The other gas combination like oxy-hydrogen, oxy-propane may be used for heat in the path.

* It is used to fabricate almost any assembling.

* Heat is applied from the torch and the joint brought uniformly upto brazing temperature.
* Borax is usually sprinkled on the joint to assist flow of the molten spelter to the joint.
* After solidification with brazed joint is formed.

~~Furnace~~ Induction brazing:

* ~~Here parts~~ The components to be brazed is heated in a coil which is carrying high frequency alternating current.
* Induction heating is used where rapid heating required.

Furnace brazing:

* Here parts to be brazed is heated to a brazing temperature under controlled atmosphere in the furnace.
* The majority furnaces are electrically-heated.

Resistance brazing:

* Here heat required for brazing is developed by resistance at the joint interface.
* High electrical current at low voltage passed through the assembly, heating can be precisely locationised.

Dip and immersing brazing:

* The parts to be brazed are heated by dipping them in a bath of molten filler materials (metals).

Advantages:

* The strength of brazing joint is stronger than soldering joint.
* Brazing joint can withstand high temperature.
* Mechanical interlooking of parts is not necessary.

~~Disadvantages:~~

~~* Brazing is very suitable for joining different~~

Disadvantages:

* It requires costly equipment for heating.
* The colour of brazing joint may not match waste metal.

Applications:

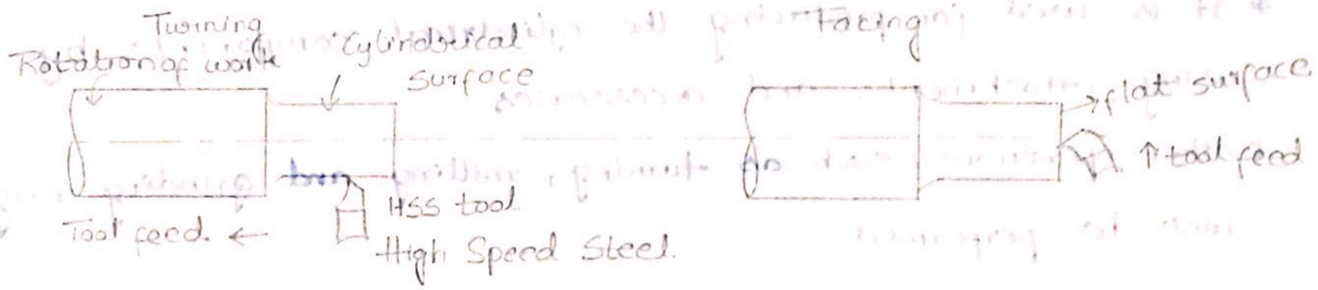
* Brazing is very suitable for joining different metals together.
* The process is used for cycle & motorcycle frames.
* Heat exchangers through away tool tips.

Introduction to machine tools

Machine tools are power driven devices designed to produce a required geometrical surface. The purpose of machine tools is to produce components with greater precision and more complex forms than is possible by the hand tools or by the primary forming process.

Working principle of lathe:

* The work piece is held in a chuck or between the centre and is rotated against the cutting tool.
* The cutting tool removes the material in the form of chips from the workpiece.



Operations made by lathe:

① Turning → Step, Taper, Turning
② Facing
③ Threading → Internal, External
④ Knurling
⑤ Drilling

Types of lathe

① Speed lathe ② Engine lathe ③ Bench lathe

④ Tool room lathe ⑤ Capstan and turret lathe.

⑥ Special purpose lathe. ⑦ Automatic lathe.

Engine lathe:

* It is a general purpose of lathe.
* The main parts of lathe are lathe bed, head stock, tail stock, carriage, lead screw and feed change gear box. It is shown in the figure.
* The cutting tool is mounted on the tool post and can be fed in the cross and longitudinal direction with the reference of lathe axis.
* Power from motor is transmitted to the spindle by belt drive or gear drive.
* The speed changes in belt drive are obtained by shifting the belt to a different steps of cone pulley.
* In gear headed lathe, the gear ratio is changed by speed leaver.
* It is used for producing the cylindrical components by using attachments and accessories.
* Other operations such as turning, milling and grinding may also be performed.

Bench lathe:

* It is a small form of a engine lathe that can be mounted on bench.
* It has all features of engine lathe and is used for small and precision work.

Tool room lathe

* A tool room lathe is engine lath more accurately.
* It is used for machining precision and more accurate work.
* It is provided with additional attachements needed for tool and dye making operations.

Capstan and turret lathe:

* These are developments of engine lathe and used for producing a large no. of identical parts.
* Its design same as engine lathe except the tail stock is replaced with hexagonal turret.
* These turret fitted with a series of pre-set tools with pre-setting tools. This can be operated with semi-skilled operators.

Speed lathe:

* It is of simple construction which consists of a bed on which head stock and tail stock are mounted.
* An adjustable slide is provided to support the cutting tool.
* It has no gear box, lead screw and a carriage.
* Here various speeds are obtained by stepped cone pulley.
* The most operations on this lathe are turning of wood polishing and spinning.

Special purpose lathe:

* It includes gap lathe, wheel lathe, tracer lathe etc.
* The gap lathe has a bed with a removable section under the spindle nose so that large work can be swang.
* Wheel lathes are used for finishing the journals and turning the threads of a rail road car and locomotive wheels.
* Tracer lathes are duplicating lathes.

The special devices are used to coordinate the motion of the tools to produce accurately the shape of template.

Automatic lathes:

* Automatic lathes are high speed heavy duty lathes and are adopted for mass production.
* It is provided with automatic control for movement of work and cutting tool at a proper rates & sequences.
* These are two lathes.

  ① NC (Numerical controlled)

  ② CNC (Computer Numerical controlled)

Specifications of lathe:

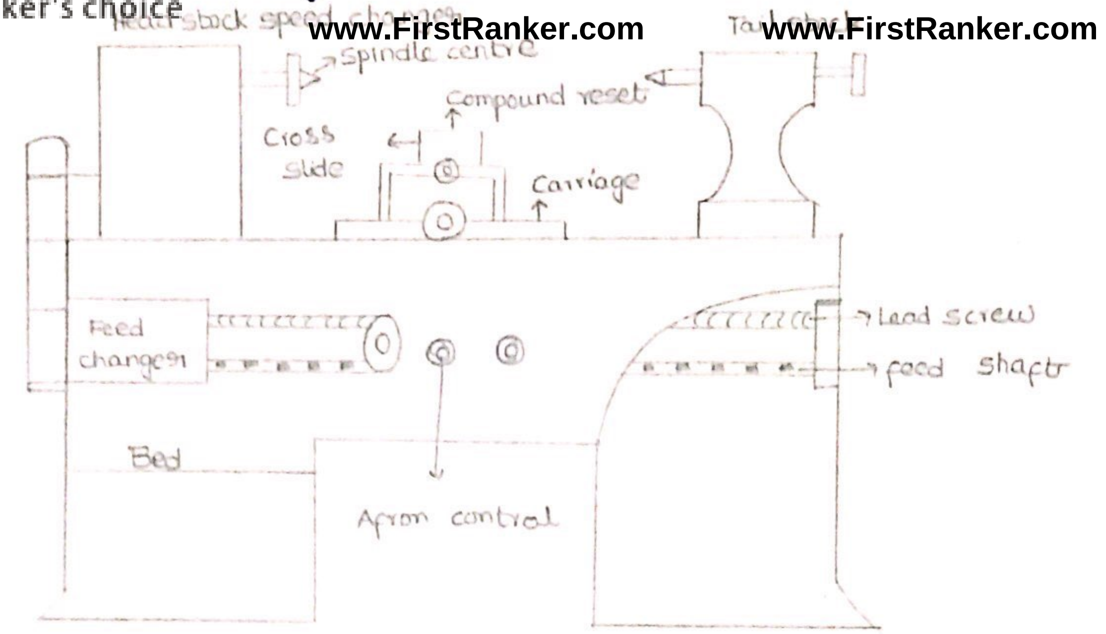
The size of lathe is specified or designated following:

* Height of the center about lathe bed.
* The largest diameter of work that can be revolved over the waste of lathe bed i.e. swing diameter over the bed.
* The largest diameter that can be accomodated over the carriage.
* The maximum diameter that can be turned over the gap of bed. i.e the swing diameter over the gap of bed.
* The maximum length of work that can be mounted between the centers.
* The maximum diameter of the bar that will pass through hollow spindle of the head stock.

Indian standard Specification IS 6893 - 1973

* Maximum swing: Over bed in mm, in gap in mm, Over cross slide in mm.
* Distance between the centres in mm.
* Maximum facing diameter in mm.
* Maximum weight in kg of work that can be held between

... test.



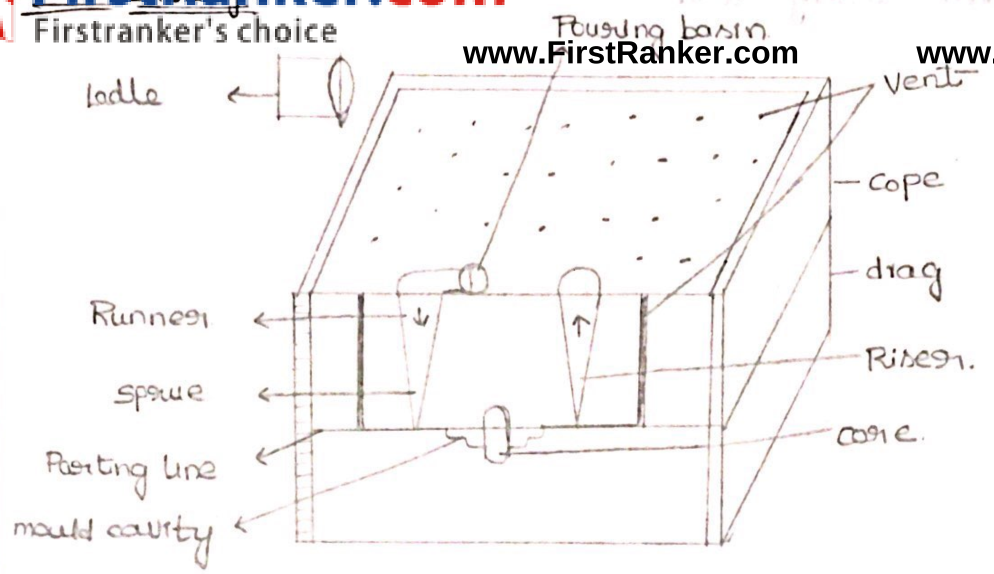
Casting:

* It generally means pouring molten metal into a refractory mould with a cavity of the shape to be made and allowing it to solidify.
* When solidified, the desired metal object is taken out from the refractory mould either by breaking the mould or taking the mould apart.
* The solidified object is called casting.
* The process is also called founding.

History of casting process:

* Discovery c 3500 BC in Mespotamia.
* Bronze age.
* Cire perdue process.
* China.
* Indus valley Civilization.
* Iron pillar in Delhi

Sand casting:



Terms involved in casting:

Drag: Lower moulding flask

Cope: Upper moulding flask.

Cheek: Intermediate moulding flask used in three piece moulding

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

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

Bottom board: This is a board normally made of wood, which is used at the start of the mould making. The pattern is first kept on the bottom board, sand is sprinkled on it and then the ramming is done in drug.

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

Moulding sand: It is freshly prepared refractory material used for making the mould cavity (Green sand).

Backing sand: It is what constitutes most of the refractory material found in the mould. This is made up of used

Core: It is used for making hollow cavities in castings.

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

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

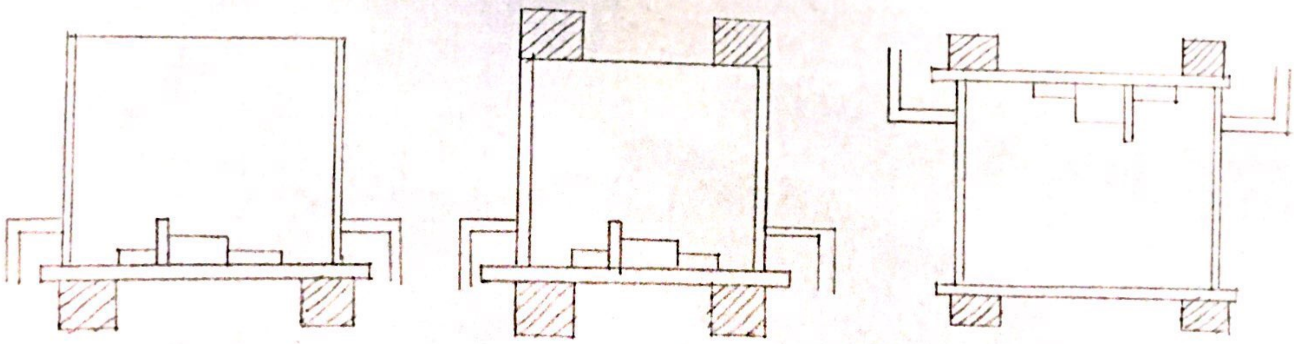
Runner: The passage way in the parting plane through which molten flow is regulated before they reach the mould cavity.

Gate: The actual entry point through which molten metal enters mould cavity.

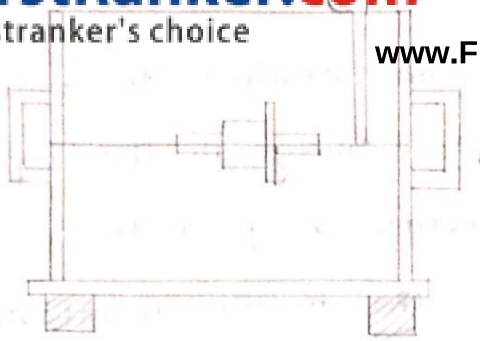
Chaplet: They are used to support cores inside the mould cavity to take care of its own weight & overcome the metallostatic forces.

Chill: They are metallic objects which are placed in the mould to increase the cooling rate of castings to provide uniform or desired cooling rate.

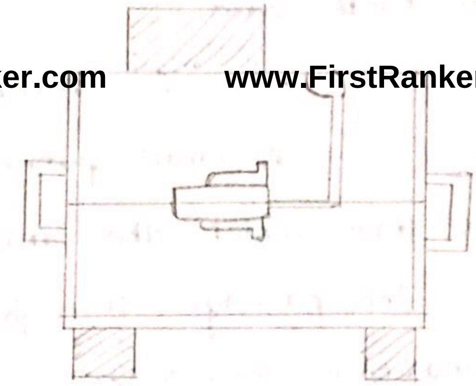
Riser: It is a reservoir of molten metal provided in the casting so that hot metal can flow back into the mould cavity. When there is reduction in volume of metal due to solidification.



(a) Drag completed (b) Ready for roll-over (c) After roll-over



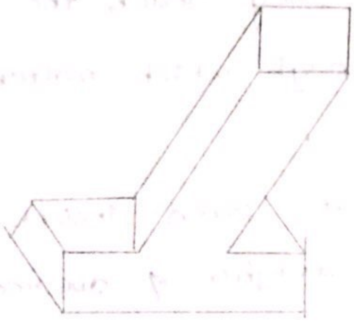
(d) Cope rammed



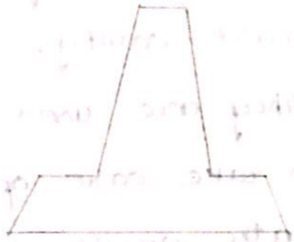
(e) Mould ready for pouring

Types of patterns

① Single piece pattern:

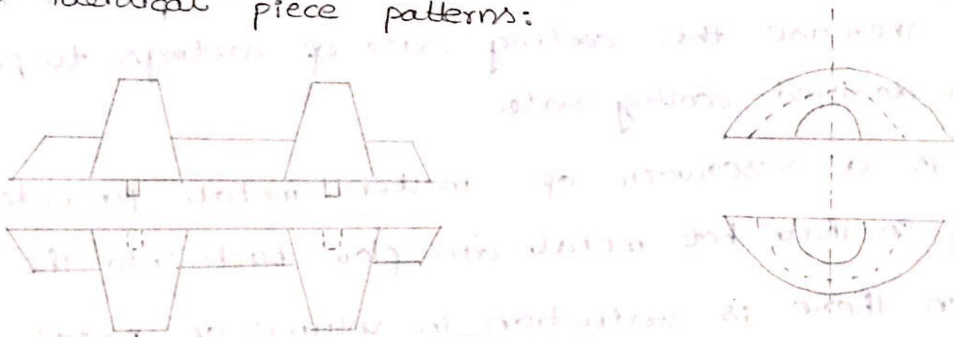


(a) Casting



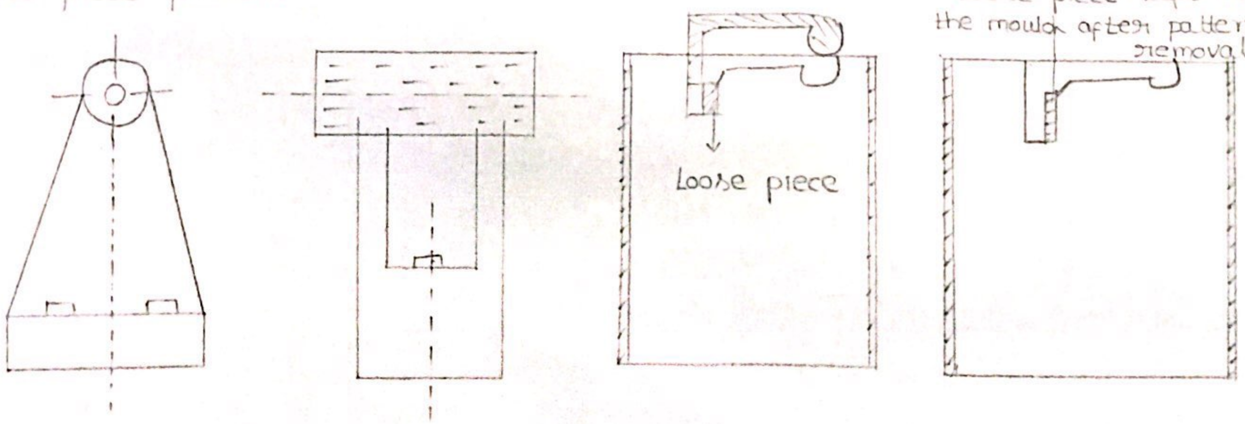
pattern

② Two identical piece patterns:

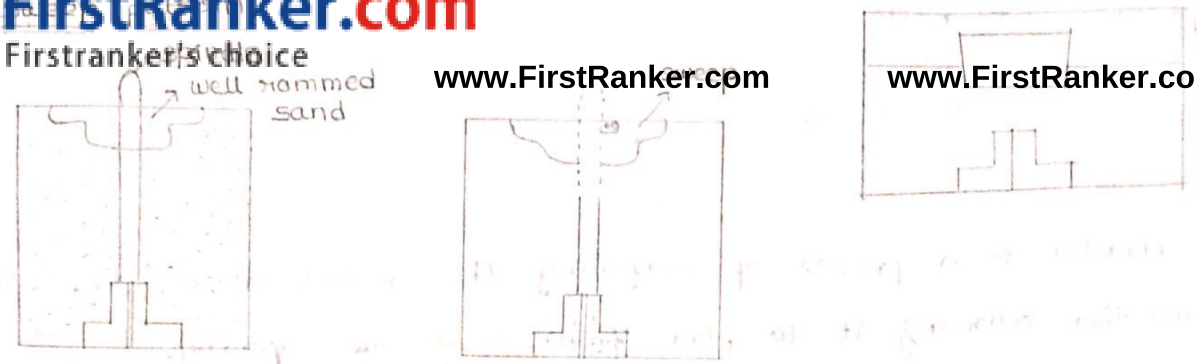


split pattern

Loose piece pattern



Loose piece left in the mould after pattern removal



Advantages:

* Any intricate shapes internal or external can be made with the casting process.
* It is possible to cast practically any material be it ferrous or non-ferrous.
* Tools required for casting are simple and inexpensive.
* Weight reduction in design can be achieved.
* Casting have no directional properties.
* Casting of any size and weight even upto 200 tons can be made.

Limitations:

* Dimensional accuracy and surface finish achieved by normal sand casting process would not be ~~be~~ adequate for final application in many cases.
* Sand casting process is labour intensive to some extent and therefore many improvements are aimed at it such as machine moulding and founding mechanization.
* With some materials it is often difficult to remove defects arising out of the moisture present in sand castings.

Applications:

* Typical applications of Sand casting process are cylinder blocks, liners, machine tools beds, pistons, piston rings, mill rolls, wheels, housings, water supply pipes and

Metal forming operations

Extrusion:

* Extrusion is a process of confining the metal in a close cavity and then allowing it to flow from only one opening.
* So, that the metal will take the shape of the opening.
* The operation is identical to the squeezing of toothpaste out of the toothpaste tube. By the extrusion process, it is possible to make components at which have a constant cross section over any length as can be formed by the rolling process.
* Some typical parts that can be extruded are given below.