# G.PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY: KURNOOL

## DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

**CLASS/SEM: IV.B.Tech I-SEM SUB: UTILISATION OF ELECTRICAL ENERGY**

# UNIT-II

**BASIC TERMS AND DEFINITIONS:**

| | |
|---|---|
| Modes of the Transfer of Heat | The modes of the transfer of heat are: Conduction, Convection, Radiation. |
| Oven | Oven is mean that a low-temperature heating chamber with provision for ventilation. |
| High-Frequency Eddy Current Heating | The process of heating any material by the heat developed due to the conversion of electromagnetic energy into heat energy. |
| Conduction | The process of heat transfers from one part of a substance to another part without movement in the molecules of substance. The rate of conduction of heat along the substance depends upon temperature gradient. |
| Convection | The process of heat transfer takes place from one part to another part of a substance or a fluid due to the actual motion of the molecules. The rate of conduction of the heat depends mainly on the difference in the fluid density at different temperatures. |
| Radiation | The process of heat transfers from the source to substance to be heated without heating the medium in between the source and the substance. |
| Pinch Effect | The formation of bubbles and voids in the charge to be heated by the electromagneticinduction due to high-electromagnetic forces, which causes the interruption of secondary circuit. This effect is known as pinch effect. |
| Maximum power output of electric arc furnace | The condition for the maximum power output of electric arc furnace is: $R_A = \sqrt{(R_T + R_L)^2 + (X_T + X_L)^2}$. |
| Types Of Arc Furnaces | There are two types of arc furnaces and they are: Direct arc furnace, Indirect arc furnace. |
| Dielectric Heating | The process of heating non-metallic materials, i.e., the insulators such as wood, plastics, due to the heat developed in the material when they are subjected to high voltage alternating electric field, the atoms get stresses and due to inter-atomic friction caused by the repeated deformation and rotation of atomic structure. |
| Induction Heating | The process of heating the material due to the heat developed by the currents induced in the material by electromagnetic induction process. |
| Resistance Heating | The process of heating the charge or substance by the heat produced due to the resistance offered by the charge or heating element. |
| Stefan's formula for heat dissipation | $H = 5.72 \times 10^4\, ke \left[\left(\frac{T_1}{1{,}000}\right)^4 - \left(\frac{T_2}{1{,}000}\right)^4\right] \text{W/m}^2.$ |

# CONCEPTS

## INTRODUCTION

Heat plays a major role in everyday life. All heating requirements in domestic purposes such as cooking, room heater, immersion water heaters, and electric toasters and also in industrial purposes such as welding, melting of metals, tempering, hardening, and drying can be met easily by electric heating, over the other forms of conventional heating. Heat and electricity are interchangeable. Heat also can be produced by passing the current through material to be heated.This is called electric heating; there are various methods of heating a material but electric heatingis considered far superior compared to the heat produced by coal, oil, and natural gas.

## ADVANTAGES OF ELECTRIC HEATING

The various advantages of electric heating over other the types of heating are:

***(i) Economical***

Electric heating equipment is cheaper; they do not require skilled persons;maintenance cost is less.

***(ii) Cleanliness***

Since dust and ash are completely eliminated in the electric heating, it keeps surroundings cleanly.

***(iii) Pollution free***

As there are no flue gases in the electric heating, atmosphere around is pollution free; no need of providing space for their exit.

***(iv) Ease of control***

In this heating, temperature can be controlled and regulated either manually or automatically.

***(v) Uniform heating***

With electric heating, the substance can be heated uniformly, throughout whether it may be conducting or non-conducting material.

## MODES OF TRANSFER OF HEAT

The transmission of the heat energy from one body to another because of the temperature gradient takes place by any of the following methods:

1. Conduction,

2. Convection, Or

3. Radiation.

**CONDUCTION**

In this mode, the heat transfers from one part of substance to another part without the movement in the molecules of substance. The rate of the conduction of heat along the substance depends upon the temperature gradient. The amount of heat passed through a cubic body with two parallel faces with thickness '*t*' meters, having the cross-sectional area of '*A*' square meters and the temperature of its two faces $T1$°C and $T2$°C, during '*T*' hours is given by:

$Q = \frac{k\,A}{t}(T_1 - T_2)\;T\;\text{MJ},$ ---------------Eq-2.1

where *k* is the coefficient of the thermal conductivity for the material and it is measured in MJ/m3/°C/hr.

**Ex:** Refractory heating, the heating of insulating materials, etc.

**CONVECTION**

In this mode, the heat transfer takes place from one part to another part of substance or fluid due to the actual motion of the molecules. The rate of conduction of heat depends mainly on the difference in the fluid density at different temperatures.

Ex**:** Immersion water heater.

The mount of heat absorbed by the water from heater through convection depends mainly upon the temperature of heating element and also depends partly on the position of the heater.

Heat dissipation is given by the following expression.

$H = a\,(T1 - T2)b$ W/m2, ------------Eq-2.2

where ‘a’ and ‘b’ are the constants whose values are depend upon the heating surface and *T*1and *T*2 are the temperatures of heating element and fluid in °C, respectively.

**RADIATION**

In this mode, the heat transfers from source to the substance to be heated without heating the medium in between. It is dependent on surface. Ex: Solar heaters.

The rate of heat dissipation through radiation is given by Stefan's Law.

$$\text{Heat dissipation, } H = 5.72\times10^4\,k\,e\left[\left(\frac{T_1}{1,000}\right)^4 - \left(\frac{T_2}{1,000}\right)^4\right]\text{W/m}^2. \qquad \text{----------- Eq.2.3}$$

where *T*1 is the temperature of the source in kelvin, *T*2 is the temperature of the substance to be heated in kelvin, and *k* is the radiant efficiency:

= 1, for single element

= 0.5–0.8, for several elements

*e* = emissivity = 1, for black body

= 0.9, for resistance heating element.

## ESSENTIAL REQUIREMENTS OF GOOD HEATING ELEMENT

The materials used for heating element should have the following properties:

o **High-specific resistance**

Material should have high-specific resistance so that small length of wire may be required to provide given amount of heat.

o **High-melting point**

It should have high-melting point so that it can withstand for high temperature, a small increase in temperature will not destroy the element.

o **Low temperature coefficient of resistance**

From above equation,the radiant heat is proportional to fourth powers of the temperatures, it is very efficient heating at high temperature. For accurate temperature control, the variation of resistance with the operating temperature should be very low. This can be obtained only if the material has low temperature coefficient of resistance

o **Free from oxidation**

The element material should not be oxidized when it is subjected to high temperatures; otherwise the formation of oxidized layers will shorten its life.

## MATERIAL FOR HEATING ELEMENTS

The selection of a material for heating element is depending upon the service conditions such as maximum operating temperature and the amount of charge to be heated, but no single element will not satisfy all the requirements of the heating elements. The materials normally used asheating elements are either alloys of nickel–chromium, nickel–chromium–iron, nickel–chromium–aluminum, or nickel–copper.Nickel–chromium–iron alloy is cheaper when compared to simple nickel–chromium alloy.The use of iron in the alloy reduces the cost of final product but, reduces the life of the alloy, as it gets oxidized soon. We have different types of alloys for heating elements.

## CAUSES OF FAILURE OF HEATING ELEMENTS

Heating element may fail due to any one of the following reasons.

1. Formation of hot spots.

2. Oxidation of the element and intermittency of operation.

3. Embrittlement caused by gain growth.

4. Contamination and corrosion.

**Formation of hotspots**

Hotspots are the points on the heating element generally at a higher temperature than the main body. The main reasons of the formation of hotspot in the heating element are the high rate of the local oxidation causing reduction in the area of cross-section of the element leading to the increase in the resistance at that spot. It gives rise to the damage of heating element due to the generation of more heat at spot. Another reason is the shielding of element by supports, etc.,which reduces the local heat loss by radiation and hence the temperature of the shielded portion of the element will increase. So that the minimum number of supports should be used without producing the distortion of the element.

**Oxidation and intermittency of operation**

A continuous oxide layer is formed on the surface of the element at very high temperatures such layer is so strong that it prevents further oxidation of the inner metal of the element. If the element is used quite often, the oxide layer is subjected to thermal stresses; thus, the layer cracks and flakes off, thereby exposing fresh metal to oxidation. Thus, the local oxidation of the metal increases producing the hotspots.

## METHODS OF ELECTRIC HEATING

Heat can be generated by passing the current through a resistance or induced currents. The initiation of an arc between two electrodes also develops heat. The bombardment by some heat energy particles such as $\alpha$, $\gamma$, $\beta$, and x-rays or accelerating ion can produce heat on a surface.

Electric heating can be broadly classified as follows.

**Direct resistance heating**

In this method, the electric current is made to pass through the charge (or) substance to be heated. This principle of heating is employed in electrode boiler.

**Indirect resistance heating**

In this method, the electric current is made to pass through a wire or high-resistance heating element, the heat so developed is transferred to charge from the heating element by convection or radiation. This method of heating is employed in immersion water heaters.

**Infrared (or) Radiant Heating**

In this method of heating, the heat energy is transferred from source (incandescent lamp) and focused upon the body to be heated up in the form of electromagnetic radiations. Normally, this method is used for drying clothes in the textile industry and to dry the wet paints on an object.

**Direct Arc Heating**

In this method, by striking the arc between the charge and the electrode or electrodes, the heat so developed is directly conducted and taken by the charge. The furnace operating on this principle is known as direct arc furnaces. The main application of this type of heating is production of steel.

**Indirect Arc Heating**

In this method, arc is established between the two electrodes, the heat so developed is transferred to the charge (or) substance by radiation. The furnaces operating on this principle are known as indirect arc furnaces. This method is generally used in the melting of non-ferrous metals.

**Direct Induction Heating**

In this method of heating, the currents are induced by electromagnetic action in the charge to be heated. These induced currents are used to melt the charge in induction furnace.

**Indirect Induction Heating**

In this method, eddy currents are induced in the heating element by electromagnetic action. Thus, the developed heat in the heating element is transferred to the body (or) charge to be heated by radiation (or) convection. This principle of heating is employed in induction furnaces used for the heat treatment of metals.

**Dielectric Heating**

In this method of electric heating, the heat developed in a non-metallic material due to interatomic friction, known as dielectric loss. This principle of heating usually employed for preheating of plastic performs, baking foundry cores, etc.

## RESISTANCE HEATING

When the electric current is made to pass through a high-resistive body (or) substance, a power loss takes place in it, which results in the form of heat energy, i.e., resistance heating is passed upon the *I*2*R* effect. This method of heating has wide applications such as drying, baking of potteries, commercial and domestic cooking, and the heat treatment of metals such as annealing and hardening. In oven where wire resistances are employed for heating, temperature up to about 1,000°C can be obtained.

The resistance heating is further classified as:

1. Direct Resistance Heating,

2. Indirect Resistance Heating, and

3. Infrared (or) Radiant Heating.

**DIRECT RESISTANCE HEATING**

In this method, electrodes are immersed in a material or charge to be heated. The charge may be in the form of powder, pieces, or liquid. The electrodes are connected to AC or DC supply as shown in Fig. In case of DC or 1-$\varphi$ AC, two electrodes are immersed and three electrodes are immersed in the charge and connected to supply in case of availability of 3-$\varphi$supply. When metal pieces are to be heated, the powder of lightly resistive is sprinkled over the surface of the charge (or) pieces to avoid direct short circuit. The current flows through the charge and heat is produced in the charge itself. So, this method has high efficiency. As the current in this case is not variable, so that automatic temperature control is not possible. This method of heating is employed in salt bath furnace and electrode boiler for heating water.

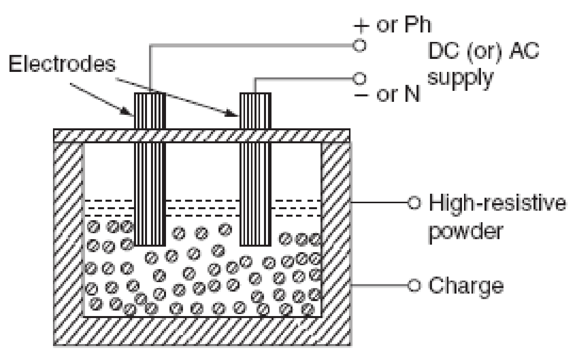


Fig.2.1. Direct resistance heating

**(i) Salt bath furnace**

This type of furnace consists of a bath and containing some salt such as molten sodium chloride and two electrodes immersed in it. Such salt have a fusing point of about 1,000–1,500°C depending upon the type of salt used. When the current is passed between the electrodes immersed in the salt, heat is developed and the temperature of the salt bath may be increased. Such an arrangement is known as a salt bathfurnace. In this bath, the material or job to be heated is dipped..

**(ii) Electrode boiler**

It is used to heat the water by immersing three electrodes in a tank as shown in Fig. This is based on the principle that when the electric current passed through the water produces heat due to the resistance offered by it. For DC supply, it results in a lot of evolution of H2 at negative electrode and O2 at positive electrode. Whereas AC supply hardly results in any evolution of gas, but heats the water. Electrode boiler tank is earthed solidly and connected to the ground. A circuit breaker is usually incorporated to make and break all poles simultaneously and an over current protective device is provided in each conductor feeding an electrode.

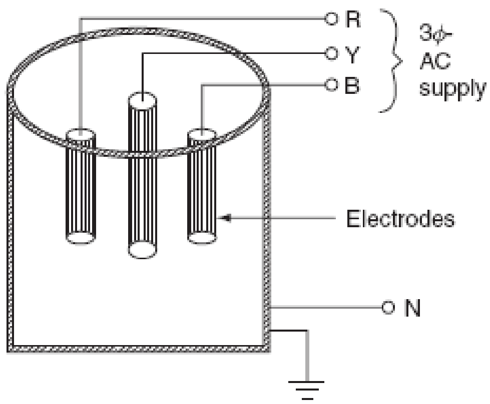


Fig. 2.2.Electrode boiler

**INDIRECT RESISTANCE HEATING**

In the indirect resistance heating method, high current is passed through the heating element. In case of industrial heating, sometimes the heating element is placed in a cylinder which is surrounded by the charge placed in a jacket is known as heating chamber is shown in Fig.

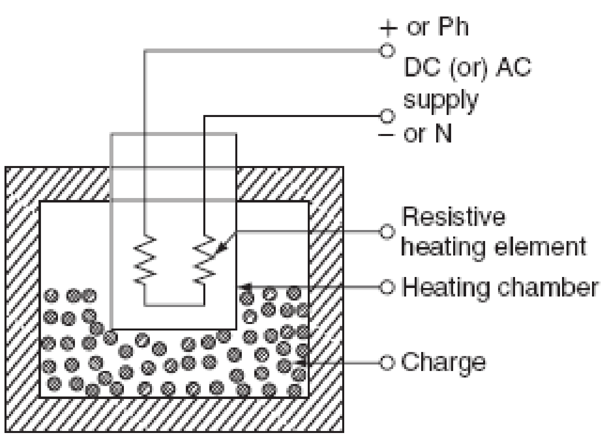


Fig.2.3.Indirect resistance heating

The heat is proportional to power loss produced in the heating element is delivered to the charge by one or more of the modes of the transfer of heat viz. conduction, convection, and radiation. This arrangement provides uniform temperature and automatic temperature control. Generally, this method of heating is used in immersion water heaters, room heaters, and the resistance ovens used in domestic and commercial cooling and salt bath furnace.

**Resistance ovens**

According to the operating temperatures, the resistance furnaces may be classified into various types. Low-temperature heating chamber with the provision for ventilation is called as oven. For drying varnish coating, the hardening of synthetic materials, and commercialand domestic heating, etc., the resistance ovens are employed. The operating temperature of medium temperature furnaces is between 300°C and 1,050°C. These are employed for the melting of nonferrous metals, stove (annealing), etc. Furnaces operating at temperature between 1,050°C and 1,350°C are known as high-temperature furnaces. These furnaces are employed for hardening applications. A simple resistance oven is shown in Fig.

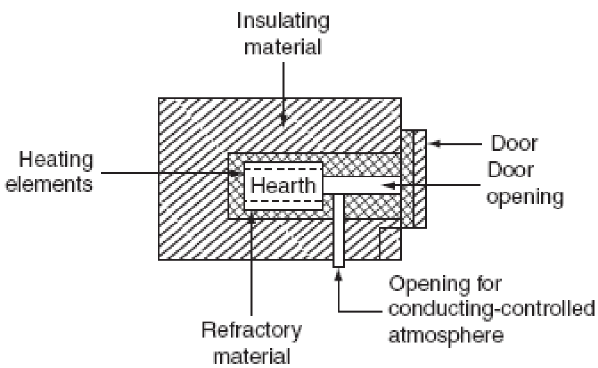


Fig.2.4.Resistance oven

## ARC HEATING

If the high voltage is applied across an air gap, the air in the gap gets ionized under the influence of electrostatic forces and becomes conducting medium, current flows in the form of a continuous spark, known as *arc.* A very high voltage is required to establish an arc but very small voltage is sufficient to maintain it, across the air gap. The high voltage required for striking an arc can be obtained by using a step-up transformer fed from a variable AC supply.

**Electrodes used in the arc furnaces**

Normally used electrodes in the arc furnaces are carbon electrodes, graphite electrodes, and selfbaking electrodes. Usually the carbon and graphite electrodes are used and they can be selected based on their electrical conductivity insolubility, chemical inertness, mechanical strength, resistance to thermal shock, etc. The size of these electrodes may be 18–27 cm in diameter. The carbon electrodes are used with small furnaces for manufacturing of ferro-alloys, aluminium phosphorous, etc. The self-baking electrodes are employed in the electrochemical furnaces and in the electrolytic production of aluminum.

**The salient features of carbon and graphite electrodes are:**

1. **Resistivity:** The graphite electrodes have low-specific resistance than the carbon electrodes, so the graphite required half in size for the same current resulting in easy replacement.

2. **Oxidation:** Graphite begins to oxides at 600°C where as carbon at 400°C.

3. **Electrode consumption:** For steel-melting furnaces, the consumption of the carbon electrodes is about 4.5 kg of electrodes per tonne of steel and 2.3–to 6.8 kg electrodes per tonne of steel for the graphite electrodes.

4. **Cost:** The graphite electrodes cost about twice as much per kg as the carbon electrodes. The choice of electrodes depends chiefly on the question of the total cost. In general, if the processes requiring large quantities of electrode, carbon is used but for other processes, the choice depends on local conditions.

## TYPES OF ARC FURNACES

There are two types of arc furnaces and they are:

1. direct arc furnace and

2. indirect arc furnace.

***(i) Direct arc furnace***

When supply is given to the electrodes, two arcs are established and current passes through the charge, as shown in Fig. 4.5. As the arc is in direct contact with the charge and heat is also produced by current flowing through the charge itself, it is known as *direct arc furnace.*

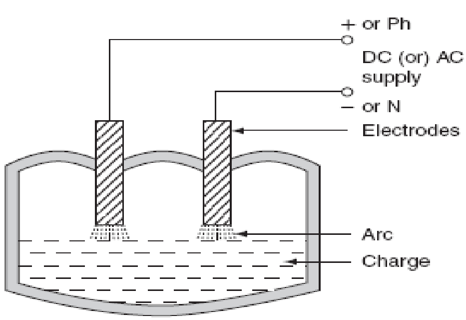

Fig. 2.5.Direct arc furnace

If the available supply is DC or 1-*φ,* AC, two electrodes are sufficient, if the supply is 3-*φ*, AC, three electrodes are placed at three vertices of an equilateral triangle. The most important feature of the direct arc furnace is that the current flows through the charge, the stirring action is inherent due to the electromagnetic force setup by the current, such furnace is used for manufacturing alloy steel and gives purer product.

It is very simple and easy to control the composition of the final product during refining process operating the power factor of arc furnace is 0.8 lagging. For 1-ton furnace, the power required is about 200 kW and the energy consumed is 1.0 MWh/ton.

***(ii) Indirect arc furnace***

In indirect arc furnace, the arc strikes between two electrodes by bringing momentarily in contact and then with drawing them heat so developed, due to the striking of arc across air gap is transferred to charge is purely by radiation. A simple indirect arc furnace is shown inFig.

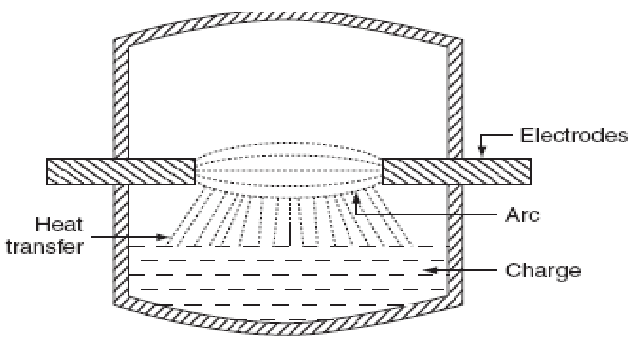


Fig.2.6. Indirect arc furnace

These furnaces are usually l-*φ* and hence their size is limited by the amount of one-phase load which can be taken from one point. There is no inherent stirring action provided in this furnace, as current does not flow through the charge and the furnace must be rocked mechanically. The electrodes are projected through this chamber at each end along the horizontal axis. This furnace is also sometimes called as *rocking arc furnace.* The charge in this furnace is heated not only by radiation from the arc between electrode tips but also by conduction from the heated refractory during rocking action; so, the efficiency of such furnace is high. The arc is produced by bringing electrodes into solid contact and then withdrawing them; power input to the furnace is regulated by adjusting the arc length by moving the electrodes.

## HIGH-FREQUENCY HEATING

The main difference between the power-frequency and the high-frequency heating is that in the conventional methods, the heat is transferred either by conduction convection or by radiation, but in the high-frequency heating methods, the electromagnetic energy converted into the heat energy in side the material. The high-frequency heating can be applied to two types of materials. The heating of the conducting materials, such as ferro-magnetic and non-ferro-magnetic, is known as *induction heating.* The process of heating of the insulating materials is known as *dielectric heating.* The heat transfer by the conventional method is very low of the order of 0.5–20 W/sq. cm. And, the heat transfer rate by the high-frequency heating either by induction or by dielectric heating is as much as 10,000 W/sq. cm. Thus, the high-frequency heating is most importance for tremendous speed of production.

## INDUCTION HEATING

The induction heating process makes use of the currents induced by the electromagnetic action in the material to be heated. To develop sufficient amount of heat, the resistance of the material must be low , which is possible only with the metals, and the voltage must be higher, which can be obtained by employing higher flux and higher frequency. Therefore, the magnetic materials can be heated than non-magnetic materials due to their high permeability. In order to analyze the factors affecting induction heating, let us consider a circular disc to be heated carrying a current of '*I*' amps at a frequency '*f*' Hz. As shown in Fig.

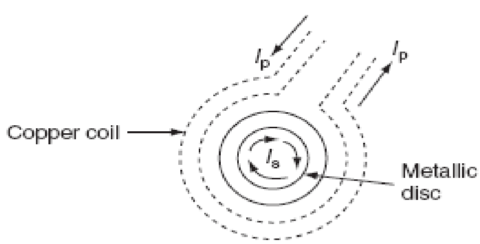


Fig**.2.7.**Induction heating

Heat developed in the disc is depending upon the following factors.

o Primary coil current.

o The number of the turns of the coil.

o Supply frequency.

o The magnetic coupling between the coil and the disc.

o The high electrical resistivity of the disc.

If the charge to be heated is non-magnetic, then the heat developed is due to eddy current loss, whereas if it is magnetic material, there will be hysteresis loss in addition to eddy current loss. Both hysteresis and eddy current loss are depended upon frequency, but at high-frequency hysteresis, loss is very small as compared to eddy currents.

The depth of penetration of induced currents into the disc is given by:

$$d = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^{9}}{\mu f}}\ \text{cm}$$

i.e., $d\ \mu \frac{1}{\sqrt{f}}$,

where $\rho$ is the specific resistance in Ω-cm, $f$ is the frequency in Hz, and $\mu$ is the permeability of the charge.

There are basically two types of induction furnaces and they are:

1. Core type or low-frequency induction furnace.

2. Coreless type or high-frequency induction furnace.

## Core Type Furnace

The operating principle of the core type furnace is the electromagnetic induction. This furnace is operating just like a transformer. It is further classified as:

1. Direct core type.

2. Vertical core type.

3. Indirect core type.

**(i) Direct core type induction furnace**

The core type furnace is essentially a transformer in which the charge to be heated forms singleturn

secondary circuit and is magnetically coupled to the primary by an iron core as shown in Fig.

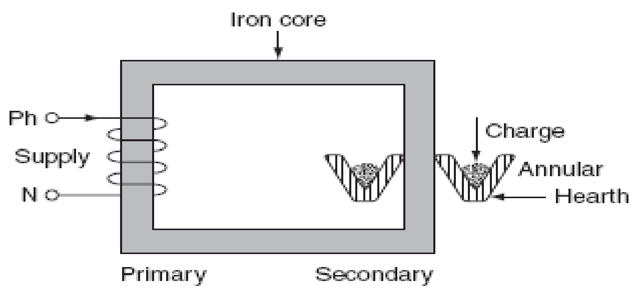


Fig.2.8. Direct core type furnace

The furnace consists of a circular hearth in the form of a trough, which contains the charge to be melted in the form of an annular ring. This type of furnace has the following characteristics:

o This metal ring is quite large in diameter and is magnetically interlinked with primary winding, which is energized from an AC source. The magnetic coupling between primary and secondary is very weak; it results in high leakage reactance and low pf. To overcome the increase in leakage reactance, the furnace should be operated at low frequency of the order of 10 Hz.

o When there is no molten metal in the hearth, the secondary becomes open circuited thereby cutting of secondary current. Hence, to start the furnace, the molten metal has to be taken in the hearth to keep the secondary as short circuit.

o Furnace is operating at normal frequency, which causes turbulence and severe stirring action in the molten metal to avoid this difficulty, it is also necessary to operate the furnace at low frequency.

o In order to obtain low-frequency supply, separate motor-generator set (or) frequency changer is to be provided, which involves the extra cost.

**(ii) Vertical core type induction furnace**

It is an improvement over the direct core type furnace, to overcome some of the disadvantages mentioned above. This type of furnace consists of a vertical core instead of horizontal core as shown in Fig. It is also known as *Ajax–Wyatt induction furnace.*

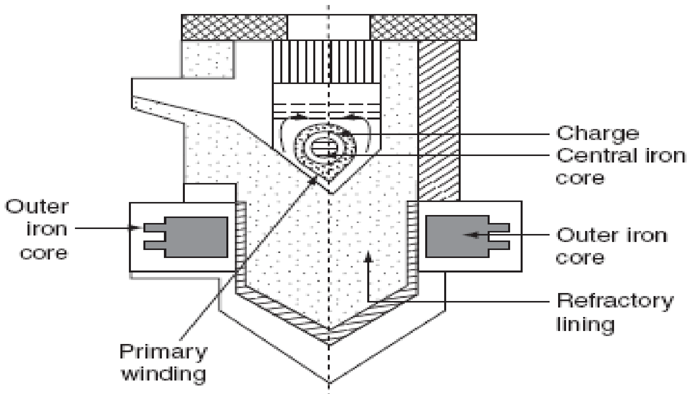


Fig.**2.9.**Vertical core type furnace (Ajax–Wyatt induction furnace)

Vertical core avoids the pinch effect due to the weight of the charge in the main body of the crucible. The leakage reactance is comparatively low and the power factor is high as the magnetic coupling is high compared to direct core type. There is a tendency of molten metal to accumulate at the bottom that keeps the secondary completed for a vertical core type furnace as it consists of narrow V-shaped channel. The inside layer of furnace is lined depending upon the type charge used. Clay lining is used for yellow brass and an alloy of magnesia and alumina is used for red brass.

***Advantages***

o Accurate temperature control and reduced metal losses.

o Absence of crucibles.

o Consistent performance and simple control.

o It is operating at high power factor.

o Pinch effect can be avoided.

**(iii) Indirect core type furnace**

This type of furnace is used for providing heat treatment to metal. A simple induction furnace with the absence of core is shown in Fig.

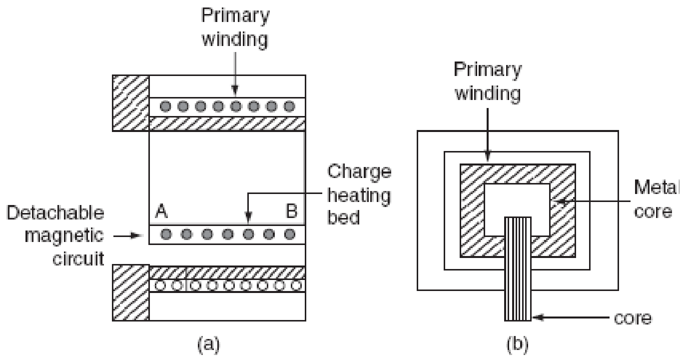


Fig.2.10. Indirect core type furnace

The secondary winding itself forms the walls of the container or furnace and an iron core links both primary and secondary windings. The heat produced in the secondary winding is transmitted to the charge by radiation. An oven of this type is in direct competition with ordinary resistance oven. It consists of a magnetic circuit AB is made up of a special alloy and is kept inside the chamber of the furnace. This magnetic circuit loses its magnetic properties at certain temperature and regains them again when it is cooled to the same temperature. When the oven reaches to critical temperature, the reluctance of the magnetic circuit increases many times and the inductive effect decreases thereby cutting off the supply heat.

**Coreless type induction furnace**

It is a simple furnace with the absence core is shown in Fig. In this furnace, heat developed in the charge due to eddy currents flowing through it.

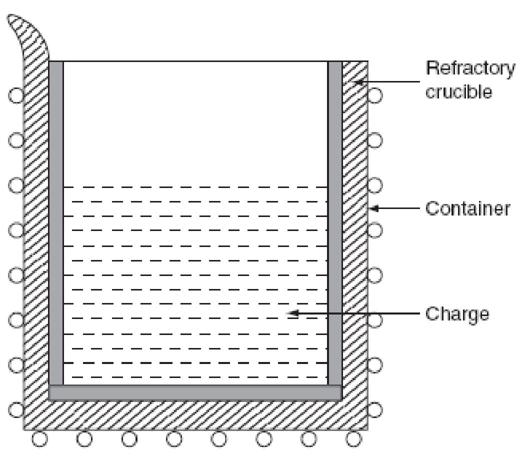


Fig. 2.11.Coreless induction furnace

The furnace consists of a refractory or ceramic crucible cylindrical in shape enclosed within a coil that forms primary of the transformer. The furnace also contains a conducting or nonconducting container that acts as secondary. If the container is made up of conducting material, charge can be conducting or nonconducting; whereas, if the container is made up of non-conducting material, charge taken should have conducting properties. When primary coils are excited by an alternating source, the flux set up by these coils induce the eddy currents in the charge. The direction of the resultant eddy current is in a direction opposite to the current in the primary coil. These currents heat the charge to melting point and they also set up electromagnetic forces that produce a stirring action to the charge. ∴ The eddy currents developed in any magnetic circuit are given as: $We \propto Bm2f2$, where $Bm$ is the maximum flux density (tesla), $f$ is the frequency in (Hz), and $We$ is the eddy current loss (watts).

Following are the advantages of coreless furnace over the other furnaces:

o Ease of control.

o Oxidation is reduced, as the time taken to reach the melting temperature is less.

o The eddy currents in the charge itself results in automatic stirring.

**DIELECTRIC HEATING**

When non-metallic materials i.e., insulators such as wood, plastics, and china glass are subjected to high-voltage alternating electric field, the atoms get stresses, and due to interatomic friction caused by the repeated deformation and the rotation of atomic structure (polarization), heat isproduced. This is known as dielectric loss. This dielectric loss in insulators corresponds to hysteresis loss in ferro-magnetic materials.

This loss is due to the reversal of magnetism or magneto molecular friction. These losses developed in a material that has to be heated. An atom of any material is neutral, since the central positive charge is equals to the negative charge. So that, the centers of positive and negative charges coincide as long as there is no external field is applied, as shown in Fig. (a). When this atom is subjected to the influence of the electric field, the positive charge of the nucleus is acted upon by some force in the direction of negative charges in the opposite direction. Therefore, the effective centers of both positive and negative charges no longer coincident as shown in Fig. (b). As there is no perfect conductor, so there is no perfect insulator. All the dielectric materials can be represented by a parallel combination of a leakage resistor '*R*' and a capacitor '*C*' as shown in Fig.(a) and (b)

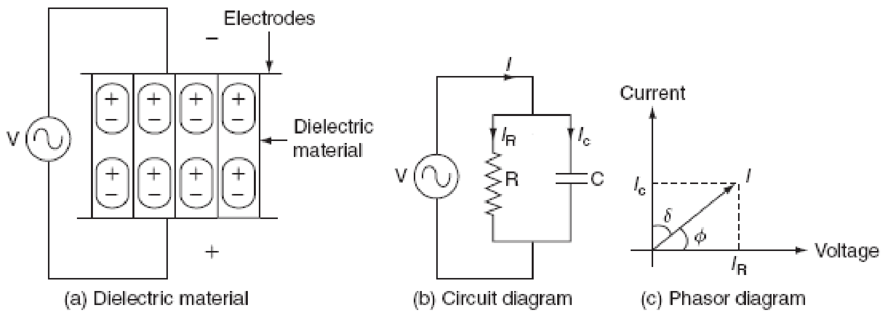


Fig. 2.12.Dielectric heating

If an AC voltage is applied across a piece of insulator, an electric current flows; total current '*I*' supposed to be made up of two components *I*C and *IR,* where *I*C is the capacitive current leading the applied voltage by 90° and *I*R is in phase with applied voltage as shown in Fig.

$$\text{Dielectric loss, } P_L = V I \cos\phi$$
$$= V I_R \qquad [\because I_R = I\cos\phi]$$
$$= V I_C \tan\delta \qquad \left[\because \tan\delta = \frac{I_R}{I_C}\right].$$
$$V \cdot \left(\frac{V}{X_C}\right) \tan\delta \qquad \left[Q I_C = \frac{V}{X_C}\right]$$
$$= V^2 \omega C \tan\delta$$
$$= V^2 \times 2\pi f \times \frac{\varepsilon_0\, \varepsilon_r\, A}{d} \times \delta \text{ W}$$

where '*V*' is the applied voltage in volts, '*f*' is the supply frequency in Hz, *ε*0 is the absolute permittivity of the medium = 8.854 × 10-12 F/m, *ε*r is the relative permittivity of the medium = 1 for free space, *A* is the area of the plate or electrode (m2), *d* is the thickness of the dielectric medium, and *δ* is the loss angle in radian

$$P_L \propto V^2 \quad \text{and} \quad P_L \propto f.$$

Normally frequency used for dielectric heating is in the range of 1–40 MHz. The use of high voltage is also limited due to the breakdown voltage of thin dielectric that is to be heated, under normal conditions; the voltage gradient used is limited to 18 kV/cm.

***The advantages of the dielectric heating***

o The heating of the non-conducting materials is very rapid.

o The uniform heating of material is possible.

o Heat is produced in the whole mass of the material.

***The applications of the dielectric heating***

o The drying of paper, wood, etc.

o The gluing of wood.

## ELECTRIC WELDING

### Introduction

Welding is the process of joining two pieces of metal or non-metal together by heating them to their melting point. Filler metal may or may not be used to join two pieces. The physical and mechanical properties of a material to be welded such as melting temperature, density, thermal conductivity, and tensile strength take an important role in welding. Depending upon how the heat applied is created; we get different types of welding such as thermal welding, gas welding, and electric welding. Here in this chapter, we will discuss only about the electric welding and some introduction to other modern welding techniques

### ADVANTAGES AND DISADVANTAGES OF WELDING

Some of the advantages of welding are:

o Welding is the most economical method to permanently join two metal parts.

o It provides design flexibility.

o Welding equipment is not so costly.

Some of the disadvantages of welding are:

o Welding gives out harmful radiations and fumes.

o Welding needs internal inspection.

### ELECTRIC WELDING

It is defined as the process of joining two metal pieces, in which the electrical energy is used to generate heat at the point of welding in order to melt the joint.The classification of electric welding process is shown in fig

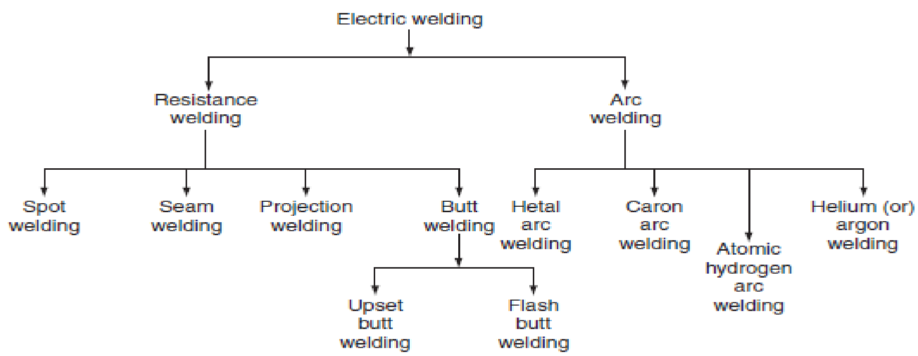


Fig.2.13. Classification of electric welding

The selection of proper welding process depends on the following factors.

o The type of metal to be joined.

o The techniques of welding adopted.

o The cost of equipment used.

o The nature of products to be fabricated.

**RESISTANCE WELDING**

Resistance welding is the process of joining two metals together by the heat produced due to the resistance offered to the flow of electric current at the junctions of two metals. The heat produced by the resistance to the flow of current is given by: *H* = *I*2*Rt*, where *I* is the current through the electrodes, *R* is the contact resistance of the interface, and *t* is the time for which current flows.

Here, the total resistance offered to the flow of current is made up of:

1. The resistance of current path in the work.

2. The resistance between the contact surfaces of the parts being welded.

3. The resistance between electrodes and the surface of parts being welded.

In this process of welding, the heat developed at the contact area between the pieces to be weldedreduces the metal to plastic state or liquid state, then the pieces are pressed under high mechanical pressure to complete the weld. The electrical voltage input to the welding varies in between 4 and 12 V depending upon area, thickness, composition, etc. and usually power ranges from about 60 to 180 W for each sq. mm of area. Any desired combination of voltage and current can be obtained by means of a suitable transformer in AC; hence, AC is found to be most suitable for the resistance welding.

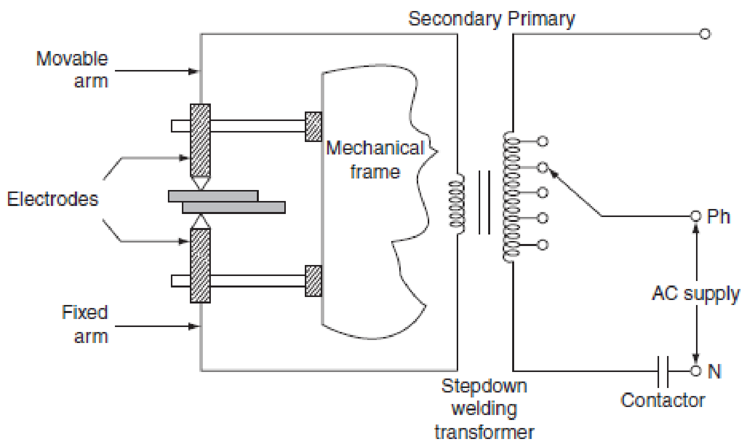


Fig. 2.14.Electric circuit for resistance welding

***Advantages***

o Welding process is rapid and simple.

o Localized heating is possible, if required.

o No need of using filler metal.

o Both similar and dissimilar metals can be welded.

o Comparatively lesser skill is required.

***Applications***

o It is used by many industries manufacturing products made up of thinner gauge metals.

o It is used for the manufacturing of tubes and smaller structural sections.

**TYPES OF RESISTANCE WELDING**

Depending upon the method of weld obtained and the type of electrodes used, the resistance welding is classified as:

1. Spot welding.

2. Seam welding.

3. Projection welding.

4. Butt welding.

**(I) SPOT WELDING**

Spot welding means the joining of two metal sheets and fusing them together between copper electrode tips at suitably spaced intervals by means of heavy electric current passed through the electrodes as shown in Fig.

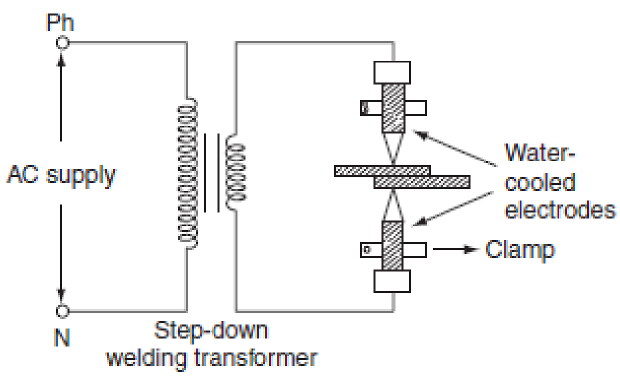


Fig. 2.15.Spot welding

This type of joint formed by the spot welding provides mechanical strength and not air or water tight, for such welding it is necessary to localize the welding current and to apply sufficient pressure on the sheet to be welded. The electrodes are made up of copper or copper alloy and are water cooled. The welding current varies widely depending upon the thickness and composition of the plates. It varies from 1,000 to 10,000 A, and voltage between the electrodes is usually less than 2 V.

When voltage applied across the electrode, the flow of current will generate heat at the three junctions, i.e., heat developed, between the two electrode tips and workpiece, between the twoworkpieces to be joined as shown in Fig. The generation of heat at junctions 1 and 3 will effect electrode sticking and melt through holes, the prevention of electrode striking is achieved by:

1. Using water-cooled electrodes shown in Fig. By avoiding the heating of junctions 1 and 3 electrodes in which cold water circulated continuously as shown in Fig.

2. The material used for electrode should have high electrical and thermal conductivity. Spot welding iswidely used for automatic welding process, for joining automobile parts, joining and fabricating sheet metal structure, etc.

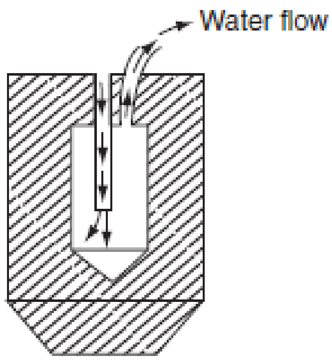


Fig. 2.16.Water cooled electrode

**(II) SEAM WELDING**

Seam welding is nothing but the series of continuous spot welding. If number spots obtained by spot welding are placed very closely that they can overlap, it gives rise to seam welding. In this welding, continuous spot welds can be formed by using wheel type or roller electrodes instead of tipped electrodes as shown in Fig.

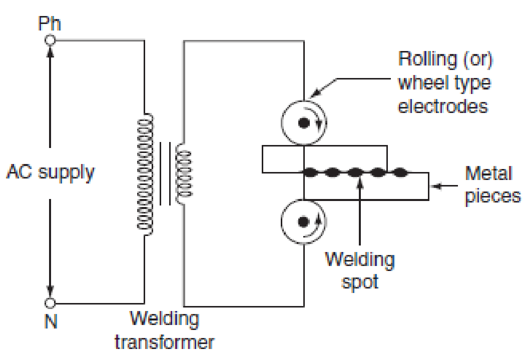


Fig.2.17. Seam welding

Seam welding is obtained by keeping the job under electrodes. When these wheel type electrodes travel over the metal pieces which are under pressure, the current passing between them heats the two metal pieces to the plastic state and results into continuous spot welds. In this welding, the contact area of electrodes should be small, which will localize the current pressure to the welding point. After forming weld at one point, the weld so obtained can be cooled by splashing water over the job by using cooling jets.

**(III) PROJECTION WELDING**

It is a modified form of the spot welding. In the projection welding, both current and pressure are localized to the welding points as in the spot welding. But the only difference in the projection welding is the high mechanical pressure applied on the metal pieces to be welded, after the formation of weld. The electrodes used for such welding are flat metal plates known as *platens*.The two pieces of base metal to be weld are held together in between the two platens, one is movable and the other is fixed, as shown in Fig.

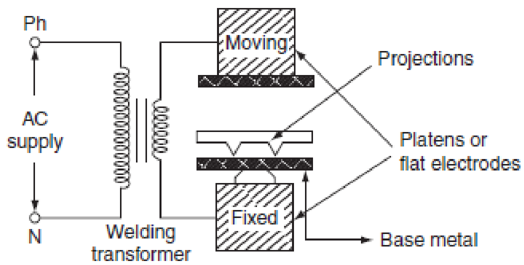


Fig.2.18. Projection welding

One of the two pieces of metal is run through a machine that makes the bumps or projections of required shape and size in the metal. As current flows through the two metal parts to be welded, which heat up and melt. These weld points soon reach the plastic state, and the projection touches the metal then force applied by the two flat electrodes forms the complete weld.This type of welding is usually employed on punched, formed, or stamped parts where theprojection automatically exists. The projection welding is particularly employed for mass production work, i.e., welding of refrigerators, condensers, crossed wire welding, refrigerator racks, grills, etc.

**(IV) BUTT WELDING**

Butt welding is similar to the spot welding; however, the only difference is, in butt welding, instead of electrodes the metal parts that are to be joined or butted together are connected to the supply.

***(a) Upset butt welding***

In upset welding, the two metal parts to be welded are joined end to end and are connected across the secondary of a welding transformer as shown in Fig.

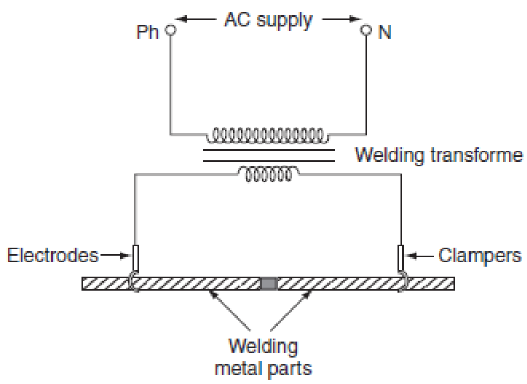


Fig.2.19.Upset butt welding

Due to the contact resistance of the metals to be welded, heating effect is generated in this welding. When current is made to flow through the two electrodes, heat will develop due to the contact resistance of the two pieces and then melts. By applying high mechanical pressure either manually or by toggle mechanism, the two metal pieces are pressed. When jaw-type electrodes are used that introduce the high currents without treating any hot spot on the job. This type of welding is usually employed for welding of rods, pipes, and wires and for joining metal parts end to end.

**(B) FLASH BUTT WELDING**

Flash butt welding is a combination of resistance, arc, and pressure welding. This method of welding is mainly used in the production welding. A simple flash butt welding arrangement is shown in Fig.

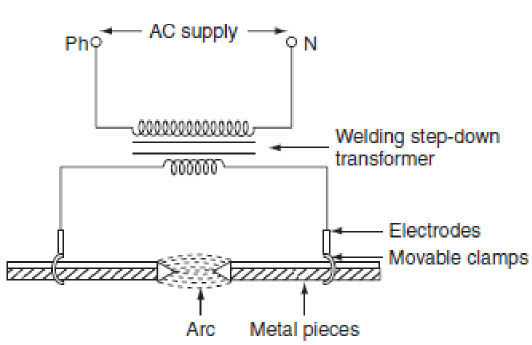


Fig. 2.20.Flash butt welding

In this method of welding, the two pieces to be welded are brought very nearer to each otherunder light mechanical pressure. These two pieces are placed in a conducting movable clamps. When high current is passed through the two metal pieces and they are separated by some distance, then arc established between them. This arc or flashing is allowed till the ends of the workpieces reach melting temperature, the supply will be switched off and the pieces are rapidly brought together under light pressure. As the pieces are moved together, the fused metal and slag come out of the joint making a good solid joint.

## ELECTRIC ARC WELDING

Electric arc welding is the process of joining two metallic pieces or melting of metal is obtained due to the heat developed by an arc struck between an electrode and the metal to be welded or between the two electrodes as shown in Fig

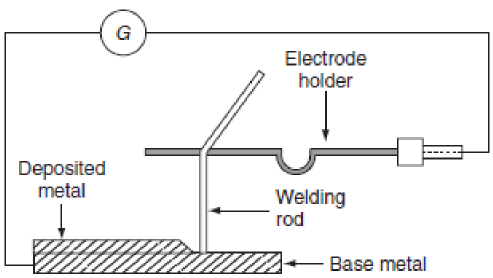


Fig.2.21. Arrangement of electric welding equipment

In this process, an electric arc is produced by bringing two conductors (electrode and metal piece) connected to a suitable source of electric current, momentarily in contact and then separated by a small gap, arc blows due to the ionization and give intense heat. The heat so developed is utilized to melt the part of workpiece and filler metal and thus forms the weld. In this method of welding, no mechanical pressure is employed; therefore, this type of welding is also known as 'non-pressure welding'.

The length of the arc required for welding depends upon the following factors:

o The surface coating and the type of electrodes used.

o The position of welding.

o The amount of current used.

Electric arc welding is extensively used for the joining of metal parts, the repair of fractured casting, and the fillings by the deposition of new metal on base metal, etc.

Various types of electric arc welding are:

1. Carbon arc welding.

2. Metal arc welding.

3. Atomic hydrogen arc welding.

4. Inert gas metal arc welding.

5. Submerged arc welding.

## CARBON ARC WELDING

It is one of the processes of arc welding in which arc is struck between two carbon electrodes or the carbon electrode and the base metal. The simple arrangement of the carbon arc welding is shown in Fig.

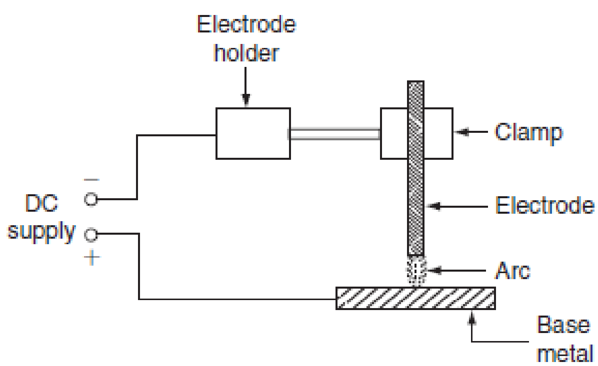


Fig. 2.22.Carbon arc welding

In this process of welding, the electrodes are placed in an electrode holder used as negative electrode and the base metal being welded as positive. Unless, the electrode is negative relative to the work, due to high temperature, there is a tendency of the particles of carbon will fuse and mix up with the base metal, which causes brittleness; DC is preferred for carbon arc welding since there is no fixed polarity maintained in case of AC. In the carbon arc welding, carbon or graphite rods are used as electrode. Due to longer life and low resistance, graphite electrodes are used, and thus capable of conducting more current. Filler metal and flux may not be used depending upon the type of joint and material to be welded.

***Advantages***

o The heat developed during the welding can be easily controlled by adjusting the length of the arc.

o It is quite clean, simple, and less expensive when compared to other welding process.

o Easily adoptable for automation.

o Both the ferrous and the non-ferrous metals can be welded.

***Disadvantages***

o Input current required in this welding, for the workpiece to rise its temperature to melting/welding temperature, is approximately double the metal arc welding.

***Applications***

o It can be employed for the welding of stainless steel with thinner gauges.

o Useful for the welding of thin high-grade nickel alloys and for galvanized sheets using copper silicon manganese alloy filler metal.

## Metal Arc Welding

In metal arc welding, the electrodes used must be of the same metal as that of the work-piece to be welded. The electrode itself forms the filler metal. An electric arc is stuck by bringing the electrode connected to a suitable source of electric current, momentarily in contract with the workpieces to be welded and withdrawn apart. The circuit diagram for the metal arc welding is shown in Fig.

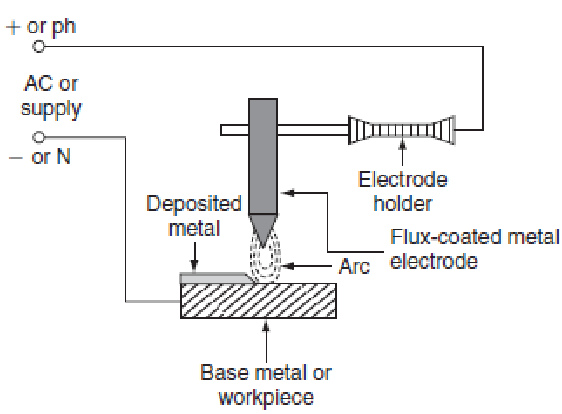


Fig.2.23.Metal arc welding

## Atomic Hydrogen Arc Welding

In atomic hydrogen arc welding, shown in Fig. 5.16, the heat for the welding process is produced from an electric arc struck between two tungsten electrodes in an atmosphere of hydrogen. Here, hydrogen serves mainly two functions; one acts as a protective screen for the arc and the other acts as a cooling agent for the glowing tungsten electrode tips. As the hydrogen gas passes through the arc, the hydrogen molecules are broken up into atoms, absorbs heat from the glowing tungsten electrodes so that these are cooled.

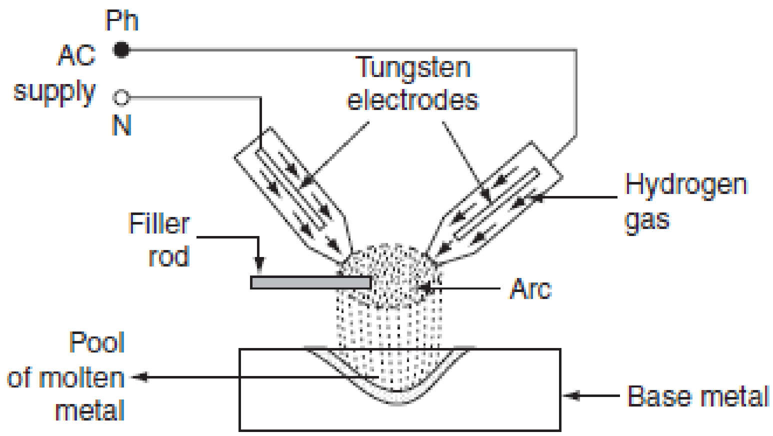


Fig. 2.24.Atomic hydrogen arc welding

But, when the atoms of hydrogen recombine into molecules outside the arc, a large amount of heat is liberated. This extraheat is added to the intense heat of arc, which produces a temperature of about 4,000°C that is sufficient to melt the surfaces to be welded, together with the filler rod if used.

### Inert Gas Metal Arc Welding

It is a gas-shielded metal arc welding, in which an electric arc is stuck between tungsten electrode and workpiece to be welded. Filler metal may be introduced separately into the arc if required. A welding gun, which carries a nozzle, through this nozzle, inert gas such as beryllium or argon is blown around the arc and onto the weld, as shown in Fig. As both beryllium and argon are chemically inert, so the molten metal is protected from the action of the atmosphere by an envelope of chemically reducing or inert gas.

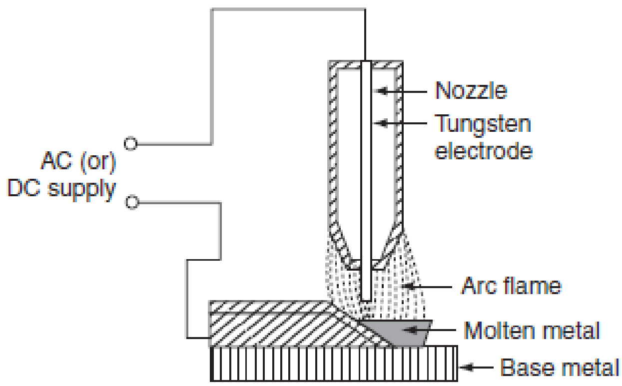


Fig. 2.25.Inert gas metal arc welding

**Submerged Arc Welding**

It is an arc welding process, in which the arc column is established between above metal electrode and the workpiece. Electric arc and molten pool are shielded by blanket of granular flux on the workpiece. Initially to start an arc, short circuit path is provided by introducing steel wool between the welding electrode and the workpiece. This is due to the coated flux material, when cold it is non-conductor of the electricity but in molten state, it is highly conductive. Welding zone is shielded by a blanket of flux, so that the arc is not visible. Hence, it is known as *'submerged arc welding'.* Therefore, the welding takes place without spark, smoke, ash, etc. Thus,there is no need of providing protective shields, smoke collectors, and ventilating systems. Figure shows the filling of parent metal by the submerged arc welding.

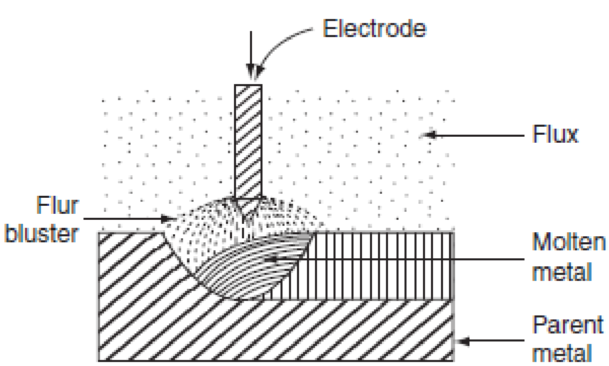


Fig. 2.26.Submerged arc welding

## TYPES OF WELDING ELECTRODES

An electrode is a piece of metal in the form of wire or rod that is either bare or coated uniformly with flux. Electrode carries current for the welding operation. One contact end of the electrode must be clean and is inserted into the electrode holder, an arc is set up at the other end. The electrodes used for the arc welding are classified as follows .

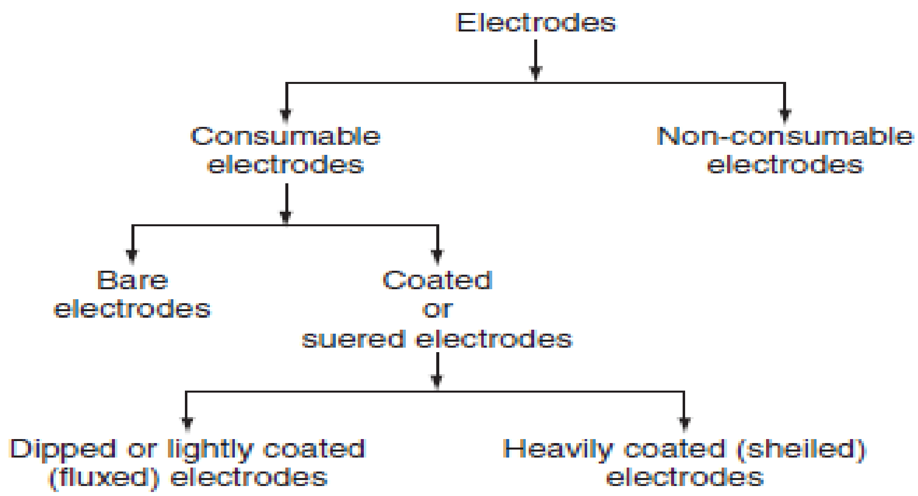


Fig.2.27.Classification of electrodes

## ELECTROLYSIS

In chemistry and manufacturing, electrolysis is a technique that uses a direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction. Electrolysis is commercially important as a stage in the separation of elements from naturally occurring sources such as ores using an electrolytic cell. The voltage that is needed for electrolysis to occur is called the decomposition potential.

## FARADAY'S LAWS OF ELECTROLYSIS:

### First law of Electrolysis

In 1832, Michael Faraday reported that the quantity of elements separated by passing an electric current through a molten or dissolved salt is proportional to the quantity of electric charge passed through the circuit. This became the basis of the first law of electrolysis: $m=k*q$ (or) $m=e*Q$. where; e is known as electrochemical equivalent of the metal deposited or of the gas liberated at the electrode.

### Second law of Electrolysis

Faraday discovered that when the same amount of current is passed through different electrolytes/elements connected in series, the mass of substance liberated/deposited at the electrodes is directly proportional to their equivalent weight.

## Important Questions

1.Mention Faradays Laws of Electroloysis. List out various applications of Electrolysis.

2.Write short on i)Resistance Welding. ii)UltraSonic Welding

3.Explain  Arc Welding with neat diagrams.

4.Explain working involved in dielectric heating and derive the expression for power consumed in dielectric heating process.

5.Explain types of Electric Heating.

6.Write about  types of welding electrodes.

7.Explain Types of Electric Welding.